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HUMAN ERROR PROBABILITY INDEX FOR OFFSHORE PLATFORM MUSTERS

by

Dino G. DiMattia

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NOMENCLATURE

ANOVA probability	P
ANOVA statistic	F
atmospheric factors PSF	*K*
coefficient of determination	R
complexity PSF	*E*
consequences PSF	*D*
constant (equation [5-8])	a
constant (equation [5-8])	b
degree of teamwork PSF	*F*
distractions PSF	*I*
time	t
event factors PSF	*J*
experience PSF	*H*
Kruskal-Wallis statistic	H
Kruskal-Wallis critical value	H_c
Kruskal-Wallis probability	p
log HEP	x
null hypothesis	H_o
procedural PSF	*A*
standard error	s.e.
standard normal error	Z
stress PSF	*B*

time pressure PSF	*C*
time	t
total number of judges	n
training PSF	*G*
weight	w

Subscripts:

one hundred	100
awareness phase	A
correlation coefficient	ρ
critical value	c
egress phase	Eg
evaluation phase	Ev
initiation of muster	I
mean	m
muster	M
muster action	j
number of error producing conditions	n
performance shaping factor	i
recovery phase	R

Greek letters:

assessed effect	φ'

associated effect	α'
chi-squared distribution	χ^2
consequence	χ
level of significance	α
normalized weight	σ
PSF relative weight	ς
PSF ranking (pairwise comparison)	λ
Probability of success	κ
risk rank	Θ
risk re-rank	Θ'
rating	δ
relative weighting	γ'
standard deviation	υ
success likelihood index	ψ
sum of success likelihood indexes	Ω
sum of weights	θ
unreliability	β'

ABBREVIATIONS

Absolute Probability Judgment	APJ
Analysis of Variance	ANOVA
Base Human Error Probabilities	BHEP
Basic Survival Training	BST
Canadian Standards Association	CSA
Cognitive Reliability and Error Analysis Method	CREAM
Command and Control Room	CCR
Core Review Team	CRT
Det Norske Veritas	DNV
Distributed Control System	DCS
Elevated Exposure Phase	EEP
Elicitation Review Team	ERT
Empirical Base Human Error Human Error Probability	EBHEP
Error of Commission Analysis	EOCA
Error Producing Condition	EPC
Errors of Commission	EOC
Failure Likelihood Index	FLI
Failure Likelihood Index Methodology	FLIM
Fire and Explosion	F&E
Gas Release	GR
Generic Accident Sequence Event Tree	GASET
Generic Error Modelling System	GEMS

Hazard and Operability Study	HAZOP
Health and Safety Executive	HSE
Hierarchical Task Analysis	HTA
Human Cognitive Reliability Correlation	HCR
Human Error Assessment and Reduction Technique	HEART
Human Error Identification	HEI
Human Error Probability Index	HEPI
Human Error Probability	HEP
Human Error Rate	HER
Human Factor	HF
Human Reliability Assessment	HRA
Influence Diagram Approach	IDA
International Organization for Standardization	ISO
Justification of Human Error Data Index	JHEDI
Kruskal-Wallis	KW
Quantified Risk Assessment	QRA
Man Overboard	MO
Maximum Success Likelihood	MaxSLI
Method to Calculate HEP for Decision Based Errors	INTENT
Minimum Success Likelihood Index	MinSLI
Multi-Attribute Utility Decomposition	MAUD
Muster Initiator	MI
National Research Council	NRC

Normal Probability Chart	NPC
Offshore Installation Manager	OIM
Optimal Risk Analysis	ORA
Paired Comparisons	PC
Performance Shaping Factor	PSF
Personnel (Person) on Board	POB
Potential Human Error and Cause Analysis	PHECA
Probability of Failure	POF
Probability of Failure determined (HEART)	POF'
Probabilistic Risk Assessment	PRA
Probability of Failure	POF
Probability of Success	POS
Process and Instrument Diagram	P&ID
Process Safety Valve	PSV
Public Announcement	PA
Quantified Risk Assessment	QRA
Range in Rating	RIR
Risk Mitigation Measure	RMM
Skill, Rule, Knowledge	SRK
Systematic Human Actions Reliability Procedure	SHARP
Success Likelihood Index	SLI
Success Likelihood Index Methodology	SLIM
Safety, Health and Environment	SH&E

Tecnica Empirica Operatori	TESEO
Technique for Human Error Rate Prediction	THERP
Temporary Safe Refuge	TSR
Workplace Hazardous Materials Information System	WHMIS

Acknowledgements

I would like to thank my graduate committee of Dr. Paul Amyotte, Dr. Faisal Khan and Dr. Yash Gupta for their technical support and understanding throughout my graduate work. I would like to particularly thank Dr. Amyotte for his friendship and guidance through the many years of this study and beyond. I would like to thank Petroleum Research Atlantic Canada (PRAC) for their valuable financial support and the many co-workers who dedicated their time and feedback which provided the backbone of this thesis.

Many thanks to those who made up the review team for their time and effort. Finally, I would like to thank my wife Denise for her understanding and encouragement and my daughter Sabrina who constantly reminded me of my priorities.

The Jester may fool
But a fool he is not
For show me one who is
What he pretends to be
Then you show me a fool
Who makes his own rules
And puts the jest on us
For not seeing that he is
What he pretends to be
Anon

If there's a flaw, it's human. It always is.

Collin Farrell, Minority Report

Man's highest merit always is, as much as possible, to rule external circumstances and as little as possible to himself be ruled by them.

Goethe

Diligence is the mother of good luck, and God gives all things to industry. Then plough deep while sluggards sleep, and you shall have corn to sell and to keep.

Benjamin Franklin

Grazie Dio, per tutti.

Abstract

The prediction of human error probabilities and their consequences in offshore platform musters, through a human error probability index (HEPI), provides a proactive quantitative approach for the inclusion of human factors in risk assessments. Due to the lack of human error databases and in particular human error data for platform musters, an expert judgment technique, the Success Likelihood Index Methodology (SLIM) was adopted as a vehicle to predict human error probabilities for three credible muster scenarios of varying severity.

A panel of twenty-four judges active in the offshore gas industry provided data for both the rating and weighting of six performance shaping factors that influence the probability of success for eighteen muster actions which range from point of muster initiation to the final actions in the temporary safe refuge (TSR). Through the use of predicted human error probabilities and a consequence table specific to muster scenarios, the risk is estimated for each muster action. Risk mitigation measures are provided to allow a re-ranking of risk potential. Predicted human error probabilities are compared to empirical data gathered from three years of muster reports from an existing operation. An example calculation is provided, utilizing HEPI, based on an actual muster event.

Results provide a clear indication of situations that provide the highest risk and which actions are the most likely to end in failure. Through HEPI, error reduction recommendations for training, procedures, management systems and equipment are brought forward allowing operators and designers to effectively apply human factors in a proactive approach to high risk scenarios. The framework of HEPI has universal application in the offshore industry providing a human factors tool to engineers, operators and health and safety personnel.

This thesis reviews and defines human error and the modes in which it is manifest. A review of past literature is conducted with focus placed on three expert judgment techniques that have enjoyed a degree of acceptability and application. A more detailed review of the SLIM technique is conducted and how this work addresses the concerns of past authors. A statistical review of performance shaping factor weights and ratings is conducted followed by the determination of human error probabilities for three muster scenarios. The results stemming from these calculations are applied in HEPI and are checked against empirical data. Recommendations conclude the work and provide a basis for future research. A separate data book complements this text and provides a listing of the over 15,000 pieces of raw data and associated calculations in the determination of human error probabilities.

Chapter 1
INTRODUCTION

This chapter provides the background that formulates the basis of this study in human factors for offshore platform musters (musters). Also included in this chapter is a description of a generic muster scenario along with an overview of platform safety systems. The goals of this work are identified and a means of predicting human reliability in new and existing platform structures is introduced in the form of a human error probability index (HEPI). In HEPI, the muster scenario is constructed and ranked. Human error probabilities (HEPs) for each action are predicted using reference graphs. The combination of HEPs and assigned consequences generates a risk level for each muster action. A set of recommendations is offered for each action to mitigate error potential and risk. A new risk level can be determined based on the implementation of these measures.

The next two chapters provide the background required for the subsequent discussions that detail the application of an expert judgement technique to predict human error probabilities. Chapter 2 reviews various modes of human error and the applicability of existing human reliability techniques to muster scenarios. Chapter 3 focuses on existing quantitative human reliability methods and performs a comparison between these models and the proposed index. A literature review of human reliability assessment techniques and prior works is contained in Chapters 2 and 3.

Chapter 4 details how data were elicited and Chapter 5 discusses the results. Chapter 6 explains how the elicited data is applied in the HEPI methodology and provides a worked example. Raw data are not included in this text due to the volume of information. An accompanying data book is provided as backup to the summary tables and charts presented in this work. Chapter 8 offers conclusions and recommendations for future work. Supporting documentation is found in the appendices including a statistical review of data. Figure 1.1 is a summary of the major topics in each chapter.

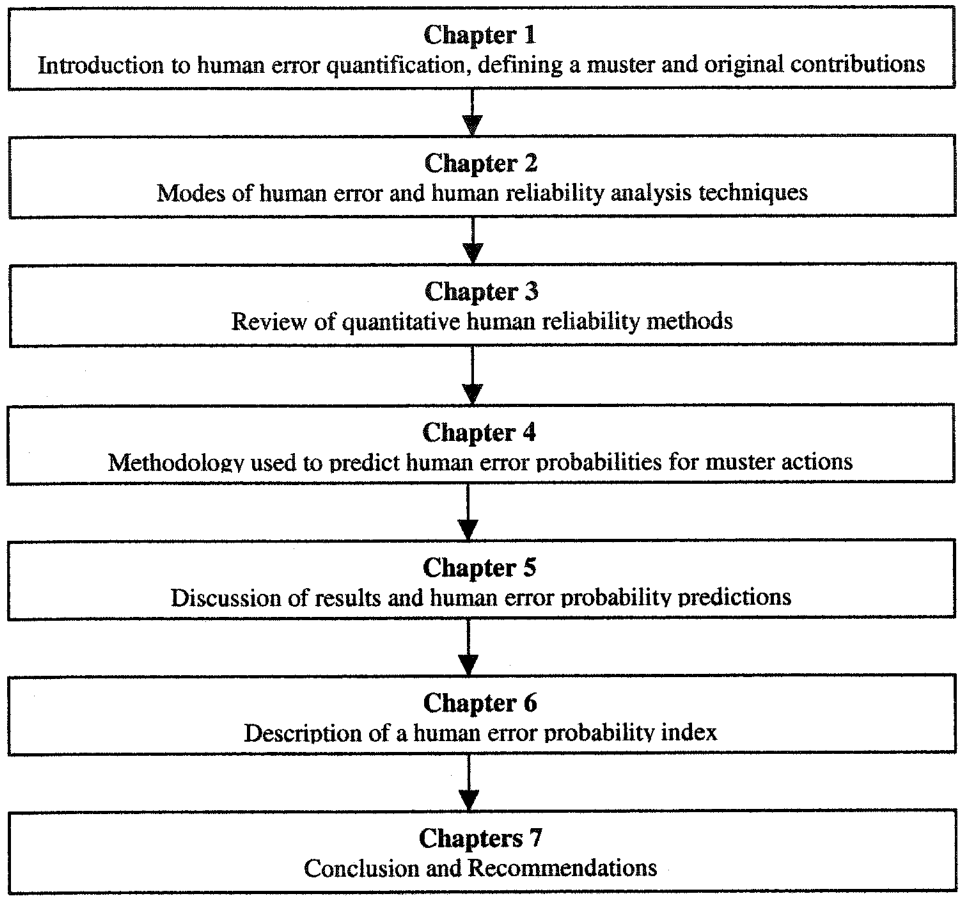

Figure 1.1 Overview of thesis.

1.1 Project Statement and Objectives

The problem statement for this PhD thesis is as follows:

Develop a methodology for the identification, risk assessment and mitigation of human error during offshore platform musters.

Offshore drilling and production platforms come in a variety of configurations and sizes as seen in Figure 1.2. The framework for a human error probability index for offshore musters is presented in this work. This index provides a quantitative evaluation for the likelihood of human error and its associated risk during a muster sequence.

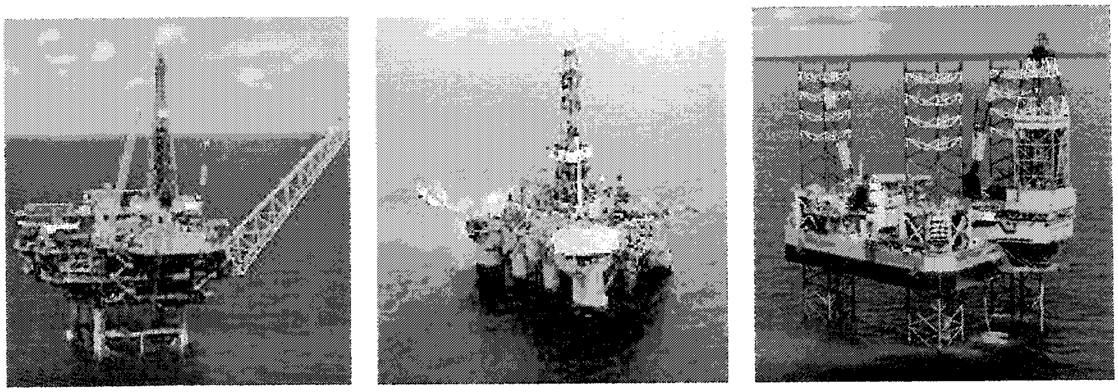

Figure 1.2 Examples of offshore platforms (Oil Career, 2003).

Indices such as the Dow Fire and Explosion Index (Dow Chemical Company, 1994) are used extensively for ranking hazards associated with various unit operations on the basis of accidental fire, explosion and gas release. Indices such as the Safety Weighted Hazard Index (Khan et al., 2001) are straightforward to implement and are modular in structure. These attributes can make an index approach to risk assessment very attractive.

An index geared solely to predicting risk levels associated with human error during platform musters has not been developed to date. The goals for this study are:

- To further the work in the field of human error identification for offshore platform musters in a unique way.
- To promote and enhance safety in platform musters through the recognition and quantification of human error.
- To provide an accessible human reliability assessment tool yielding a meaningful and useful result.
- To provide risk reduction recommendations to mitigate the potential for human error during platform musters.

This study applies the principles of Optimal Risk Analysis (ORA) (Khan, 2001) in the development of HEPI. ORA employs hazard identification (i.e. human error identification), hazard assessment (i.e. human error assessment), quantification of hazards (i.e. human error probabilities) and risk estimation, based on human error probabilities and consequences. Upon reviewing several existing human reliability assessment (HRA) methodologies it, was decided that a human error probability index specifically for musters would be beneficial for risk assessment purposes. HEPI is based on empirically determined human error probabilities derived from the Success Likelihood Index Methodology (SLIM) (Embrey et al., 1984). Figure 1.3 provides an overview of the HEPI framework.

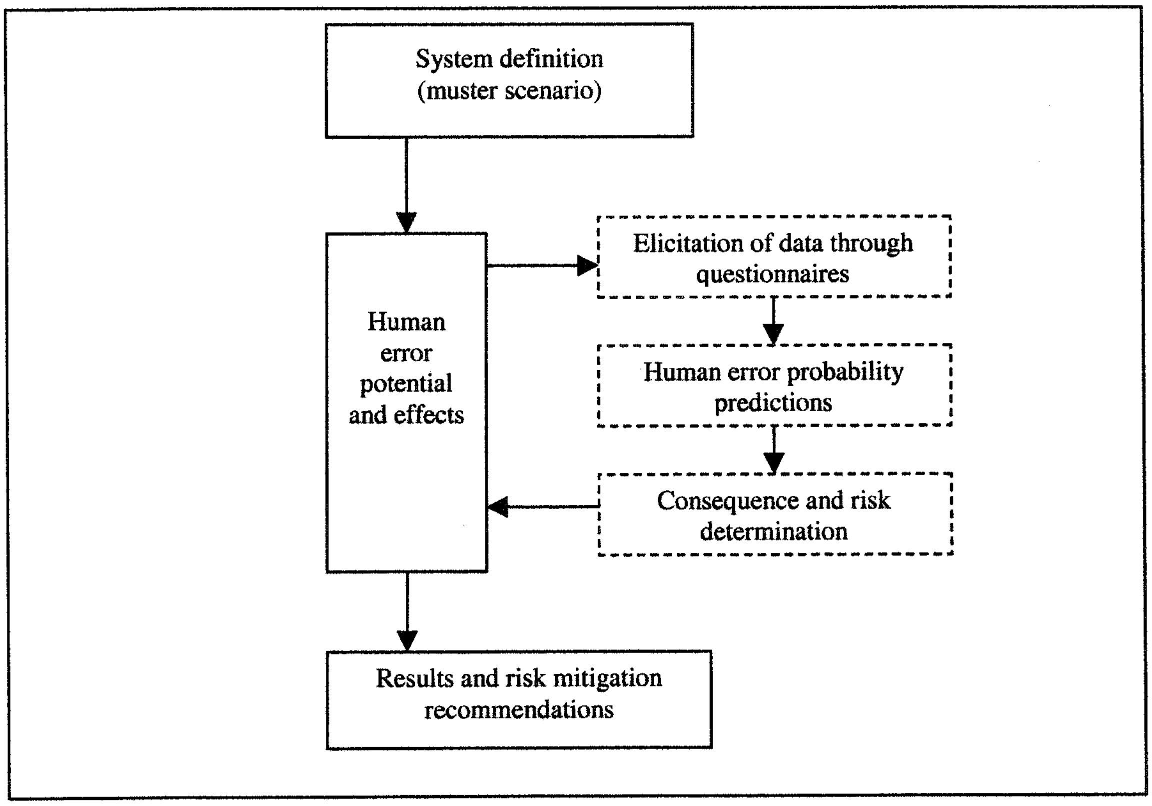

Figure 1.3 HEPI framework.

Human error probabilities are based on factors that affect human performance, known as performance shaping factors (PSFs). These PSFs are weighted and rated through the SLIM technique to develop a success likelihood index (SLI) for each muster action from which the probability of success (POS) is estimated. Rating and weight data are attained through a pre-selected set of judges responding to questionnaires. Figure 1.4 provides a more detailed breakdown of HEPI. This process is reviewed in detail in Chapter 6.

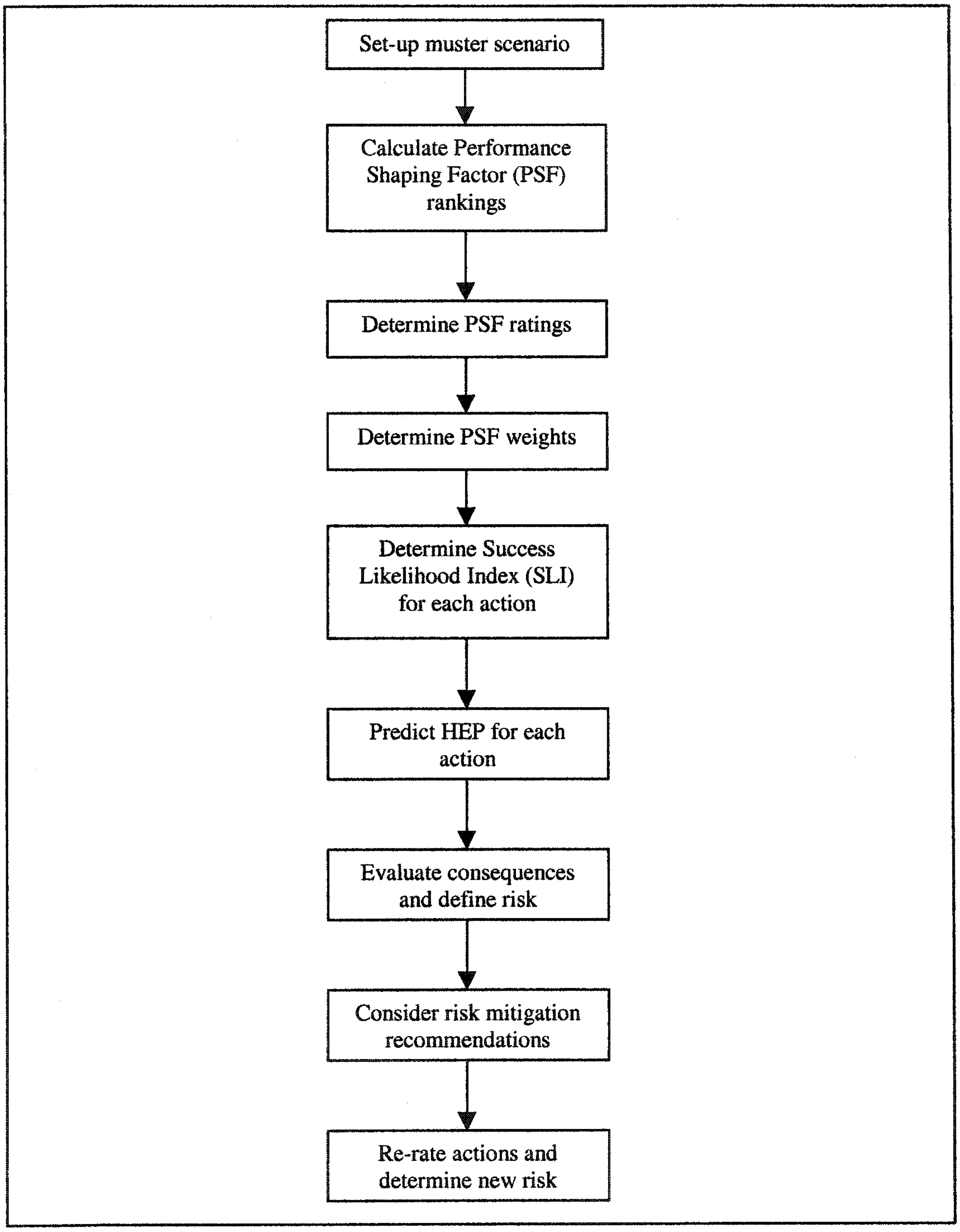

Figure 1.4 The HEPI process.

The process to develop an index which incorporates error predictions and consequences to develop a risk picture can be broken down into five distinct steps, which are:

1. Establish criteria to choose the judges.

   Develop a basis for choosing judges to review questionnaires and for a larger group of judges to respond to the elicitation of data.

   1.1 Rank the judges by attributes pertinent to the elicitation of data.

2. Define the muster scenario parameters.

   Establish a small group of core review team members who have a wide variety of experience.

   2.1 Define actions through a hierarchical task analysis (HTA).

   2.2 Develop a comprehensive list of the most relevant PSFs through pairwise comparison.

   2.3 Build a list of three credible muster scenarios that encompass a wide range of severity.

   2.4 Construct questionnaires for determining the PSF weights and ratings.

3. Elicit the data.

   3.1 Meet with the judges individually to present the questionnaire for weighting PSFs.

   3.2 Review the responses and clarify where necessary. Discard responses that have departed significantly from the instruction provided.

   3.3 Meet with the judges individually to present the questionnaire for rating PSFs.

   3.4 Review the responses and clarify where necessary. Discard responses that have departed significantly from the instruction provided.

4. Analyze the data.

   4.1 Perform statistical checks on the data.

4.2 Calculate HEPs through the SLIM procedure.

4.3 Develop the PSF weight and rating reference graphs.

4.4 Develop the conversion curves between SLI values and the probability of success (POS).

4.4 Establish a muster ranking table based on PSFs.

4.5 Develop the consequence and risk tables.

4.6 Develop risk mitigation measures (RMMs) for each muster action based on training, procedures, management systems and equipment.

4.7 Build input tables to record PSF weights, PSF ratings, SLI values, assigned consequences and risk.

The index concerns itself with the actions beginning at the point of muster initiation (t_I) and ending with the tasks performed in the Temporary Safe Refuge (TSR) before standing down or moving on to the abandonment phase (Figure 1.5). Each phase of the muster has an associated elapsed time (i.e. t_A, t_{Ev}, t_{Eg}, t_R) that makes up the total time of muster (t_M). This study focuses on the muster phases that precede evacuation and for which there is significant risk to personnel.

The first three phases of muster are brief compared to the total time of muster. They are typically 10 to 30% of t_M. It is during these three phases that individuals have the greatest exposure to the effects of the muster initiator (e.g. heat, smoke, pressure); these phases are identified as elevated exposure phases (EEPs). During the EEPs an individual's local egress route and surrounding environment can rapidly degrade. The quality of the egress path and the surrounding environment is referred to as tenability throughout this work. The concept of tenability is well established in the modeling of human behaviour within building fires (Fraser-Mitchell, 1999) and lends itself well to muster scenarios as a factor influencing the success of muster tasks.

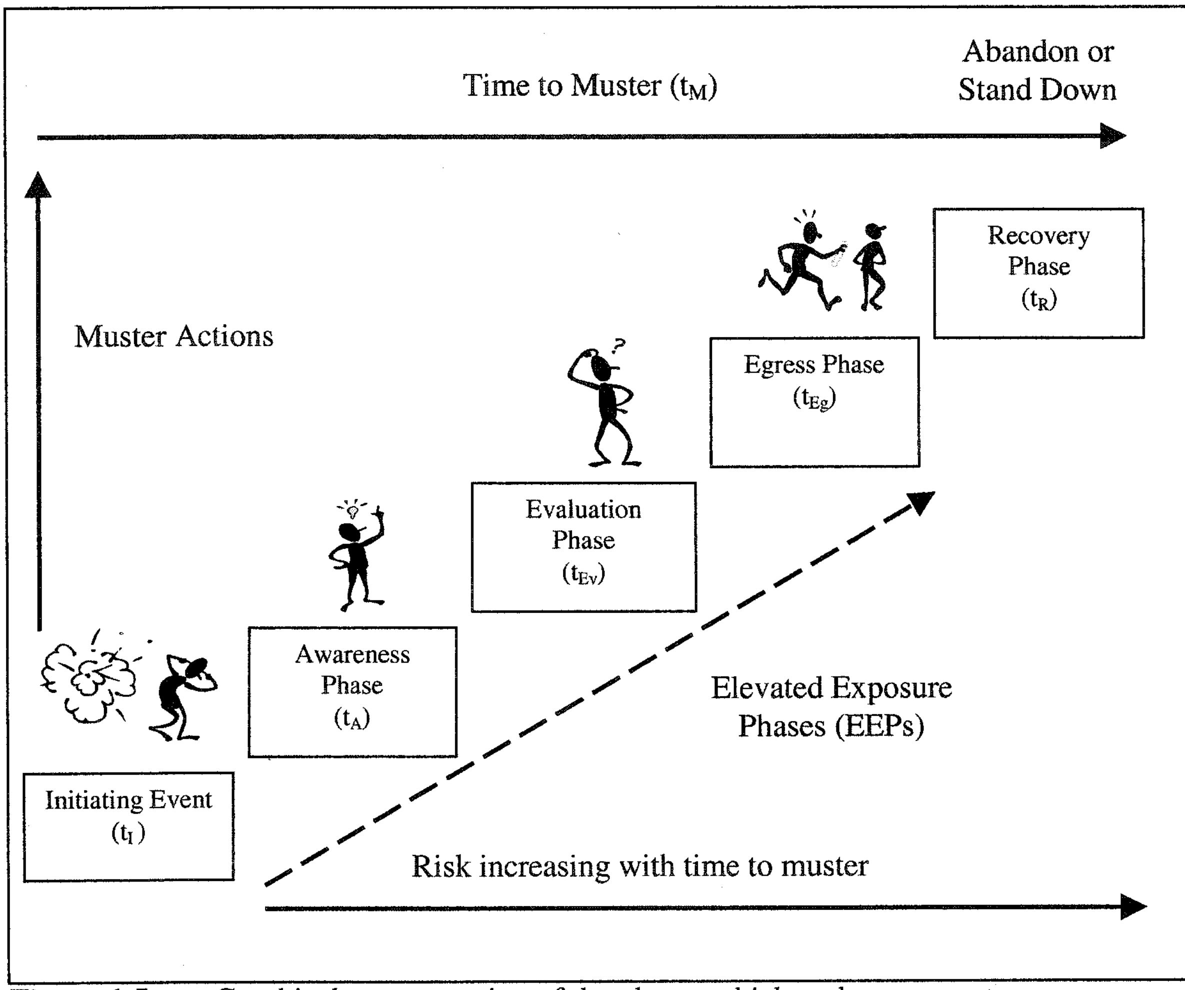

Figure 1.5 Graphical representation of the phases which makeup a muster sequence.

This study was initiated through a group of five judges known as the core review team (CRT) The CRT members have a wide range of offshore experience and expertise. The CRT performed several tasks including the development of 18 key muster tasks (actions), three muster scenarios of varying severity and six performance shaping factors (PSFs) that influence human reliability.

Following the set-up of this basis, a broader elicitation review team (ERT) of 24 judges was solicited to determine key parameters in the calculation of human error probabilities using the SLIM technique. The elicitation and gathering of these data occurred over a four-month period. The ERT was comprised of judges who are active in the offshore industry through operations, engineering, health and safety, training, regulatory activities and administration.

The proposed human error probability index is an evolutionary development of the SLIM technique and is based on three muster scenarios of varying severity, which cover the range of likely muster sequences. The index predicts the probability of human error associated which each muster action and the associated risks. Mitigation measures are identified and recommendations are made to improve the POS based on training, procedures and equipment. Human error evaluation through the proposed index is conducted in a manner where experience in expert judgment techniques is not required. Rather, personnel familiar with the muster process may apply their industrial experience to make risk determinations and identify areas of improvement. The generic framework of the index as developed can be applied to any offshore operation involved in hydrocarbon exploration or production.

To understand the basis from which HEPI was developed a discussion is presented identifying the need for preemptive quantification of human error and the forms in which human errors manifest themselves. The following section reviews the drivers for quantifying human error and the consequences associated with human failure.

1.2 Defining the Need for Human Error Quantification

The study of human factors is a scientific discipline that involves the systematic application of information regarding human characteristics and behaviour to enhance the performance of man-machine systems. The preponderance of work in human error prediction has come from the nuclear power industry through the development of expert judgment techniques such as SLIM and the Technique for Human Error Rate Prediction (THERP) (Swain and Guttmann, 1983). The need for expert judgment techniques lies in the systemic lack of human error data and serious nuclear industry accidents such as Chernobyl. Analogously, the Piper Alpha and Ocean Ranger disasters have generated a greater awareness of the effects and ramifications of human error in offshore hydrocarbon processing. Humans play a significant role in both accident causation and in emergency response (Bellamy, 1994).

Offshore platform musters have significant potential for severe ramifications and present a challenging scenario to human error prediction and reduction. Due to the relatively slow progress in the field of quantification of human reliability there is a need to progress this area of research and provide techniques that are useful in quantitative risk assessments (QRAs). A primary issue is the concept of human error and how it has entered the safety vernacular as a catchall phrase with a lack of consistent definition and application. The result is an inadequate understanding of how human error identification may be applied in a useful preemptive manner in high-risk scenarios.

A better understanding of human error and its consequences can be achieved through the application of human error identification models. Human error must be removed from the emotional domain of blame and punishment and placed in a systems perspective. Through this viewpoint, human error is treated as a natural consequence from a discontinuity between human capabilities and system demands. From this standpoint the factors that influence human error can be recognized and managed. The human error probability index developed in the current work provides a means of identifying human error mechanisms and the risks associated with failure to successfully complete tasks. The index provides a list of potential consequences and risk mitigation recommendations for each muster action designed specifically to reduce the level of risk from human error.

Human error plays a significant and sometimes overriding role in accident causation. Statistics that attribute accidents or losses to human error are varied and are reported to be as high as 85 % (Sanders and McCormick, 1987). This wide variation is dependent on the source of data and the definitions applied to categorize human error. Nonetheless, it is reasonable to state that human error plays a very significant role in accidents through either direct action or poor design.

Providing a definition for human factors and human error is necessary to establish a basis for this discussion. A definition of human factors, modified slightly from the

United Kingdom's Health and Safety Executive (Reducing Error and Influencing Behaviour, 1999), is as follows:

> Environmental and organizational and job factors, system design, task attributes and human characteristics that influence behaviour and affect health and safety.

Human error, whether intentional or unintentional, is 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).

Human factors play a major role in platform musters and their successful outcome (Kennedy, 1993). The importance of human factors in offshore operations has been recognized through several reports published by the Health and Safety Executive (UK) dealing with the inclusion of human factors in the offshore industry (Widdowson and Carr, 2002) and the human factors assessment of safety critical tasks in the offshore industry (Johnson and Hughes, 2001). These reports provide guidance for the integration of human factors principles into offshore system design and development processes.

Despite this, initiatives have not been developed to quantify the HEPs associated with the major actions that take place during a muster. On a regulatory basis there is no clear definition or specific requirement for the inclusion of human error in management systems or risk assessments. This may be attributed to the ambiguity and comprehensiveness of this subject, but more likely due to the lack of readily available Human Reliability Assessment (HRA) tools.

The next section provides a description of an offshore platform muster sequence. Understanding the components of this process permits the identification of the mechanisms through which human errors occur as well as their potential consequences.

1.3 The Muster Sequence

An offshore platform facility presents many risks (Khan et al., 2002) in the form of process hazards, dropped objects and structural failures which lead to musters. These events can occur at any time and in any weather. The muster alarm is typically one of several that are annunciated over a platform's public address (PA) system. The other alarms may include a general process alarm and an abandon platform alarm. Each alarm is typically complemented by the activation of alarm lights flashing in a predetermined sequence. The generic approach to this sequence is that first a process alarm would sound to warn individuals of a process upset. A parallel process alarm would sound in the control room via the distributed control system (DCS) to warn the operator.

If the upset is not controlled and escalates, a muster may be initiated. The muster alarm indicates to all personnel to start the muster sequence and gather at the TSR (Figures 1.6 and 1.7) which is typically next to the control room and adjacent to the life boats. Individuals everywhere on the platform are required to stop work and return the process to a safe state, if working in the production units. The next step is to make their workplace safe so that others will not be impeded by egress obstructions. Also, it is important and that the work-site (including accommodations) is not left in a state that could escalate the severity of the muster (e.g. leaving bedroom doors open).

A PA announcement typically follows the muster alarm to provide information as quickly as possible to all platform personnel on the nature of the muster and if any areas on the platform are to be avoided. Once the TSR is reached, all personnel are required to register, typically at an identification card rack where each person has their name on a tag that is relocated to another rack. All personnel are accounted for when all the identification cards have been relocated and a head count is performed. It is during this period that specific individuals who have already mustered may be required to fulfill a role in a rescue, fire suppression or incident command. Once registered, all individuals are required to remain in the TSR.

Updates are provided by the Offshore Installation Manager (OIM) who is the incident commander and resides in the adjacent command and control room (CCR). If

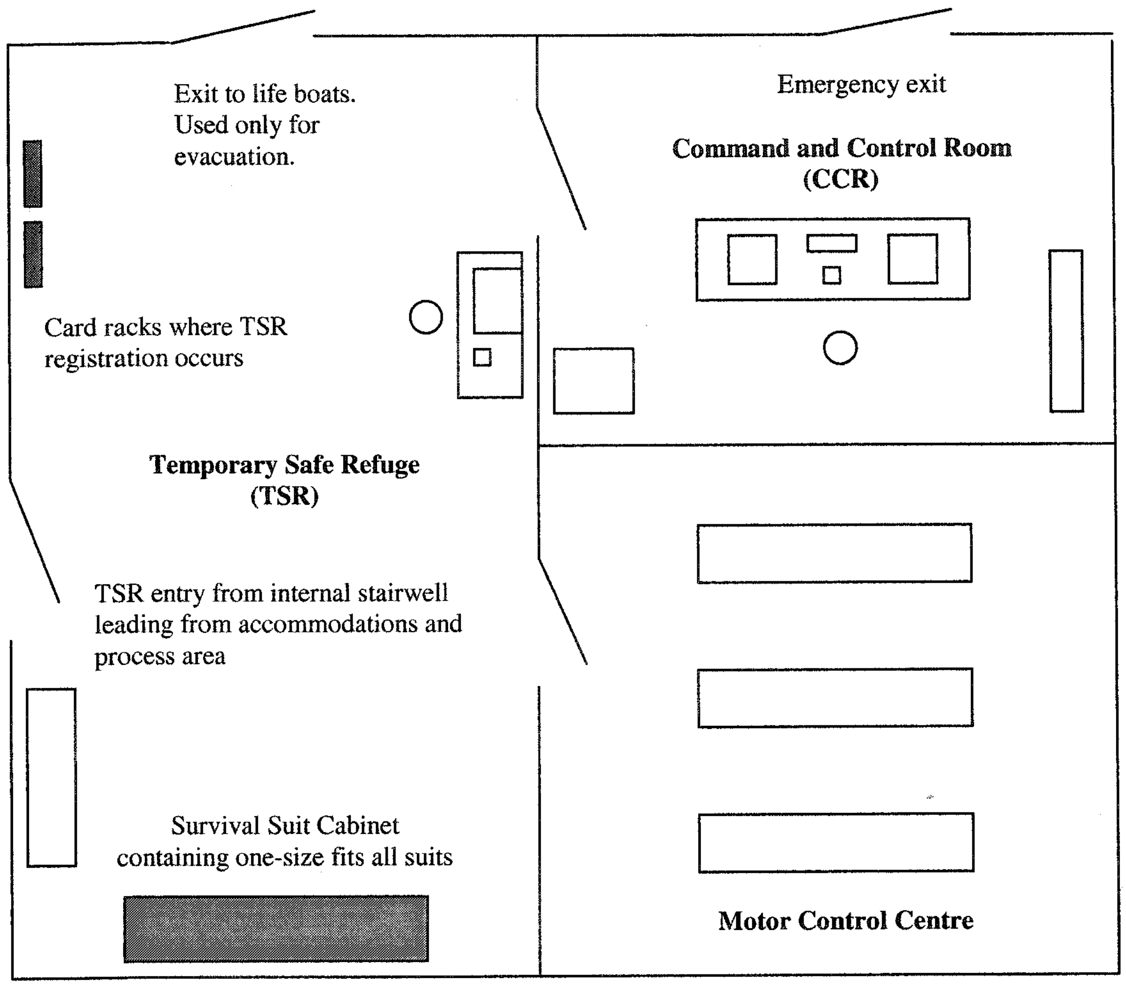

Figure 1.6 Schematic of a generic temporary safe refuge set-up.

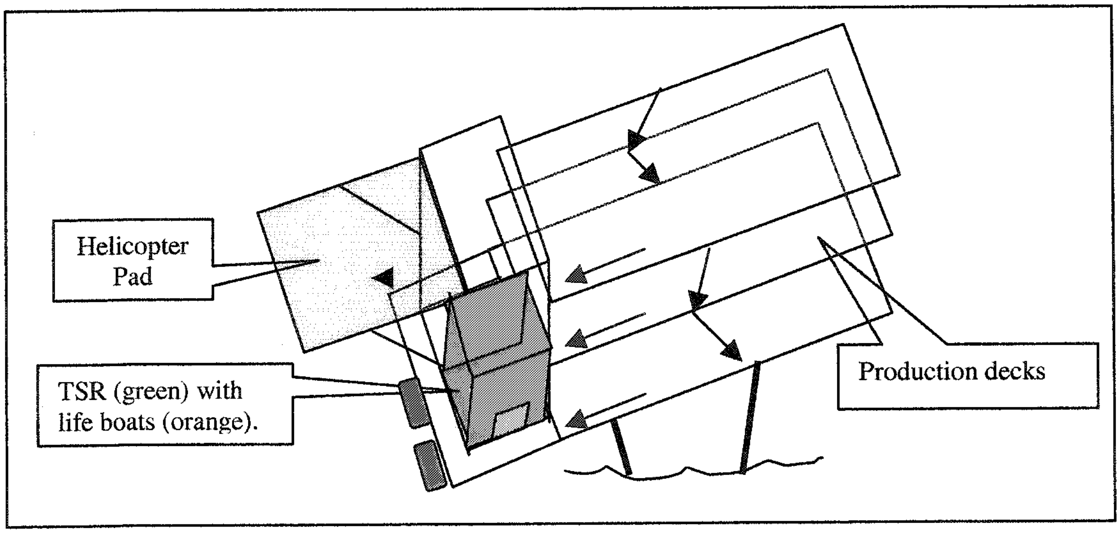

Figure 1.7 Schematic of generic three deck platform and location of TSR.

the muster initiator is not controlled and the events warrant it, the OIM may decide to have the personnel don their personal survival suits or the TSR survival suits and load the life boat for evacuation from the platform (or if time permitting, by helicopter). During an actual muster, stress levels are elevated, as drills are usually identified post alarm through PA announcements. The cause or severity of the initiating event may not be known during the elevated exposure phases (EEPs). Muster drill training emphasizes that all musters be treated in the most serious fashion with no discrimination. For the duration of this period, personnel are not permitted to leave the TSR unless directed to, based on the cause of the drill. Reaction to the muster alarm is to be fast and immediate.

Though drills are conducted at a regular frequency, they are generally held during daylight hours and often occur on weekends, making training predictable. Personnel who have regular shifts offshore can become accustomed to the repetitive nature of the drills, while infrequent visitors may experience the same level of anxiety in a drill in a real muster.

Key aspects to a successful muster are presented through a muster chain-of-survival in Figure 1.8. A break in this chain decreases the chance for a successful muster, which is defined by both the time it takes to muster and the individuals' state of health. The opportunity to recover from a break in this chain is dependent on the type of error and the severity of the muster initiator (MI). The level of risk associated with human error is determined by predicting the consequences associated with a break in this chain.

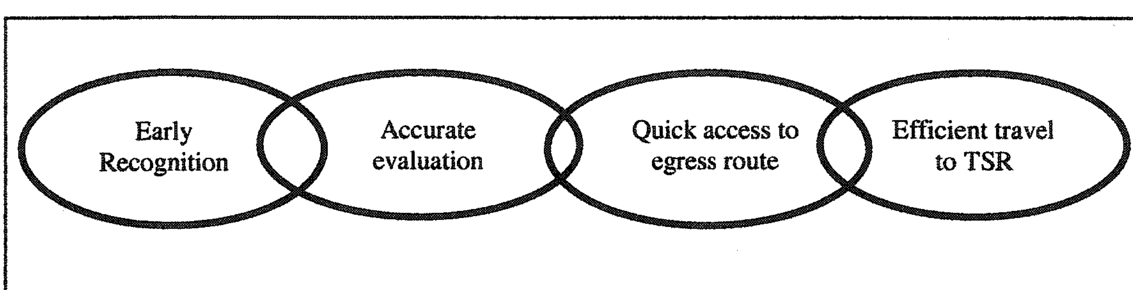

Figure 1.8 Muster chain of survival.

The following section describes active and passive protection systems that play an important role during a platform muster. These systems improve the survivability of individuals through gas detection, alarm, fire suppression and enhanced wayfinding.

1.4 Protection Systems

The purpose of this section is to provide an overview of devices and protective systems that exist on most platforms. These systems come into play before and after the muster initiating event. Management systems play a preemptive mitigating role in the prevention of accidents through rigorous work permitting procedures that include risk assessments. Work rules may include a total ban on welding, while platform design can provide for various levels of electrical equipment classification (e.g. explosion proof) – thus reducing sources of ignition. Post event systems include devices for the detection and protection from combustible gases and fires and ways of assisting egress.

Passive systems (i.e. no moving components) such as signage (Figure 1.9), floor markings (Figure 1.10) and evacuation plans (Figure 1.11) assist mustering personnel to orientate themselves and egress efficiently. Audible and visual systems (Figure 1.12) provide the means to instigate musters and provide guidance to mustering personnel. Protective systems such as heat detection wire and combustible gas/fire detection sensors (Figure 1.13) provide control systems with the feedback required to activate water deluge (Figure 1.14) and blowdown flare circuits designed to mitigate the spread of fire and eliminate the fuel source.

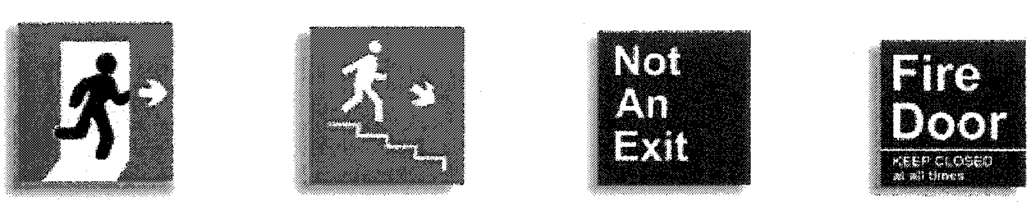

Figure 1.9 Muster signage (Egress Systems, 2003).

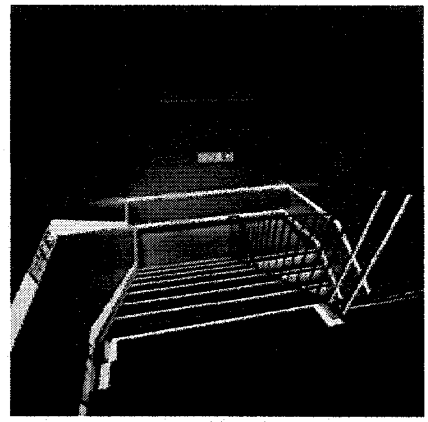

Figure 1.10 Photoluminescent tape markings in a stairwell (NRC, 2003).

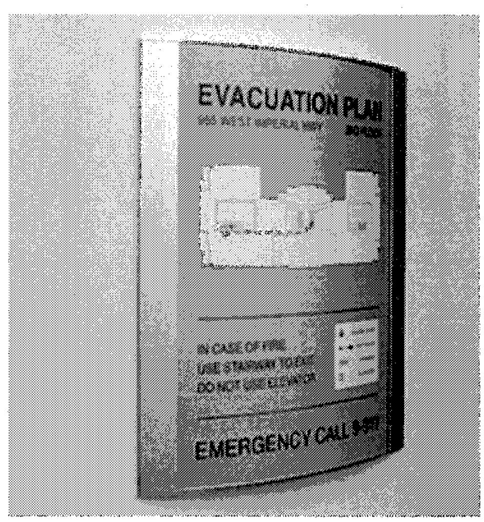

Figure 1.11 Posted evacuation plan providing egress directions (Impact Signs, 2003).

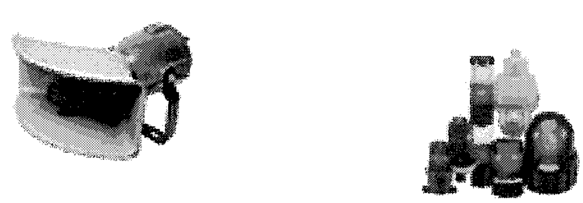

Figure 1.12 Public address horn (Guardian Telecom Inc., 2003) and emergency lighting (Federal Signal, 2003).

Figure 1.13 Combustible gas monitor (left) and fire detection monitor (right) (Offshore Technology, 2003).

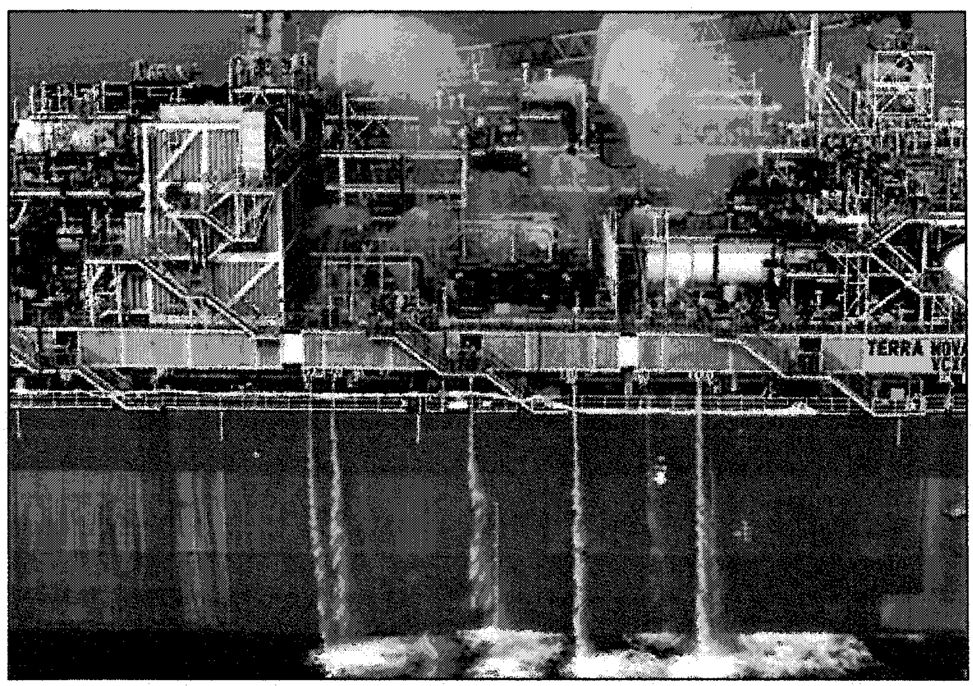

Figure 1.14 Deluge system test – Terra Nova FPSO (floating production, storage and offloading), (Terra Nova, 2003).

Deluge systems deliver sea water to specific areas of the platform in the event of fire detection. Deluge is an automated response from the platform's control system and does not require manual activation. Another key safety feature on all platforms is the ability to stop the processing of hydrocarbons. Push buttons allow individuals in the production area to stop production (Figure 1.15). Push buttons are typically located at

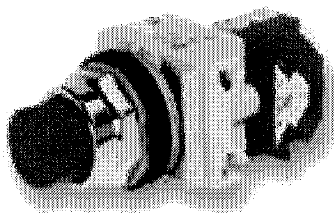

Figure 1.15 Emergency pushbutton (Square D, 2003).

strategic locations along egress paths permitting personnel to generate a process shutdown or activate a deluge system.

Blowdown systems are an integral part of an offshore platform's flare system. This system relieves combustible gases via pressure safety valves (PSVs) to be burned in a flare (Figure 1.16). The blowdown valves are similar in concept to PSVs except they are designed to remain open and not reseat at a specified pressure. The purpose of the blowdown system is to lower the pressure in the process units typically within 15 minutes to less than 500 kPag. This pressure reduction during a blowdown event can be in excess of 10,000 kPa. The blowdown valves are manually activated in the CCR and are used only in circumstances where there is a confirmed fire or gas release.

Figure 1.16 Offshore platform flare burning gases from vent system (NAO Inc., 2003).

Protection extends from the process units to the accommodations and TSR. Blast walls and doors protect these modules from overpressure, and internal sprinkler systems protect them from fire. A pressurized system supplies air to these areas preventing the ingress of smoke or toxic gases. Survival suits are stored in the TSR in the event personnel are required to abandon the platform by life boat. These suits are one-size-fits-all with integrated mitts reducing dexterity and freedom of movement (Figure 1.17).

The ability to move freely is compromised and this makes subsequent evacuation actions (e.g. strapping into the survival craft harness) difficult to accomplish. The personal survivals suits (Figure 1.17) provided to all personnel prior to departure from shore are superior in fit and flexibility. These suits are kept in the sleeping quarters and are typically not retrieved during a muster unless the individual is in their room. Donning the TSR survival suit can be made problematic in the TSR as a full complement of personnel provides minimal space to maneuver into the suit. The personal survival suit is equipped with a whistle, inflatable life vest, sea spray protection and an immersion light. None of these features are normally available on the TSR survival suit.

Figure 1.17 TSR one-size-fits-all survival suit (left) and personal survival suit (right) (Mustang Survival, 2003).

The next chapter classifies different modes of information processing and identifies categories of human behaviour and error types. These error forms are defined and put into the context of a platform muster. Existing human reliability assessment techniques are examined for their applicability in assessing platform musters.

1.5 Original Contribution

Prior studies have been performed that progress the utility of expert judgment techniques to predict human error potential. This area of study remains primarily with human factor specialists. The current work attempts to formulate an index that promotes the inclusion of human factors into risk assessments. Through this index (HEPI), a consistency is achieved that will help raise the confidence of both health and safety professionals and engineers in addressing the issue of human reliability.

The breadth and scope of human factors can be daunting. Focusing on specific high risk applications such as platform musters brings greater clarity to potential for human error where consequences are severe. The aspects of this work that are original to this area of study and are detailed in subsequent chapters are as follows:

1. The prediction of human error probabilities during a muster sequence through an expert judgment technique (SLIM). Human error probabilities are predicted for a range of muster scenarios of varying severity. No prior work has applied this predictive technique to offshore musters.

2. The development of a human error identification index (HEPI). HEPI permits the determination of human error probabilities for a variety of muster types. Consequences are specified and preventive measures are recommended to mitigate the probability of failure. No such index has been previously developed to specifically address high risk muster sequences.

3. The use of empirical data from actual musters to generate human error probability predictions. Muster reports were utilized to determine if predicted HEPs are reasonable and to validate the logarithmic relationship between HEP and SLI.

The following chapter reviews the various modes of human error and discusses several human reliability assessment techniques.

Chapter 2
MODES OF HUMAN ERROR AND
HUMAN RELIABILITY ANALYSIS TECNNIQUES

This chapter categorizes different modes of information processing and defines categories of human behaviour and error types. These error types are put into the context of a muster scenario. Human reliability assessment techniques are reviewed for their applicability in assessing platform musters through an Optimal Risk Assessment (ORA) approach.

2.1 Human Behaviour and Error Types

The principles of conscious and unconscious (automatic) behaviour and their relationship to the skill-rule-knowledge (SRK) cognitive model, promote an understanding of how people tend to work under a variety of circumstances (Rasmussen et al., 1987). The terms skill, rule and knowledge refer to the level of conscious control exercised by an individual over their activities (Table 2.1).

Conscious behaviour is utilized when a task is being learned and is known as the knowledge-based mode of behaviour. This behaviour occurs when a person is learning a task for the first time or when an experienced individual carries out a new or novel task. Rule-based behaviour is an intermediate level where rules are developed on how to perform tasks through interaction with the process or by working with experienced individuals. Automatic behaviour, also known as skill, is predominant once proficiency is attained. Skill-based responses can be initiated by an event, from a stimuli such as a muster alarm, or from another individual.

The SRK system provides a useful framework for identifying the types of errors that are likely to occur in different muster situations or within different aspects of the same task where various types of information processing requirements occur. A platform muster is a situation where there are many individuals (large platforms can exceed 200 personnel) with a range of experience, interacting in various modes of behaviour.

Table 2.1 Knowledge and skill-based behaviour characteristics and sources of error.

Knowledge-based mode (conscious)	**Skill-based mode (unconscious)**
Characteristics: • lacking training • new environment • slow • much effort • requires lots off feedback	Characteristics: • highly trained • familiar environment • fast • little effort • requires little to no feedback
Sources of error: • overload • variability • lack of knowledge of methods and/or awareness of consequences	Sources of error: • strong habits • frequently invoked rule used inappropriately • changes in the situation do not trigger the need to change habits

In general, people at work attempt for as long as possible to control demands on their time by using skill-based behaviour. Through this, people can work for extended periods without experiencing an unacceptable level of tiredness. Skill (S) is defined as behaviour where little cognitive control is performed with almost reflexive responses to stimuli. Slips (i.e. attention failure) and lapses (i.e. memory failure) are common in this mode of behaviour.

When the situation necessitates a greater amount of analytical reasoning, as when process incidents occur, rule-based and knowledge-based behaviour will dominate the mode in which actions take place. In short, the terms knowledge-based, rule-based and skill-based information processing refer to the degree of control exercised by a person over their activities. Rule-based (R) behaviour is defined by higher level cognitive control. Pre-packaged units of behaviour are displayed in rule-based thinking; if symptoms are X then do Y. Slips, lapses and mistakes may occur in this mode of behaviour. Knowledge-based (K) behaviour is defined by a high degree of cognitive control. Knowledge-based behaviour is required when there is a lack of procedures, signs and other displays to assist in making decisions. Actions are based on the individual's expertise. Lapses and mistakes occur in this mode of behaviour.

Human errors manifest themselves in distinct ways in these modes of behaviour and are classified as slips, mistakes and violations (Rasmussen et al., 1987) as illustrated in Figure 2.1.

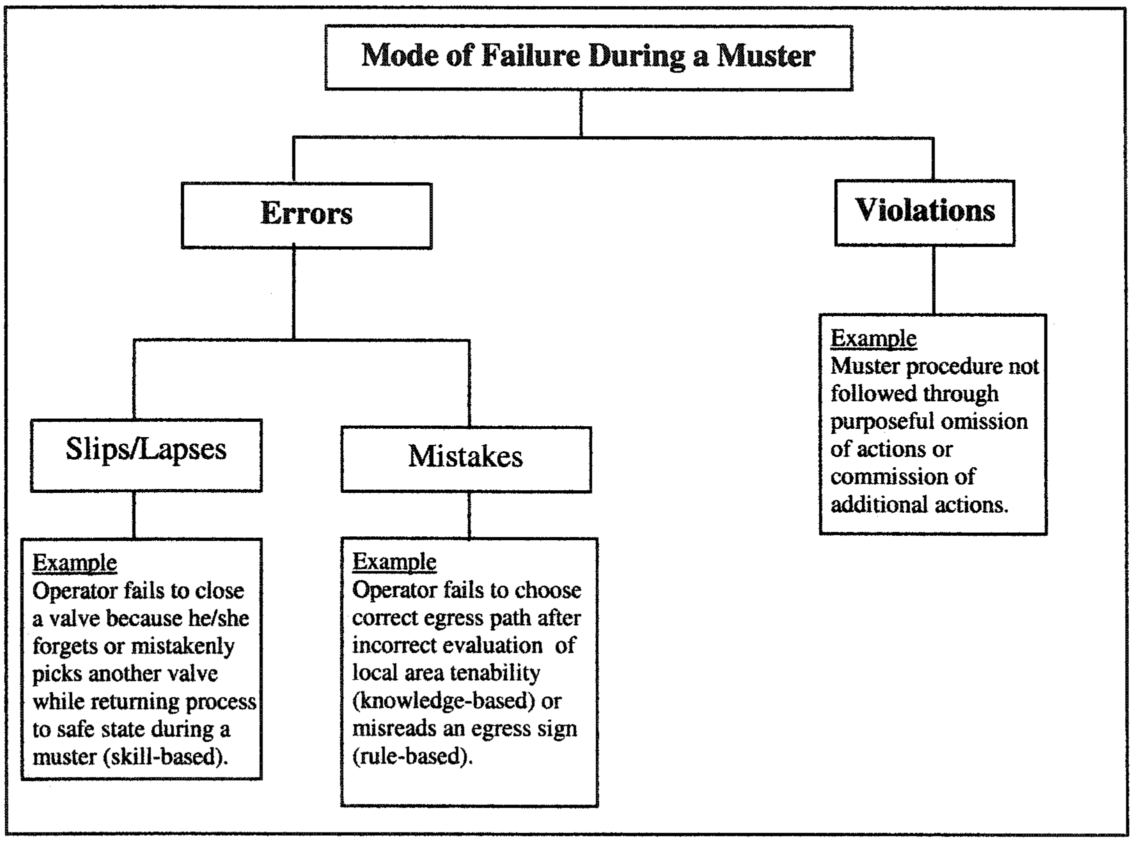

Figure 2.1 Classification of human errors with muster examples (adapted from Reason, 1990).

The three basic stages in decision making are activation, integration and interpretation. The activation stage corresponds to the initial alerting of an individual that an action is required. In most cases, the individual will take the correct action based on their expertise and experience; this is skill-based behaviour. If the individual does not immediately recognize a pattern of symptoms, a process of information collection begins. This will usually lead to the selection of the appropriate action presenting itself as either a procedure or a rule. A negative aspect of this mode of behaviour is that strong habits may take over when the individual is distracted or when unfamiliar activities are embedded in a familiar context. This is typical of a severe muster occurrence requiring personnel to perform the same actions that they perform in drills. This mode of behaviour is rule-based since it involves explicit rule following.

If after the integration phase a diagnosis is not made that leads to the implementation of a required action, the individual enters a knowledge-based type of behaviour. In this mode the individual cannot rely on past experience but has to formulate a new hypothesis based on their level of knowledge. Once an interpretation is complete and a strategy selected, an appropriate action is taken which may take the form of an existing procedure or the development of a new procedure. This process concludes in the execution of the action which may be either correct or incorrect. The following sections define each category of human error and how they are manifested through slips, mistakes and violations.

2.2 Slips and Lapses

A slip or lapse is an error experienced when an individual is operating in an automatic skill-based mode. It occurs when actions are not planned. The intentions of the individual are correct, but a failure occurs while carrying out that activity. Slips cannot be prevented by additional training (Kletz, 1991). For example, an experienced individual, who has participated in many muster drills opens a valve instead of closing it while returning the process to a safe state before starting their egress to the TSR. Some physical errors can be linked to slips, that is, to skill-based performance errors such as not applying enough force to open or close a valve. A lapse occurs when an action is simply forgotten.

Slips may also occur even when personnel are well prepared. Individuals working on offshore platforms are sometimes required to make decisions short notice (under 5 seconds). If a mindset has been established prior to an incident that a certain piece of equipment is likely to fail and generate a dangerous situation, operators may prepare themselves mentally to deal quickly with that situation when it arises. Under stress, an operator may take an incorrect action based on this predisposition. Well trained and motivated personnel are capable of making this type of slip.

Slips and lapses do not infer that people are inadequately trained; in fact, slips can occur because people are well trained. Routine skill-based tasks require little conscious effort and are not highly regulated by individuals. Errors related to these tasks are more likely to occur when distractions or stress become a factor as in severe muster scenarios. Training regimens designed to challenge participants in completing muster tasks can help promote a transition to a higher level of thinking where actions are thought out methodically, thus minimizing the possibility of slips.

2.3 Mistakes

A mistake is an error in conscious behaviour that may be either knowledge-based when the task involves evaluation of a new situation, or rule-based if the task merely involves following a set of procedures. Mistakes which are knowledge-based are more likely when musters occur under unusual circumstances. Conversely, mistakes may also occur under a rule-based mode of thinking during more common muster drills and low severity muster sequences. Mistakes occur when a person does not know what action to perform because of some lack of knowledge. Mistakes may also occur due to a lack of knowledge whereby a person incorrectly thinks they know what action to perform. Mistakes often arise when planning or training is inadequate. Personnel may believe they must always follow rules and may therefore be unable to react correctly when some degree of flexibility in response is required.

Mistakes based on an inability to properly diagnose emergency scenarios can occur when procedures are inappropriately followed. Mistakes can also be the result of a contradictory or ambiguous muster procedure that can place pressure on personnel to take risks. Under this scenario, performing the correct action is difficult even for experienced individuals. Like slips, mistakes are more likely under severe muster circumstances in which a lack of experience and knowledge, for the circumstances, will exist for most personnel.

2.4 Violations

A violation is an intentional departure from a developed procedure. Violations are often the most difficult type of human error to predict and are specific to individuals for various reasons at various timers such as malicious intent. Though a violation with the intent to sabotage a process is very uncommon, accidents can occur when an operator did not carry out an action in a procedure because they found it to be troublesome or unnecessary. Under a muster scenario, a violation is more likely with increasing stress levels. Positive violations are made when procedures fail to identify appropriate actions or systems do not provide for error recovery. A positive violation may occur because the muster circumstance is desperate and a radical course of action is necessary (such as jumping from a platform when egress routes are not tenable).

The structure of a procedure the potential can affect the probability of a violation. Muster procedures must highlight dangers under difficult scenarios and provide options in the event of their occurrence. Figure 2.2 illustrates the continuum that exists between

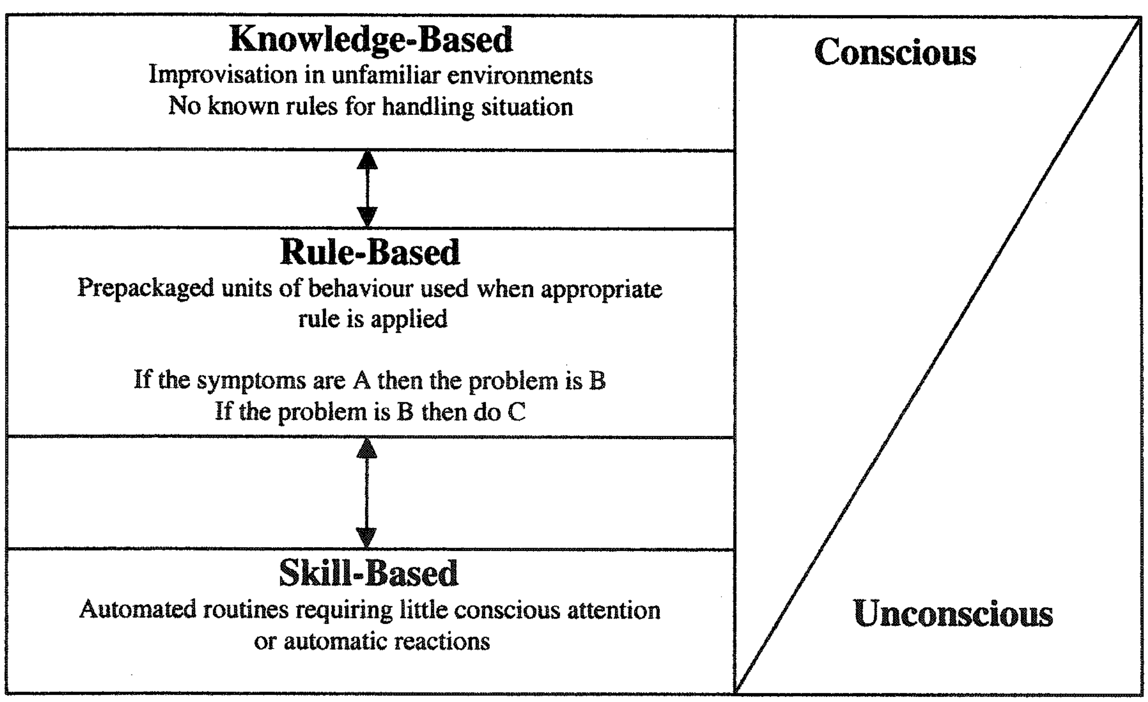

Figure 2.2 Modes of operation and relative level of conscious behaviour (adapted from Reason, 1990).

knowledge, rule and skill-based information processing. Figure 2.2 also indicates the level of conscious and unconscious behaviour associated with each mode of information processing. The following section discusses how individuals move between these three modes of operation.

2.5 Generic Error Modeling System

The Generic Error Modeling System (GEMS) (Reason, 1990) describes how individuals move between the three modes of information processing (Figure 2.3). A series of checks are performed as an action is progressed. If in one of these checks the operator determines the tenability of their immediate surroundings has degraded to a level of unacceptability, the operator will transition to rule-based thinking to determine the nature of their circumstance. This can involve information gathering from available sources which are used as input to a diagnostic rule; if the symptoms are A, then the cause of the problem is B. Establishing the most likely cause of the problem, an action rule is formulated - that is, if the cause of the problem is B, then do C.

If the problem is solved, the operator may move back into a skill-based routine. If the problem is not solved then more information will be gathered in order to identify a pattern of symptoms corresponding to a known cause. If a cause to the problem cannot be established by application of any rule, the individual will revert to a knowledge-based level of operation. The individual will seek an analogy between the unfamiliar situation and a pattern of events for which rules are available. If a diagnostic rule can be found that applies in a valid manner, the operator will revert back to the rule-based level and use an appropriate action rule.

If a suitable analogy cannot be found, then it will be necessary to either conduct some form of research or utilize another's experience or knowledge. Muster initiators that produce dangerous environments will generate conditions that make normal muster actions unusual and will directionally move individuals into knowledge-based thinking. As stress levels increase, the ability to effectively move between these three modes of thinking may be adversely affected. The ability to apply correct rules or

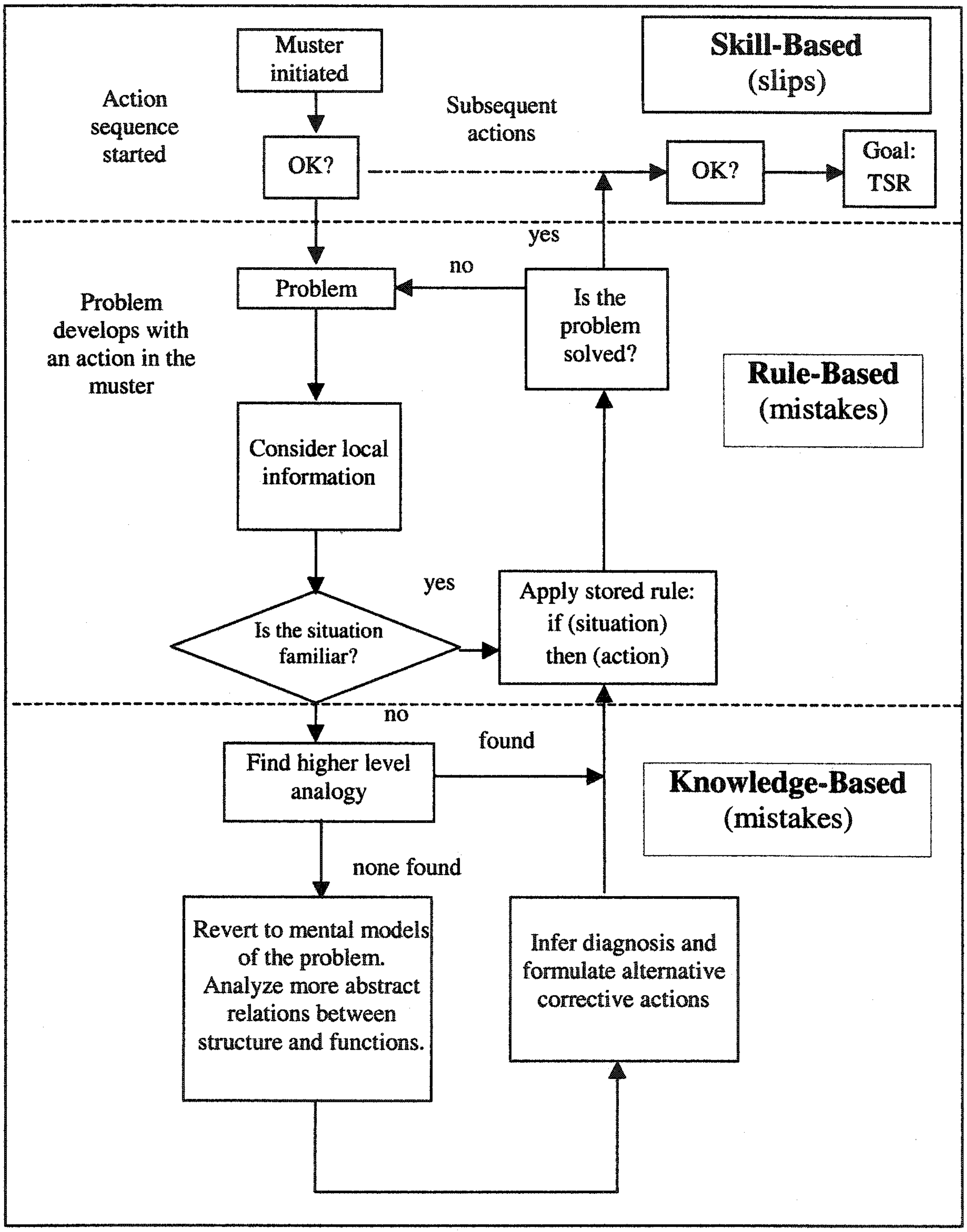

Figure 2.3 Generic error modeling applied to a muster scenario (adapted from Reason, 1990).

develop a correct hypothesis can be detrimentally affected, increasing the probability of error. Consider an experienced operator performing a muster action which is routine under a drill scenario (e.g. closing a valve to return the process to a safe state before commencing an egress). The operator, working in the automatic skill-based mode, systematically checks his situation as indicated by the "OK" boxes in Figure 2.3. If during one of these checks a problem develops, the operator may move into the rule-based mode of thinking to apply a known rule to solve the problem. If an appropriate rule cannot be found, then transition to the knowledge-based mode occurs. Information is gathered and an action plan is formulated to address the problem. If the problem is not solved, more data gathering and analysis occur to formulate another action. Once the problem is solved, the individual reverts back to the skill-based mode of behaviour.

As severe muster scenarios present unfamiliar situations and high stress levels, a reactionary approach to muster actions results in actions that are performed quickly but have increased potential to be in error. It is during these dangerous situations when individuals must exhibit the ability to reason at the highest level to provide themselves with the greatest chance of survival. The following section provides examples of the various mechanisms from which human errors are generated. Understanding these error paths is a crucial step in developing methods to limit the possibility of their occurrence.

2.6 Modes of Human Error

This section outlines the causes and mechanisms through which human errors may occur during a muster sequence. Recognition and understanding of these error paths is important in developing mitigation plans to address the potential for human error in a proactive fashion. Table 2.2 provides a list of mechanisms through which human errors occur. The explanations are indicative of a variety of problems that can happen during a muster sequence. Identifying the potential for these occurrences is the first step in determining appropriate methods for reducing the likelihood of human errors. The basic cognitive process (the act of knowing) is made up of three phases, which relate to the muster sequence as follows:

Table 2.2 Modes of human error that can occur during a muster sequence.

Implementation of an extra action	A muster error due to: • misalignment requiring a corrective action • delay or premature action • incorrect action • wrong duration of an action • use of excess force, such as a closing or opening action • performing an action out of sequence
Exclusion of an action	A muster error due to: • lack of response due to time pressure • lack of attention due to distraction • lack of awareness of need for action caused by no signal or incorrect interpretation of information
The implementation or exclusion of an action due to mental or physical change of operator	A muster error due to: • working in non-optimal conditions (smoke, fire) • operator not being in optimal condition (injured)

1. Detection phase activated by a change from normality (awareness of muster).

2. Information processing phase involving observation, identification, interpretation, defining tasks and procedure formulation (evaluation of surroundings).

3. Operation phase involving execution, confirmation and error detection and recovery actions (egress to TSR).

During a muster, information is gathered from local cues (i.e. audible, visual), safety systems (i.e. deluge) and environmental conditions (i.e. heat, smoke, vibration). Response time varies between individuals according to the time taken for event diagnosis based on their level of training and experience. In reaction to a muster alarm, a person will try to apply learned skills if the conditions appear similar in nature to the set of muster conditions from which the skills were learned (i.e. drills). In order to mitigate the potential for human error during a muster, it is necessary to understand and recognize how these slips, mistakes and violations are generated. Table 2.3 provides a list of root causes based on system design and muster conditions for three predominate error

Table 2.3 Human error conditions and causes (adapted from Wells, 1996).

Error Condition	Causes
Erroneous or absent information (e.g. no PA announcement, poor egress signage or no egress signage)	When information is: • Not accessible • Too detailed • Not readily available • Illegible • Not existing • Not provided • Obscured • Incomplete • Ambiguous • Incorrect
Adverse conditions (e.g. poor weather or muster initiator generating an untenable area and/or confusion)	When conditions are affected by: • Stress • Cold • Vibration • Chemicals • Noise • Ventilation • Emergency chaos • Lack of visibility • Temperature
Erroneous or absent interface (e.g. egress route has been compromised due to muster events)	When interface is: • Not working • Inadequate • Hazardous • Unprotected • Inaccessible • Confined • Inappropriate • Not provided

conditions (i.e. erroneous or absent information, adverse conditions and erroneous or absent interface). Table 2.4 offers a list of factors that lead to conditions where human error may occur and the factors that generate human error from inherent and process conditions. These error conditions promote mechanisms that lead to human failure (Table 2.5). Human reliability can be improved through an awareness of these

Table 2.4 Factors leading to human error (adapted from Wells, 1996).

Factors	Examples
Human factors	• Stress • Information overload • Haste • Inadequate communication or instruction • Inadequate procedures • Difficult operational interface • Bad communication channels • Inadequate controls • Poor definition of responsibilities • Inadequate training • Poor co-operation
Inherent factors	• Inadequate information from safety system, memory • Inadequate information processing/decisions • Inadequate physical attributes
Process factors	• Inadequate systems for recovery (limited egress routes) • Inadequate active protection systems (deluge) • Inadequate passive protection systems (signage)

mechanisms and their causes. This understanding can be applied proactively during the development of muster procedures and training. Platform design, hardware and management systems can also be improved so that muster systems are more error tolerant by providing means of recovery for as many of the errors as possible.

In the next section, task analysis is reviewed in the context of a hierarchical task analysis. In order to quantify the likelihood of human error within the muster framework, the muster activities must be characterized and broken down into task elements. A list of established, unambiguous actions that an individual may perform is formulated, followed by the identification of performance shaping factors (PSFs). The influence of the PSFs can then be analyzed and the probability of this error determined through an expert judgment technique.

Table 2.5 Mechanisms which generate human error (adapted from Kennedy, 1993).

Error Mechanism	Error Form	Muster Example
Short cut invoked	A wrong intention is formed based on familiar cues which activate a short cut or inappropriate rule	Not bothering to make workplace safe before starting egress to TSR
Failure to consider special circumstances	A task is similar to others but special circumstances prevail which are ignored and the task is carried out inappropriately	An egress path is picked without considering its proximity to a gas release
Need for information not prompted	Failure of internal or external cues to prompt need to search for information	A malfunction of the muster alarm system preventing important messages reaching personnel
Stereotype overrule	Due to a strong habit, actions are diverted along a familiar but incorrect pathway	An egress route taken during muster drills is chosen during a gas release despite the path's close proximity to the muster initiator
Assumption	Response is based, inappropriately, on data supplied through recall or guesses which do not correlate with available external information	Prior to opening a door, no checks are performed on surface temperature despite a known fire in the local area
Misinterpretation	Response is based on incorrect interpretation of data or the misunderstanding of verbal message command or request	Misinterpreting PA announcement and taking an egress path of low tenability
Mistake among alternatives	Several options available of which the incorrect one is chosen	Muster process offers alternative modes of egress and incorrect path is picked
Losing one's place	The correct position in the sequence of actions is misidentified as being later than actual	Once in the TSR individual does not register, generating a missing person scenario
Motor variability	Lack of manual precision or incorrect force applied	Does not effectively close a valve while making workplace safe
Panic	Lack of composure; result is disorientation, incoherence and possibly static movement	Upon hearing muster alarm or witnessing muster initiator, person becomes incapacitated and unable to cope
Memory slip	Forgets to perform an action or some component of the action	Forgetting which direction the TSR is from current location
Spatial orientation inadequate	Despite individual's correct intention and recall of identification markings, performs an action in the wrong place or on the incorrect object	Closing similar but incorrect valve while in haste to make workplace safe before starting egress to TSR

2.7 Hierarchical Task Analysis

Hierarchical Task Analysis (HTA) is a systematic method of describing how work is organized in order to meet an overall objective (Embrey et al., 1994). There are two methods of representing HTA - tabular and diagrams. Diagrams are more often used because of their ease of assimilation. The technique involves identifying, in a top down fashion, the overall goal of the task, followed by the various sub-tasks and the conditions under which they should be carried out to achieve that goal. Through this method, complex tasks are represented as a hierarchy of operations and plans, that is, the various actions that people must perform within a system and the conditions needed to achieve these operations. HTA was developed by Annett et al. in 1971 (Embrey et al., 1994) as a method of representing various tasks involving significant planning. HTA was developed for process control training, and has since been utilized in other applications including human error analysis (Kennedy, 1993). HTA starts by formulating an overall objective that an individual needs to accomplish.

This objective is then described into a set of sub-operations and the sequence in which actions are to be carried out. The sequence of events is an essential part of HTA as it describes the prerequisites that signal the start of a set of activities. Each sub-operation is then described further if the analyst deems it required and there is supporting information.

Figure 2.4 illustrates an HTA of a muster sequence where operations are broken down into more plans and sub-operations where necessary. As the operation is hierarchical in nature, the description is in general terms and captures the major actions of all musters. The decision to break down an operation into greater detail depends on whether a significant error mode is likely to be revealed. Until the operation is broken down in more detail, it is not easy to ascertain how a sub-operation may fail and what are the resultant consequences. The general quality of the performance shaping factors (e.g. training) provides an indication of the overall likelihood of error in the specific task being evaluated. The consequences of errors are evaluated in terms of the individual's health,

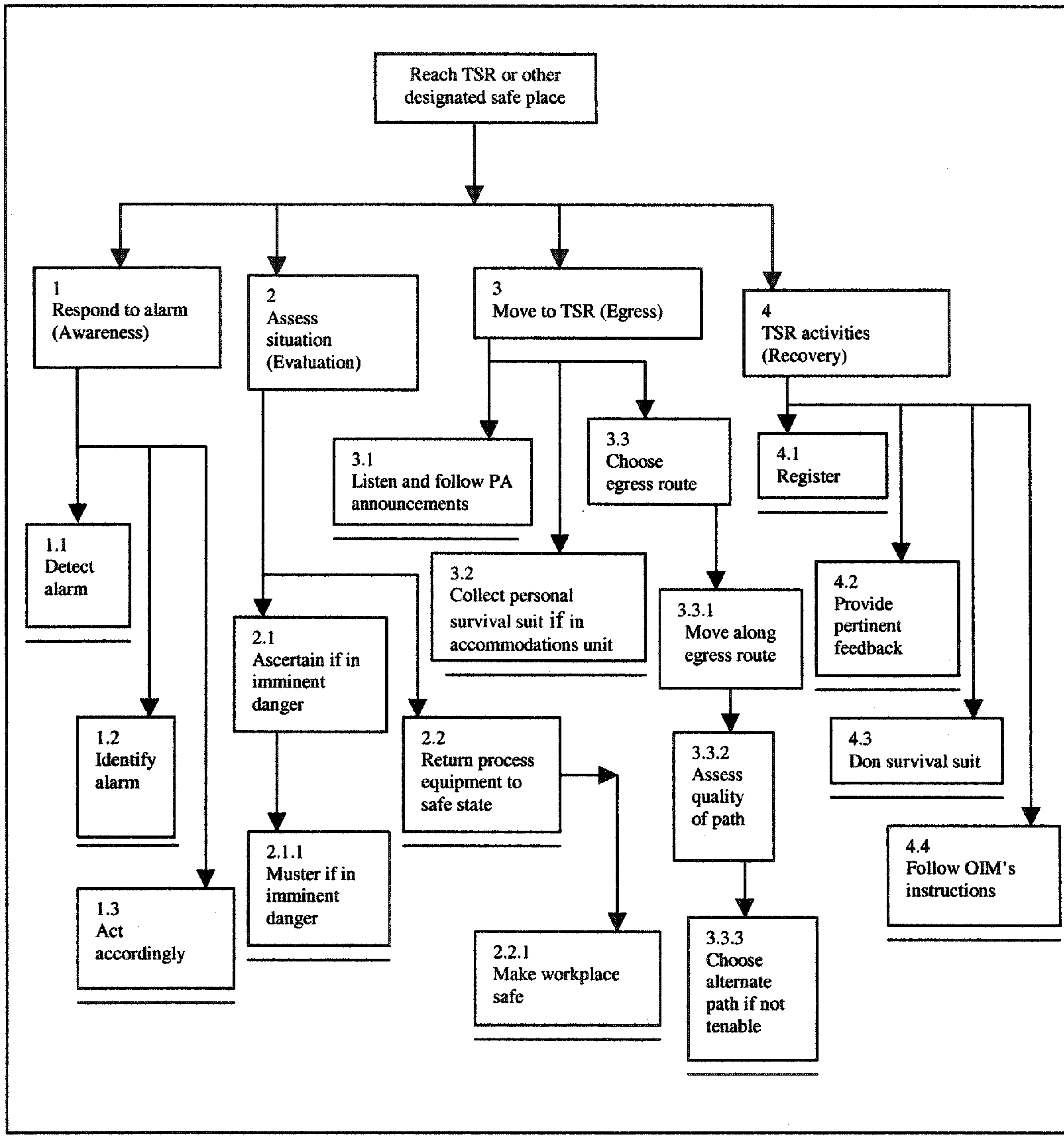

Figure 2.4 Graphical HTA of a muster sequence (the order of actions follow the numbering sequence).

effect on others, effect on muster initiator and effect on time to muster (i.e. egressability).

The progress of an HTA can start with diagrams and end with a step by step record of the analysis. A tabular form is utilized in this work as a means of presenting risk mitigation measures in the implementation of a human error probability index (HEPI). Analyzing tasks in a complex situation is typically performed with knowledgeable people such as operators, supervisors and engineers. Information can be collected from a variety of sources including procedures, protocols, and records of incidents. HTA offers several advantages when applied to an application such as offshore musters. The hierarchical structure of HTA allows the user to focus on crucial aspects of the task:

- HTA allows functional objectives to be specified at the higher levels of the analysis prior to final decisions.
- HTA may be used as a starting point for other error analysis methods to examine the error potential in the performance of required tasks.
- HTA enables the user to choose the level of event breakdown for which data are available when conducting a quantitative risk analysis.

The next section provides an overview of the human reliability assessment process and illustrates the need for the recognition and provision of human error identification. Subsequently, an overview of hazard and operability studies is conducted along with error of commission analysis.

2.8 Human Reliability Assessment

The assessment of human error and its associated risk is performed through the use of Human Reliability Assessment (HRA) tools. During the risk assessment of a muster it is fundamental that the consequences from human error be determined in order to evaluate risk. Quantitative human reliability analysis estimates the likelihood of failure and provides a prediction of the consequences from failure. If the calculated risks are too high, the HRA should provide a means of reducing the probability of failure

(POF). Figure 2.5 illustrates the HRA process through the adaptation of HTA and an expert judgment method (i.e. SLIM) to determine error probabilities, consequences and

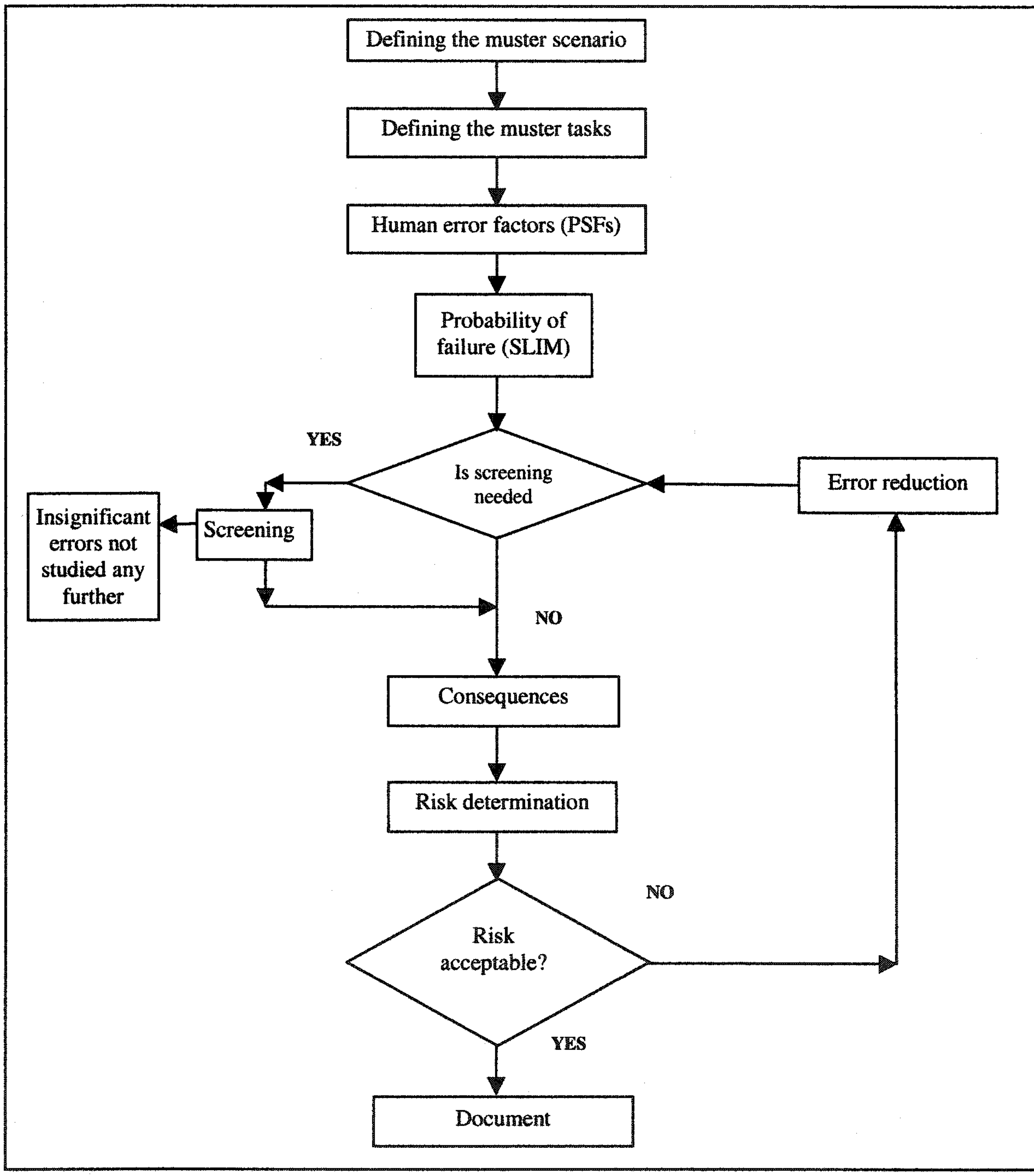

Figure 2.5 Human reliability assessment of a muster sequence.

mitigating actions. The muster actions are defined first and then the performance shaping factors that influence the POF are formulated.

Human error probabilities (HEPs) are determined through the application of the Success Likelihood Index Methodology (SLIM) and a consequence matrix is applied to determine the level of risk associated with the failure of that action. Human error for muster tasks does not imply that there is no opportunity for recovery, that is, to correct the error. In a muster scenario the time to complete a task is relevant. Muster times are of the order of a few minutes (e.g. three to six minutes) for a typical offshore facility. The muster time incorporates the period from point of alarm to a successfully completed personnel count in the temporary safe refuge (TSR). The predicted HEP in relation to time is discussed in more detail in Chapter 3.

Error recovery can come through the realization that a mistake was made (i.e. internal recovery) or through an external cue (e.g. other personnel, PA announcement, or change in environment). The consequences from human error are directly related to the severity of the muster. Further, the time requirement to complete tasks shortens as muster severity increases. Failure in this sense is defined as an inability to complete a set of actions within a critical period of time. Errors are quantified by their probability of occurrence, which is the HEP as shown in equation [2-1] (Bedford and Cooke, 2001).

$$HEP = \frac{number\ of\ failures}{number\ of\ opportunities\ for\ failures} \qquad [2\text{-}1]$$

Predicting the probability of failure (POF) based on relevant performance shaping factors is central to expert judgment methodologies such as SLIM. Effective HRA applies the concepts of Optimal Risk Assessment (ORA) and links error identification with error quantification and error reduction measures. Tabular HTA can be utilized to present error modes and causal factors along with risk mitigation measures to lower risk potential. This methodology provides a comprehensive approach to the incorporation of human error into a detailed muster analysis.

A common method of representing failure is through event trees (Figure 2.6). Event trees are useful within an overall system analysis in identifying weaknesses or where important errors are probable (Kirwan & Ainsworth, 1992). The benefits from event trees include:

- Ability to model sequences of actions,
- A ready interface with systems analysis techniques, and
- Identification of tasks or errors which are most critical and have the greatest impact upon success or failure.

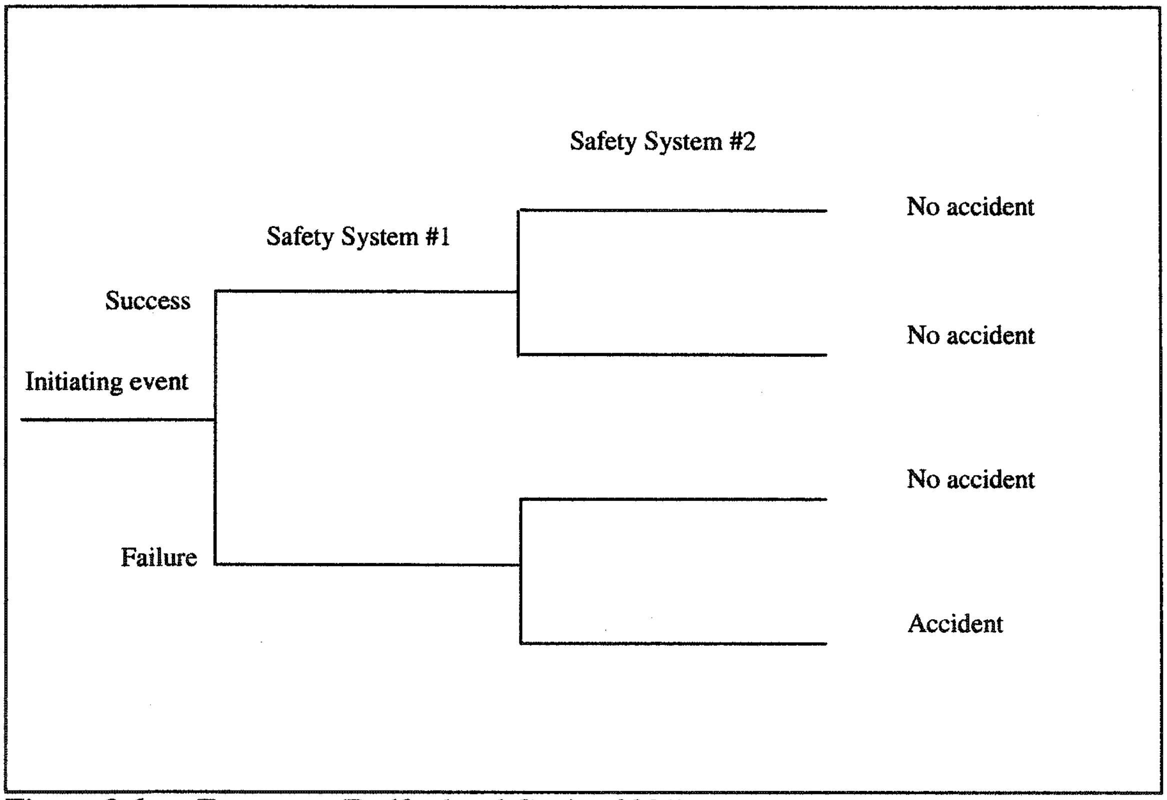

Figure 2.6 Event tree (Bedford and Cooke, 2001).

Event trees start with an initiating event and propagate this event through the system under review by considering all possible ways in which the event can affect the behaviour of the subsystem. A path through an event tree resulting in an accident is termed an accident sequence. In Figure 2.6, the event tree consists of an initiating event and two safety systems. If one of the safety systems works properly there is no accident. If both fail there is an accident

Despite these advantages, event trees are best suited to identify errors of omission, while errors of commission are difficult to include satisfactorily. Event trees do not identify root causes nor do they offer error reduction suggestions and hence do not provide the flexibility required for an effective muster HRA. The following section reviews a common process hazard assessment technique, HAZOP (hazard and operability study), and shows how human error identification is not typically a formal consideration, despite the exhaustiveness of this method.

2.9 Hazard and Operability Study

A Hazard and Operability study (HAZOP) is a systematic technique carried out by a team of individuals to identify hazards and problems that may prevent the safe and efficient operation of a process plant or procedure. A HAZOP is usually carried out on a Piping and Instrumentation Diagram (P&ID) at the detailed design stage or as a check on the operability of an existing plant. A HAZOP can also be applied to procedures such as plant start-ups or platform musters. Hazard and operability study uses parameters and guidewords (Table 2.6) to suggest deviations of process variables and their causes. The parameter selected is one that is relevant to the system being reviewed. Typical parameters are as follows:

- Pressure
- Flowrate
- Level
- Temperature
- Composition
- Physical properties
- Flow quantity

Table 2.6 Basic guide words in a HAZOP (adapted from Kletz, 1992).

Guideword	Muster Examples	Traditional Examples
No, Not, None	Does not hear PA announcement.	No activity or operation takes place. There is no forward flow when there should be. A task may not be done, something may not be delivered or be there. There may be no action in response to an activating signal. A check is omitted.
More of	Too much haste in making workplace safe, leaving obstacles blocking the egress path.	There is more of something. More of any physical quantity than there should be; for example, more of temperature, pressure, quantity or flow. More of a task can be carried out. An activity is done for a longer time.
Less of	Does not apply enough force to close a valve.	There is less of something present. Less of an activity is carried out. Less time is taken.
Part of	Does not complete returning process equipment to safe state.	Only part of an action is carried out. There might be a transfer of part of a load or batch. More components or an extra phase or impurities might be present.
Reverse	Gathers survival suit after registering in TSR.	Something happens backwards. For example, a back siphon occurs or heating rather than cooling takes place.
Other than	Chooses incorrect egress path that has lower tenability.	A gas B can be sent down the pipe instead of gas A. An operator may press the wrong button or open the wrong valve. This keyword is also used to identify what is required other than the normal operation, for example start-up, shutdown, regeneration or maintenance.
As well as	Gathers personal survival suit though not in the accommodations module at time of muster.	Can buttons X and Y be pressed when only X was meant to be pressed? Can both gas A and B occupy the same pipe? What happens if a valve is adjusted while the system is operational? What happens if the operator eats their lunch at the same time as packing a hazardous material?
Sooner or later than	Muster actions performed at a slow pace indifferent to severity of muster.	Every system has its running clock. What happens if a certain task is done before another task? What if the batch reaction is not finished in the normal or allocated amount of time?

Figure 2.7 illustrates the HAZOP process from start to finish and the cycle of identifying the causes and consequences of each deviation. A HAZOP is typically conducted on a specified piece or combination of equipment. It is often useful to break down the system into smaller components that are more easily managed. The beginning and end of these smaller sections are highlighted on P&IDs and are known as nodes. A large process system will often consist of many nodes that are examined individually in a HAZOP.

The HAZOP study continues until each node associated with the equipment in question is completed. A deviation is worth considering if it has a realistic cause and related consequence which can generate a hazard or operability problem (Wells, 1996). This can be referred to as a meaningful deviation, which may require more information to determine the extent of the potential problem.

Despite the desired high level of safety, essential in the process industries, predictive assessment techniques such as hazard and operability studies do not formally consider human error. Even though HAZOP is a widely used and effective tool, it generally lacks the recognition of humans as technical failures that need to be modeled and assessed with particular emphasis on higher level human functions such as diagnostic and decision making errors. Failures of this type can and will have substantial effects on the safety of hazardous systems due to their capacity to overcome engineered safeguards. It is important to realize that any predictive technical analysis of a complex system will make implicit assumptions about the way the system will be operated. If these assumptions are not accurate or are incorrect, then the technical analysis may no longer be valid. Hence, it is necessary to clearly state the assumptions that underlie the assessments of risk and to frequently review these assumptions.

Human hazard and operability studies are derived from the traditional HAZOP technique (Kirwan, 1994). This type of assessment can vary from a straightforward biasing of the HAZOP procedure towards the identification of human errors to a more radical alteration of the HAZOP procedure itself (Kirwan, 1994).

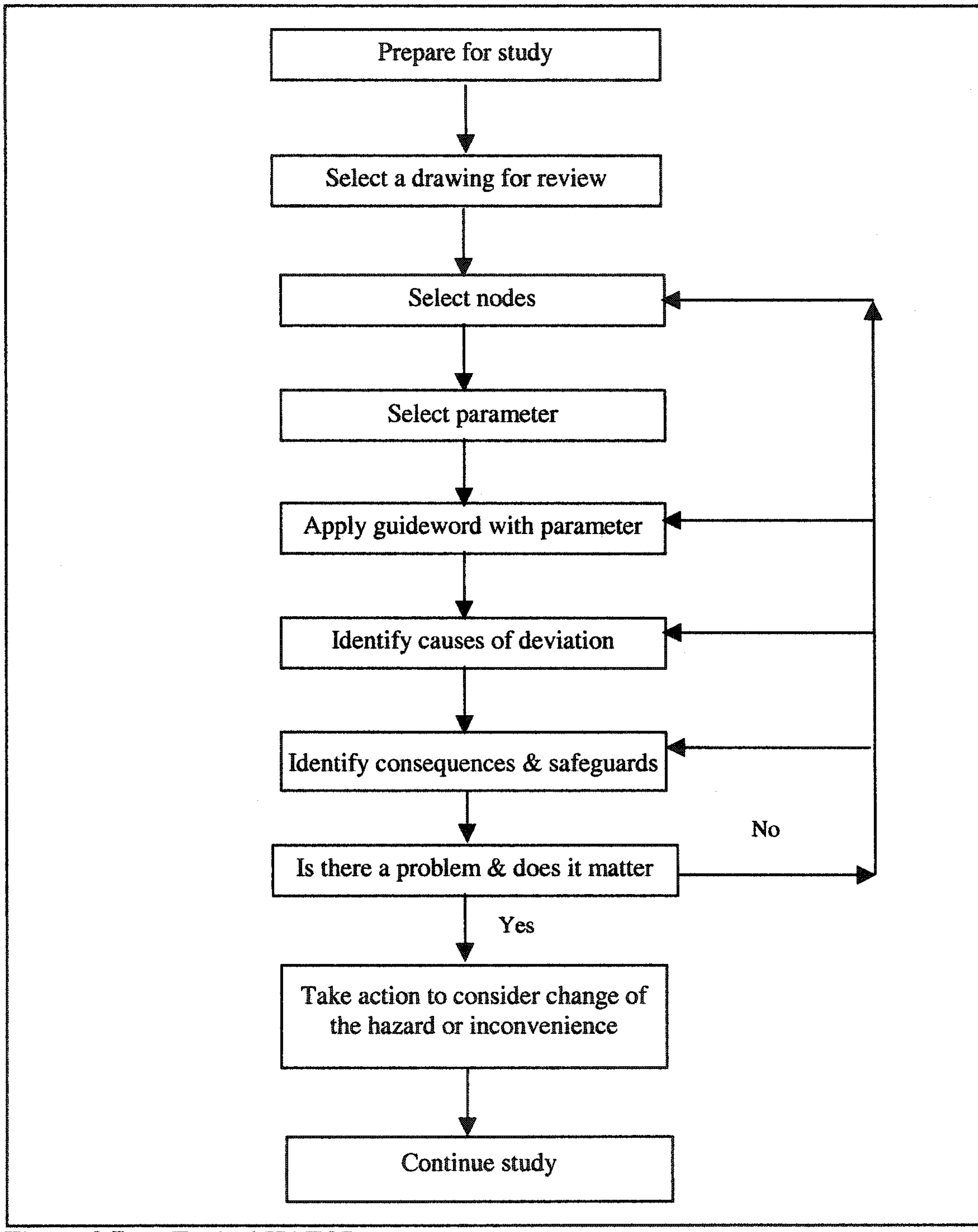

Figure 2.7 Typical HAZOP process.

The HAZOP technique utilizes the experience and knowledge of the HAZOP facilitator and of the participants to analyze a design or procedure. There are synergies between the traditional HAZOP and an approach that combines a task description with error taxonomy (i.e. skill, rule or knowledge-based classification). An important advantage of extending HAZOP to a systematic identification of human errors is that the technique can be applied at an early stage in the design process, when human factor considerations can be taken into account in a relatively cost effective manner. The Potential Human Error and Cause Analysis (PHECA) system uses human error type guidewords related to the traditional HAZOP guidewords (Kirwan, 1994). The human-error modes derivable from HAZOP are listed in Table 2.7.

Table 2.7 PHECA error types related to HAZOP key words (Kirwan, 1994).

HAZOP Guideword	PHECA Error Type	Muster Action Example
No	Not Done	Fails to make workplace safe, creating obstacles in egress path
Less	Less Than	Egresses slowly to the TSR while local area tenability degrades
More	More Than	Takes too much time to assess egress path quality as local tenability degrades
As Well As	As Well As	Gathers personal survival suit when not in accommodations at time of muster, delaying arrival at TSR
Other Than	Other Than	Egresses immediately after muster alarm rather than making workplace safe before starting egress
----	Repeated	Chooses egress path incorrectly and has to choose another path to reach TSR
----	Sooner Than	Egresses before returning process equipment to safe state
Reverse	Later Than	Does not begin egress to TSR in a timely manner
----	Misordered	Gathers survival suit after registering at TSR
Part Of	Part Of	Puts away only some of the equipment, blocking egress path before leaving work site

HAZOP practitioners are usually not trained to identify human errors with additional guidewords. Human error may be identified serendipitously during a HAZOP. This approach is not rigorous or reliable without additional human factor (HF) guidewords. It is through these HF guidewords that a greater awareness of human error is generated in the HAZOP process. The extension of the traditional HAZOP to include human factors can be useful in applications such as offshore production platforms, but due to its qualitative nature, probability predictions are difficult and may not properly represent the risk associated with human failure and identify root causes.

2.10 Error of Commission Analysis

Another technique commonly employed in hazard identification is the error of commission analysis (EOCA). This technique utilizes a HAZOP type approach to identify actions made in error on the part of an individual, caused by lapses, slips, violations and mistakes. To successfully perform an EOCA for a muster, it is necessary to have a very good understanding of the muster scenario and then take advantage of this knowledge from a human error perspective. An EOCA requires a facilitator with hazard analysis experience and operational expertise to be successful. If expertise is lacking, then a detailed task analysis is required. The facilitator's level of experience is important in that the significance of errors of commission (e.g. misdiagnosis) must be predicted.

For identification purposes, these errors can be addressed from an HRA perspective through a review of critical tasks and functions carried out by the individual during a muster. A HAZOP style approach requires a review of the muster tasks and a consideration of those PSFs and failure modes that may lead to significant EOCs. There are four elements of such an analysis:

1. Operational Experience
2. Procedures
3. Task Analysis
4. Probabilistic Safety Assessment

Keywords are based on PSFs and error types. Error types are based on the Justification of Human Error Data (JHEDI) technique, (Kirwan, 1997), while PSFs are developed by the review team based on the factors that are relevant to errors of commission. The JHEDI system contains a small number of conditional probabilities concerned with checking actions (e.g. operator must check the contents of a computer report prior to an action). The output from a HAZOP under such a format will provide information on the following:

- Errors of commission (EOC)
- Cause of EOC
- Recoverability of EOC
- Consequences from EOC
- Error reduction measures

The consequence output will also state whether the EOC in question significantly increases the probability of an already identified fault path or whether it gives rise to a new event sequence. As part of the ECOA, a Generic Accident Sequence Event Tree (GASET) can identify the following types of errors:

- Initiators
- Latent errors (pre-event errors)
- Slips and lapses (which worsen the scenario)
- Detection and decision making failures (including diagnostic errors)

A GASET based approach is useful in structuring the ECOA. The technique employs an event tree structure to graphically represent the various paths of behaviour that are possible in an activity (Kirwan and Ainsworth, 1992). Each task in an event driven sequence is represented by a node in the tree structure. The potential outcomes of the tasks are shown by paths that lead out of the node. Typically, two paths corresponding to failure or success are drawn from each node.

The possible behaviour at each step is identified by some human reliability or error identification method. The level of detail of the task elements can vary as it would within an HTA. At a high level, a step definition may be "initiate emergency shutdown", while at a lower level the component sub-steps such as detection and diagnosis would be defined. Recovery paths can be indicated where there are opportunities for the individual to correct errors. Figure 2.8 is a representation of a sequence event tree. It provides in a generic fashion the human contributions (negative and positive) towards accident progression.

This approach can be supplemented by a quantitative assessment in which the probability of failure for each sequence is assessed. As data on human error during

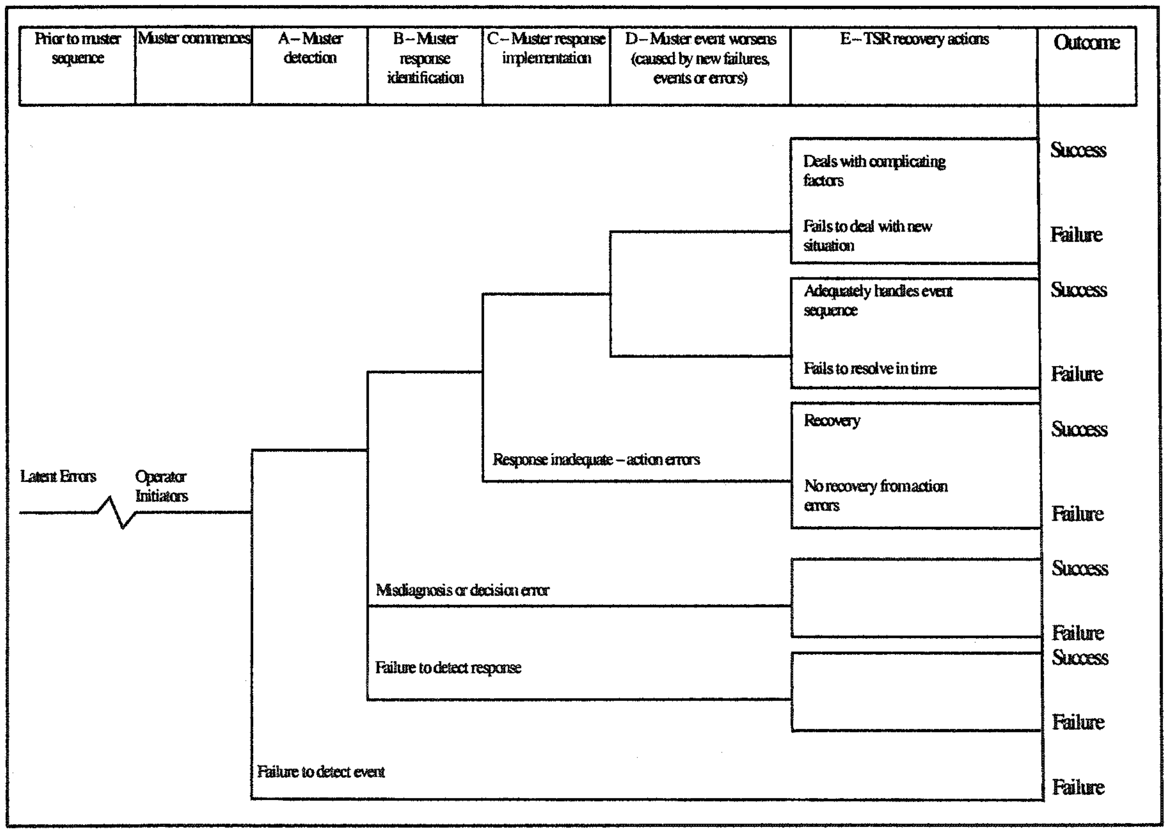

Figure 2.8 Generic accident sequence event tree (adapted from Kirwan and Ainsworth, 1992).

muster events do not exist in the public domain, an expert judgment technique has application in this method. The relative likelihood of the different sequences can be investigated and the most significant errors identified. The effect of various changes such as improved design can be measured by reassessing the probabilities of the errors and recalculating the probabilities. This approach is thorough but unwieldy and does not satisfy the goal of producing a flexible and useful HRA tool. The next chapter reviews quantitative human reliability techniques as a prelude to a review of expert judgment models.

Chapter 3
QUANTITATIVE HUMAN RELIABILITY ANALYSIS

This chapter introduces the Systematic Human Actions Reliability Procedure (SHARP) (Miller and Swain, 1987). SHARP is a methodology that applies human factors in risk assessments. Also included in this chapter is a review of quantitative human reliability analysis (QRA) techniques (i.e. HEART, THERP and SLIM) and their applicability to human error evaluation for a variety of platform musters. A summary overview of these methods is conducted followed by a more detailed review with focus placed on SLIM. The SLIM technique and prior investigations of this methodology are discussed in detail.

3.1 Quantitative Human Reliability Techniques

Early approaches to human reliability were based on behaviourism. Behaviorism is the doctrine that psychological theories should be based on the outwardly observable data of human actions. This approach concentrates on the visible aspects of human performance in terms of the stimuli received by the human and responses that the individual makes based on those motivations. This approach ignores the person's capacity for problem solving and diagnosis. Muster training is typically centered on a behaviouristic response to the muster alarm despite expectations of diagnosis and problem solving to successfully complete the muster actions under severe circumstances.

In the 1960's and 1970's cognitive psychology replaced the concept of a person as a passive component responding to stimuli. The cognitive approach treated humans as dynamic goal-directed processors of information. In reality, it was found that functions critical for system reliability were not routine actions that could be addressed from a behaviouristic approach. Rather, problem solving and decision making predominated during abnormal situations where human failure has severe consequences.

This viewpoint has been reinforced by data from accidents where decision making errors in extreme situations resulted in serious consequences. Accidents such as Piper

Alpha have increased concern about the effects of human errors in complex systems (Basra and Kirwan, 1998). Although a behaviouristic approach has application in scenarios where the actions are performed at a low level with little problem solving (i.e. muster drills), this approach does not adequately prepare individuals for severe musters.

Reliability analysis can confine human reliability to an evaluation of whether or not an individual will correctly carry out a prescribed task as part of a defined procedure. These failures can be generated by carrying out the correct action but on the incorrect button or valve, or applying insufficient force and not achieving the desired goal, or even carrying out the wrong action on the right piece of equipment. Understanding why the error occurred is valuable input in predicting its occurrence and providing a means to improve the probability of success.

There are a variety of underlying mechanisms that may be responsible for these externally visible error modes, some of which are:

- Person reverts to a habitual action, possibly due to some form of distraction, that results in an incorrect action.
- Person cannot determine what the correct action is, due to either lack of training or feedback information.
- Person misdiagnoses the nature of the issue at hand and deliberately, but not maliciously, performs the wrong action.
- Person initiates an incorrect action with malicious intent.

The probability of an incorrect action is dependent on the relevant performance shaping factors (PSFs). HRA tools should allow the analyst to take into account characteristics of the task, physical environment, organizational environment and operator characteristics. The application of PSFs in human reliability analysis of emergency tasks is seen as an important factor in HRAs (Kim and Jung, 2003). This necessitates the meaningful collection of human performance data by specifying the contextual information that needs to be gathered to allow aggregation of error into categories with underlying commonalties. Databases tend to focus on the types of injuries and operations that were carried out at the time of the accident (Gordon et al., 2001). Causal analysis related to human factors that may have led to the injury is not easily identified and is often overlooked. These models should also allow a what-if approach by specifying the way error probabilities change with differing conditions (i.e. severity of muster initiator). It is through such models that weaknesses in a muster system are identified to permit the analyst to seek remedial measures.

Although there has been a degree of research applied to the quantification of human error probabilities, a very small number of these techniques have actually been applied in practical risk assessments (Embrey et al., 1984). Table 3.1 provides a list, though not exhaustive, of techniques that have been proposed as a means of estimating HEPs. Of this group, HEART, THERP and SLIM have enjoyed the widest application and are the techniques texts most often reference (Bedford and Cooke, 2001, Embrey et al., 1994).

Table 3.1 Human error quantification techniques (Kirwan et al., 1988).

Acronym	Technique
SLIM	Success Likelihood Index Methodology
APJ	Absolute Probability Judgment
PC	Paired Comparisons
TESEO	Tecnica Empirica Operatori
THERP	Technique for Human Error Rate Prediction
IDA	Influence Diagram Approach
INTENT	Method to Calculate HEP for Decision Based Errors
HCR	Human Cognitive Reliability Correlation
JHEDI	Justification of Human Error Data Information
CREAM	Cognitive Reliability and Error Analysis Method
HEART	Human Error Assessment and Reduction Technique

Extensive reviews of many of these techniques have been conducted (Kirwan, 1998, Kirwan, 1992, and Kirwan et al., 1988). Several works (Williams, 1983, Aspostolakis et al., 1988, Kirwan and James, 1989, Zimolong, 1992, and Spurgin and Lydell, 2002) have been presented that focus on the SLIM procedure along with other expert judgment methods (e.g. THERP and HEART). Table 3.2 is a comparative summary of these three methods based on accuracy, validity, utility and effective use of resources. The ability to use SLIM in a what-if approach is a useful and powerful aspect of this technique that permits a variety of muster sequences to be analyzed efficiently.

Table 3.2 Comparison of three QRA methods (adapted from Kirwan et al., 1988).

Criteria	**THERP**	**HEART**	**SLIM**
Accuracy	M	M	M
Validity	M	M/H	M/H
Usefulness	M	H	H
Effective Use of Resources	L/M	H	M

Note: L = Low, M = Medium, H = High

The Systematic Human Actions Reliability Procedure (SHARP) provides a methodology by which human reliability assessment techniques (e.g. THERP) can be applied to risk assessments (Table 3.3) (Miller and Swain, 1987). The SHARP framework has been considered a basis from which an industry standard may be set. The current work extends the SHARP framework by including recommendations to mitigate the probability of human error and reassess the initial risk level based on the implementation of these recommendations.

Since the comparative work by Kirwan et al. (1988), SLIM has evolved into a group of techniques (e.g. FLIM, Chien et al., 1988) while gaining wider recognition (Bedford and Cooke, 2001). The flexibility that SLIM offers is a key advantage in the evaluation of multiple muster scenarios. SLIM is an expert judgment technique

Table 3.3 Comparison of SHARP elements to HEPI.

<table>
<tr><th>SHARP Component</th><th>Definition</th><th>HEPI</th></tr>
<tr><td>Definition</td><td>Ensure that different types of human factors are considered</td><td rowspan="4">Development of performance shaping factors and muster actions through hierarchical task analysis (HTA)

Review of PSFs and muster actions with the core review team (CRT)

Elicitation of PSF weights and ratings through the elicitation review team (ERT)</td></tr>
<tr><td>Screening</td><td>Identify significant human factors</td></tr>
<tr><td>Breakdown</td><td>Develop a detailed description of important human factors</td></tr>
<tr><td>Representation</td><td>Model important human factors</td></tr>
<tr><td>Impact assessment</td><td>Impact of significant human actions</td><td>Consequence and risk tables</td></tr>
<tr><td>Quantification</td><td>Probability estimation</td><td>HEPs determined through SLIM</td></tr>
<tr><td>Documentation</td><td>Include all information for assessment to be understandable and reproducible</td><td>HEPI procedure</td></tr>
</table>

that employs judges to provide numerical feedback which acts as input to formulate the probabilities associated with human error. A formal expert judgment technique such as SLIM provides a structured and well documented approach to gathering data.

Expert judgments are primarily of interest when data are lacking. In the case of offshore platform musters, there are few data that directly pertain to human errors that occur during a muster, especially for musters that occur under severe circumstances (e.g. fire and explosion). The author has not found any HEP data as applied to muster scenarios of any severity. It is through the application of SLIM, that HEPs were estimated under such circumstances in the current work.

A review of the HEART, THERP and SLIM QRA techniques follows next with focus being placed on their comparative ability to be applied effectively to offshore muster scenarios.

3.2 Human Error Assessment and Reduction Technique

There are two steps required in the application of Human Error Assessment and Reduction Technique (HEART): a screening process and reliability calculations. HEART has gained a level of acceptance due to the large number of human factors it considers and the remedial measures the technique provides to improve human unreliability (Williams, 1988). Unlike other methods, HEART does not have an itemized procedure. Qualitative guidelines are used for identifying the likely sources, classes and strengths of human error as shown in Table 3.4.

Table 3.4 HEART screening process guidelines (adapted from Kirwan et al., 1988).

Sources of Human Unreliability	Principal Classes of Error	Strength of Effect
Impaired system Knowledge	• Substitution • Omission	Very great, especially if a model or stereotype is violated
Response time	• Omission • Substitution	Great, if system is unforgiving
Poor or ambiguous system feedback	• Omission • Transposition	Strong
Significant judgment required of operator	• Omission • Substitution • Multiple • Mixed	Measurable
Level of alertness resulting from duties, ill-health, or environment	• Omission • Substitution • Transposition	Comparatively small

The assessor decides which sources of unreliability apply and then determines from the strengths of the effect what factor (which represents unreliability) is to be used in moving from a favourable to an unfavourable condition. Once the sources of human unreliability have been determined, the extent of any underperformance is predicted. This is accomplished by deciding what the likely range of human unreliability is in relation to the task being considered.

Through an existing set of nominal human unreliability values (β'), an assessment of the likelihood of failure is conducted. To calculate the effect of the error-producing conditions (EPC) it is necessary to estimate what proportion of any given EPC might exist and multiply the basic task unreliability by the appropriate proportions of the error-producing conditions. The relative weighting (γ') of each EPC is predicted and multiplied by the associated effect (α') to achieve an assessed effect (φ') as seen in equation [3-1] (Kirwan et al., 1988). The probability of failure (POF') is the product of the action's unreliability value (β') and the assessed effect (φ') as provided by equation [3-2] (Kirwan et al., 1988).

$$\alpha' \times \gamma' = \varphi' \quad [3\text{-}1]$$

$$POF' = \varphi' \times \beta' \quad [3\text{-}2]$$

The determination of weighting values in HEART is presented as an activity for the assessor alone. This approach places a tremendous emphasis on the knowledge and experience of the individual. A cooperative team effort is more appropriate and likely to provide more accurate PSF weights as exhibited by the SLIM method. The precision of HEART can be measured by its numerical accuracy and consistency of use. Accuracy can be gauged by comparing estimates to empirical data while consistency is gauged by how different users of the technique agree in terms of numerical results.

Recently HEART has been software packaged and marketed to the oil and gas industry by the Jaakko Poyry Group in Finland under the brand name HEART-PC. The backup data used for this software are from the confidential CORE-DATA database (Kirwan et al., 1997). The empirical justifications of the HEART multipliers are obscure and the dependence between different factors is not modeled within the technique.

HEART concentrates on errors of omission and does not consider errors of commission, violations or tasks where slips may occur. This limits it usefulness in terms of an HRA technique for muster sequences.

3.3 Technique for Human Error Rate Prediction

The Technique for Human Error Rate Prediction (THERP) was developed in the early 1980's for use by the U.S. Nuclear Regulatory Commission (Swain and Guttmann, 1983). The technique utilizes PSFs and models human errors using probability trees and models of dependence. There are four phases to THERP (Table 3.5). Phase 1 of this approach is an attempt by the analyst to become familiar with the risk area (e.g. offshore platform).

Table 3.5 THERP phases (adapted from Kirwan et al., 1988).

Phase	Description
Familiarization	• Plant visit • Review information from system analysis
Qualitative assessment	• Talk or walk through • Task analysis • Develop HRA event tree
Quantitative assessment	• Assign nominal human error probabilities • Estimate the relative effects of PSFs • Assess dependence • Determine probability of success • Determine the effect of recovery factors
Incorporation	• Perform a sensitivity analysis

This initial phase provides some concern in that an assessor unfamiliar with the area in question will be unfamiliar with the risk scenario and the tasks to be evaluated. Fundamentally, decisions made in an HRA without good experience and knowledge cast doubt on the results. A team made-up of a individuals with a variety of backgrounds can avoid biases in risk assessment. The guiding principle of the HEPI method developed in the current work is that a core group of very knowledgeable and experienced individuals with varied backgrounds contributes to all aspects of the HRA process. Following Phase

1, the primary goal is broken down into sub-tasks using a task analysis technique. Each step that may occur in a possible error scenario must be broken down in a detailed manner so that a thorough human reliability analysis can be performed.

To analyze each step in terms of human reliability, THERP utilizes event trees. The use of event trees is not easily applied to a muster sequence. The range of actions and potential outcomes during a muster is too large for this approach. The HRA event tree does not allow for any ambiguity in terms of decision making; each node on the tree corresponds to a binary decision point, where one of two events can occur.

Each branch of the event tree must have a HEP associated with it. The THERP handbook developed by Swain and Guttmann (1983) contains many HEP tables targeted for actions in a nuclear power plant control room. The handbook's HEPs are derived from simulations, actual data and subjective judgment. From the event tree, cumulative human error probabilities can be predicted and the overall reliability of the system ascertained. Though not directly targeted to a muster sequence, the human error probabilities contained in the THERP tables (Swain and Guttman, 1983) have been used in this work to help develop the requisite reference HEPs for SLIM. The use of THERP HEPs in SLIM was suggested by Gertman and Blackman (1993). The following steps are utilized in the application of the THERP data tables:

1. Define the error. Find appropriate HEP table in the THERP handbook.
2. Identify the PSFs associated with this error.
3. Identify the category of error in the databank that is closest to that being assessed.
4. Identify the HEP associated with this category.
5. Identify the PSF associated with the error in the data bank.
6. Modify the databank value to reflect any differences between PSFs assumed for the databank HEPs and those that exist for the task being evaluated.
7. Modify the value so that it is a conditional probability. The success/failure of many tasks is directly dependent on the success/failure of previous tasks.
8. Produce task HEP from task step HEPs using a probabilistic evaluation.

The THERP technique recognizes that human reliability may increase over time (Dougherty and Fragola, 1988). This time reliability correlation (TRC) is incorporated into a model that takes into account other operators providing error recovery. As the dependency between operators increases and time permitted to perform tasks lengthens, the probability of error decreases. Decision making is not modeled explicitly in this approach. Further, no other PSFs are considered by the THERP TRC system

The accuracy of THERP for a complete analysis of a muster sequence is questionable and its consistency of approach is doubtful in this context due to the variability in event tree construction. THERP is not readily suited to the evaluation of errors concerned with diagnosis or high level decisions (knowledge-based actions) which can dominate tasks in severe muster scenarios. Further, THERP does not produce explicit recommendations to mitigate the probability of failure (POF).

3.4 Success Likelihood Index Methodology

The Success Likelihood Index Methodology is a rating oriented model originally developed with the support of the U.S. Nuclear Regulatory Commission, and has been applied to other industries including chemical and transport (Embrey et al., 1994). Technology and experience associated with nuclear power plants has influenced developments in safety systems for offshore platforms (Bea, 2001). The SLIM technique is intended to be applied to tasks at any level of detail (Embrey, 1983), making it applicable to a range of musters. The development of SLIM was prompted by the lack of HEP data (Embrey et al., 1984) that still exists today in the public domain. Errors can be quantified at various stages including whole tasks, sub-tasks, and task steps.

The premise behind SLIM is that the probability of an error associated with a task, sub-task, or task step is a function of the performance shaping factors (PSFs) associated with the task. In reality, a large number of PSFs can affect the probability of failure (POF). The PSFs that are considered in the current SLIM analysis of platform musters are stress, task complexity (complexity), level of training (training), level of experience (experience), factors associated with the event (event factors), and environmental factors (atmospheric factors). The PSFs used to analyze platform musters in the present work were determined through consensus by a five-person review team (core review team, CRT). The method of choosing these PSFs is detailed in Chapter 4.

SLIM is a flexible technique that has developed into a family of methods. The SLIM methodology is specifically designed to overcome situations where the POF cannot otherwise be estimated with any degree of confidence. The SLIM technique has evolved and taken on several forms since the initial work (Embrey, 1983) and the follow-on study (Embrey et al., 1984). An example is the failure index method (FLIM) which utilizes a failure likelihood index (FLI) as opposed to a success likelihood index (SLI) (Chien et al., 1988).

The fundamental basis of both SLIM and FLIM lies in the logarithmic relationship between the action's SLI or FLI and its HEP (Pontecorvo, 1965). Pontecorvo presented a method by which a reliability estimate could be provided for a given task. As there was no practical method for describing functional relationships between a person and machine at the time, a method was developed by which it was possible to predict the effect of a person as a system contributor. Each task was provided a rating on its error potential and empirical data were utilized to determine a best fit curve (logarithmic) to relate the task ranking to the error potential.

The correlation was then used to predict reliability of sub-tasks. The sub-task reliabilities were combined through a sum of all tasks to determine the overall reliability. Sixty task reliability estimates were generated by Pontecorvo (1965); fifteen of these tasks were non-physical in nature (e.g. inspection, verification and reading). The remaining tasks were physical in nature (e.g. close hand valves). It was stressed in this work that there were differences between empirical data obtained in the field and those obtained from laboratory conditions.

The level of job decomposition ranged from task to task (e.g. record reading, rotate gearbox train). The tasks involved in a muster sequence also include several non-physical activities including identifying muster alarm and evaluating egress path tenability. The level of decomposition for a muster scenario must be kept at a level where the task description can be usefully applied for all personnel. From the reliability predictions, areas were identified by Pontecorvo (1965) that can affect the POF, including system automation, procedures and maintenance activities. Pontecorvo (1965) recognized that redundancy improved reliability and that the length of time this level of redundancy is available is pertinent. This redundancy may come in the form of aid from another person.

Variants of the core SLIM procedure lie in the treatment of the rating and weighting data, and how the elicitation of those data is performed. As the amount of data handling can be considerable, SLIM was adapted into an interactive computer program by Embrey et al. (1984) that could process a maximum of ten tasks. Embrey et al. presented an extension of SLIM through the use of multi-attribute utility decomposition (SLIM-MAUD). Multi-attribute decision problems are decision making situations in which the alternatives are described by their attributes (PSFs) that cannot be optimized simultaneously. This technique provides a method for quantifying how important each PSF is in comparison to the other PSFs. As the number of PSFs increase, the method becomes unwieldy and impracticable unless computer application is applied. Complex models of SLIM should be considered only if there are empirical data that validate the results from a more complicated approach.

Chien et al. (1988) presented an application of SLIM whereby a predefined set of seven PSFs were applied against the actions of a plant operator. A set of forms was generated to organize and document the information required to rate the action against its PSFs. The ratings obtained from a team, which included operators, were translated into a failure likelihood index (FLI) via a spreadsheet application, which is analogous to the traditional approach of generating an SLI from the weight and ratings of each action's PSFs. The approach utilized the traditional SLIM technique and did not use MAUD to determine SLI values. The result of this work was a structured approach to HRAs and an illustration of the importance of the team approach in prediction of HEPs.

Zamanali et al. (1998) applied SLIM through a team which included operators to predict human error rates (HERs) for a processing plant. PSFs were treated as directly acting and indirectly acting. Direct acting PSFs provide a high likelihood of success while indirect PSFs make success less likely. SLIs were calculated for three action phases (identification, diagnosis and response) and for each of the three classes of operator action (skill, rule and knowledge). Weighting factors were calculated by expert judgment via a pairwise comparison of the importance of each PSF relative to the other. The result was a series of HER equations for each class of operator actions incorporating the three phases of action. A set of eight PSFs was used in this analysis. Specifically, the PSFs were rushing, training, experience, plant indications, personnel availability, communication, action consequences, confusion and equipment location. The approach, while thorough, is cumbersome and does lend itself well to an efficient application in the development of an index.

These modifications of the core SLIM procedure are all attempts to improve the predictive nature of this method or provide some improved level of detail. As SLIM is an empirical approach to HEP prediction, the lack of empirical data to validate the results is problematic. Focus on the level of accuracy dominates past work (Chien, 1988, Zimolong, 1992) while very little attention is applied to the usability of the technique. SLIM remains primarily a tool solely for the HRA practitioner to use within Probabilistic Risk Assessments (PRAs). It has not transitioned into a form that permits the easy use of it's predictive strengths. It is through the development of the HEPI framework that this transition will occur. The next section overviews previous HRAs that have included SLIM or some variant of the method.

3.5 Prior Assessments of SLIM

This section summarizes past assessments of the SLIM technique and draws comparison to the human error probability index (HEPI) presented in this work. As was noted in section 3.1, SLIM has been included in several reviews of HRA techniques. Williams (1983) recognized that there had been limited attempts to validate the predictive power of the published assessments up to that time. As validation attempts continue to this day, it is clear that the acceptability and confidence in these techniques (e.g. SLIM, HEART, THERP) has not yet been established. A contributing effect is the lack of a usable and understandable HRA tool.

Apostolakis et al. (1988) critically reviewed two groups of models of which one was SLIM-MAUD. The evaluation was based on two criteria: the treatment of uncertainties and the coherence of the model. SLIM-MAUD was noted as being a highly structured technique for the derivation of human error rates for a given circumstance. It was also noted that the treatment of weights and ratings was internally inconsistent. The approach to normalize the PSF ratings, based on a solicited ideal rating, is dependent on the range of PSF ratings. Despite this, the ranges are renormalized on an equivalent scale.

This approach to normalization generated two concerns: 1) the probabilities for the tasks may change if a new task is added to a set, and 2) the weights are based on a relative scale, not a normalized scale. The HEPI method addresses these concerns by fixing the tasks prior to the elicitation of PSF weights and ratings. HEPI does not require an elicitation of an ideal PSF rating as the scales for both weights and ratings are identical and include the range of worst possible to best possible values (i.e. 0 to 100). Embrey et al. (1984) applied equal PSF weights for all tasks as a retrograde attempt to generate better HEP predictions. HEPI applies the mean PSF weights and ratings of a relatively large group of judges and does not standardize the PSF weights by equalizing their values (i.e. all PSF weights = 100).

Apostolakis et al. (1998) expressed concern that because SLIM is traditionally conducted through the consensus of judges, the mean value of the weights and ratings are only point estimates and do not convey the uncertainties that would be reflected in a more rigorous approach to uncertainty analysis. It has been shown however (Johnson et al., 2001) that the analytic value of averaged probability judgments increased in accuracy as the number of judges increased. Accuracy was diminished as the level of conditional dependence increased between the judges. A high diagnostic value can be attained in the case of moderate conditional dependence through the use of more judges. A relatively large number of judges (24) was used in the current work for the elicitation of PSF weights and ratings. The judges exhibited a wide range of years of experience and training, and the elicitation was conducted on an individual basis over an extended period of time, lowering the possibility of joint work (i.e. conditional dependence).

An opinion forwarded by Apostolakis et al. (1988) concerns the level of independence between the PSF weights and the task ratings. The elicitation of the PSF weights and ratings for HEPI was conducted independently. The weighting of the PSFs for a muster sequence are clearly distinguishable from the task PSF ratings. Responses from the elicitation review team (ERT) were scrutinized to determine if they followed the intention of the elicitation. If the response was not consistent with the intent, it was discarded as opposed to re-presenting the questionnaire to the judge. This avoided the risk of lowering the level of independence in the judges' responses due to coaching.

Zimalong (1992) presented an empirical evaluation of THERP and SLIM. It was again recognized in this work that empirical data are not typically available for human reliability assessments (HRAs). PSFs were presented as external (e.g. work environment) and internal (e.g. level of patience) with no discrimination in their treatment. The approach was based on a manufacturing scenario and made use of 48 undergraduate students and six undefined judges to conduct the testing. Serious concerns arise in the use of students to derive meaningful empirical data from a manufacturing scenario in which they have no experience. More importantly, the judges practiced for only twenty minutes under the experimental conditions.

These concerns stem from the lack of actual training and experience these "workers" would have (even in comparison to a novice worker). The application of expert judgment techniques to laboratory analogies of real world scenarios is unsound when the individuals involved are not the same people in the real world scenario. The elicited data is based on limited knowledge and experience. Further, a laboratory set-up would be a poor emulation of a manufacturing environment. The motivations of these student workers would have no representation of the actual manufacturing workers, and this leads to questionable results. The HRA approach taken by Zimalong (1992) provides a high level of susceptibility regarding the validity of results.

Kirwan (1997) conducted a validation study of three human reliability quantification techniques (THERP, HEART and JHEDI) but did not include SLIM. Thirty judges were utilized with ten judges employed per technique. The basis of their review was nuclear power plant scenarios and reprocessing tasks. The results were generally positive in regards to the precision of the predicted HEPs. Kirwan recognized the need for more formal training in these techniques to increase the level of accuracy and consistency of approach. An expressed concern centered on the error reduction perspective of the techniques. Kirwan proposed that recommendations for error reduction should be based on an analysis of both the results of the action and the probability of occurrence.

Kirwan (1998) conducted a second exhaustive review and evaluation of a wide range of human error identification (HEI) techniques. SLIM was treated as a means of quantifying HEPs but not evaluated alongside other techniques such as THERP. Kirwan noted that communication in emergency and routine situations is often a contributor or cause of real events. Kirwan's work also reinforces the importance and role of human error in risk and stresses the need to continue a scientific approach towards predicting and managing human error.

Spurgin and Lydell (2002) conducted a review of HRA methods and techniques as applied in current probabilistic safety assessments (PSAs) of nuclear power plants. It is noted in their work that practitioners continue to rely on data that originated in the 1970s. Spurgin and Lydell (2002) reviewed both SLIM and FLIM along with HEART and THERP. A noteworthy comment by Spurgin and Lydell is that there still exists a significant gap between academic research and practical HRAs. HEPI is an attempt to help bridge this gap and provide meaningful error reduction suggestions.

Spurgin and Lydell (2002) concentrated on the responses of control room personnel in nuclear power plants. Simulators in both the oil and gas and nuclear industries provide the closest real-world analogy to control room crisis management. The simulator is a valuable tool in evaluating the potential for human error in this workplace. Due the variety and large number of personnel on a platform, the application of HRA to non-control room individuals in a platform muster presents a significant challenge over the traditional control room scenario of one of two individuals, for which HRA techniques have been applied and tested.

Dougherty and Fragola (1988) developed time reliability correlations (TCR) to predict an the probability of failure of an action. A TRC is a probability distribution based on the time to complete an action and the action's likelihood of success (Bedford and Cooke, 2001). Dougherty and Fragola's approach was based on the premise that if a correct diagnosis is not made within a critical period of time, then a failure occurs. The probability of this failure decreases as elapsed time and the success likelihood index (SLI) value increases (Table 3.6). A time period of 60 minutes was utilized by Dougherty and Fragola (1988) for rule-based actions. This length of time does not correlate to muster scenarios as muster times are usually a few minutes in length for a typical offshore platform muster (e.g. three to six minutes).

The severity of the muster and the individual's location relative to the initiating event dictate the amount of time available to perform the muster tasks. The time to complete an action was not used as a PSF in this current work. The PSFs (i.e. stress, complexity and event factors) are a measure of time constraints and the muster severity. Muster severity and the rate of escalation of an event in the case of gas releases, fires and explosions depend on the scale of the initiating event as well as the design and construction of the platform (Strutt et al., 1998).

Table 3.6 Structure of a time reliability correlation (TRC) table (adapted from Dougherty and Fragola, 1988).

Time (minutes)	**Human Error Probability (HEP)**				
	SLI = 10	SLI = 30	SLI = 50	SLI = 70	SLI = 100
5	decreasing human error probability → ↓				
10					
20					
30					
60					

The muster sequences used in the development of HEPI are defined at a level of detail that does not permit the determination of a rate of escalation. Instead, the muster scenarios are described in a manner that allows a relative measure of muster severity through the weighting and rating of the relevant PSFs. Understanding human decision-making in complex high-risk scenarios with relatively severe time constraints is an extremely formidable problem (Sharit and Malone, 1991). Until empirical data are available, the ability to develop an accurate TRC for a muster is highly doubtful.

Chapter 4
METHODOLOGY

This chapter provides the basis and methodology for the selection of judges and the subsequent elicitation of PSF weights and ratings used to predict HEPs through SLIM. The process of selecting the most relevant PSFs, muster actions and muster scenarios is detailed. The judges are ranked on their experience and training, which form the foundation of future comparison of elicited PSF weights and ratings. The judges are purposefully picked from the oil and gas industry in order to attain high quality responses based on their knowledge and experience. The judges have a wide cross-section of skill and job types that provide diversity and helps to limit biased responses.

4.1 Application of SLIM

Figure 4.1 provides a generic illustration of how a structured expert judgment technique such as SLIM can be applied in a quantified risk assessment process. As mentioned in Chapter 4, the motivation to use SLIM is driven by a lack of empirical HEP data. The SLIM process is broken down into three main components: preparation of questionnaires, elicitation of PSF weights and ratings and calculation of HEPs. This is followed by an analysis of the data and final results that can be adopted into a larger quantified risk assessment (QRA). Figure 4.2 provides a more detailed graphical representation of the SLIM process applied in the current study. This procedure follows the generic framework outlined in Figure 4.1; however in implementation several reviews took place to ensure that agreement was reached by the core review team for the set-up of the elicitation of PSF weights and ratings through questionnaires. A key aspect of the approach is that the judges worked independently so that results are not biased. Clear instruction and personal communication with the judges on how to complete the questionnaires was a crucial aspect in achieving a common understanding on how to answer the weight and rating questionnaires.

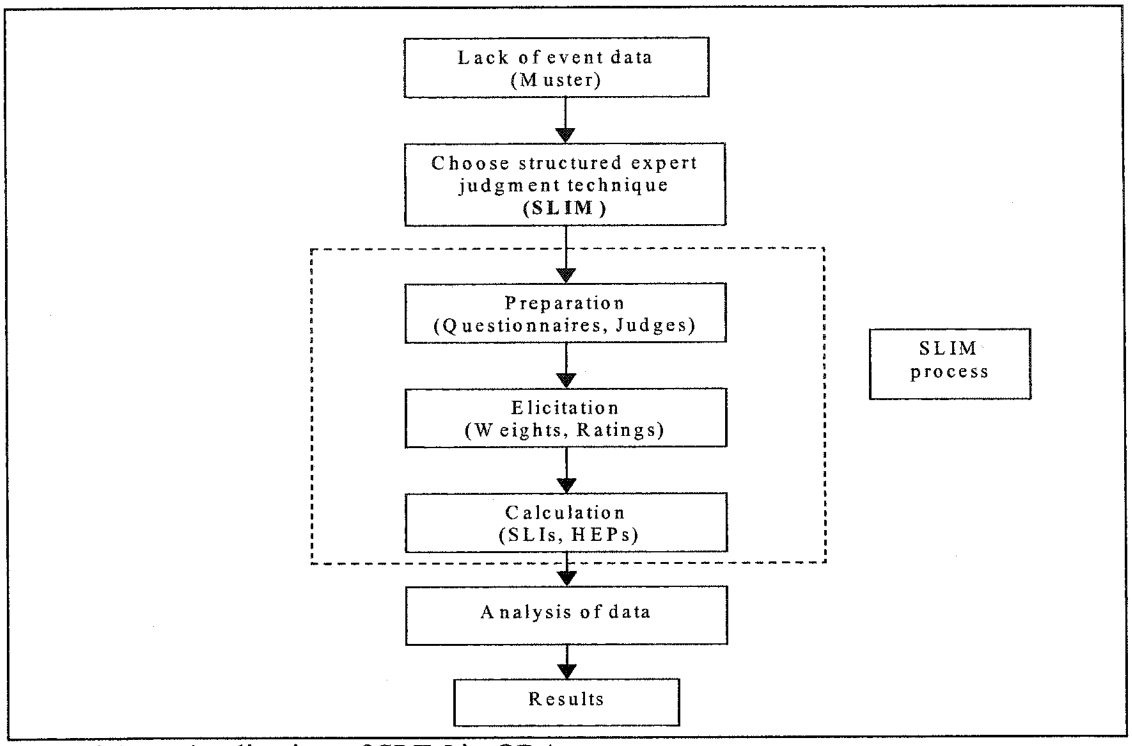

Figure 4.1 Application of SLIM in QRA.

4.2 Establishing the Core Review Team

The core review team (CRT) was made up of five individuals (Judges A through E) who met the set of criteria outlined in Table 4.1. The CRT judges spanned a range of professions knowledgeable in platform operations and muster scenarios. Their backgrounds are varied and their job types were specific to various aspects of the offshore industry. Each judge was met with independently to discuss the purpose of the work and their responsibilities. These five judges were utilized to establish the basis of the elicitation phases. The CRT is made up of a process engineer, regulatory authority engineer, health and safety professional, offshore control room operator and an operations supervisor. A key facet of the CRT was that these individuals were able to commit their time and efforts to perform this work. There was no gratuity or motivation offered and the judges were permitted to perform the work at their own pace. This philosophy was applied in all aspects of the data gathering stages. This approach lengthened the time it took to conduct the work but promoted continuity, as judges remained part of the total process.

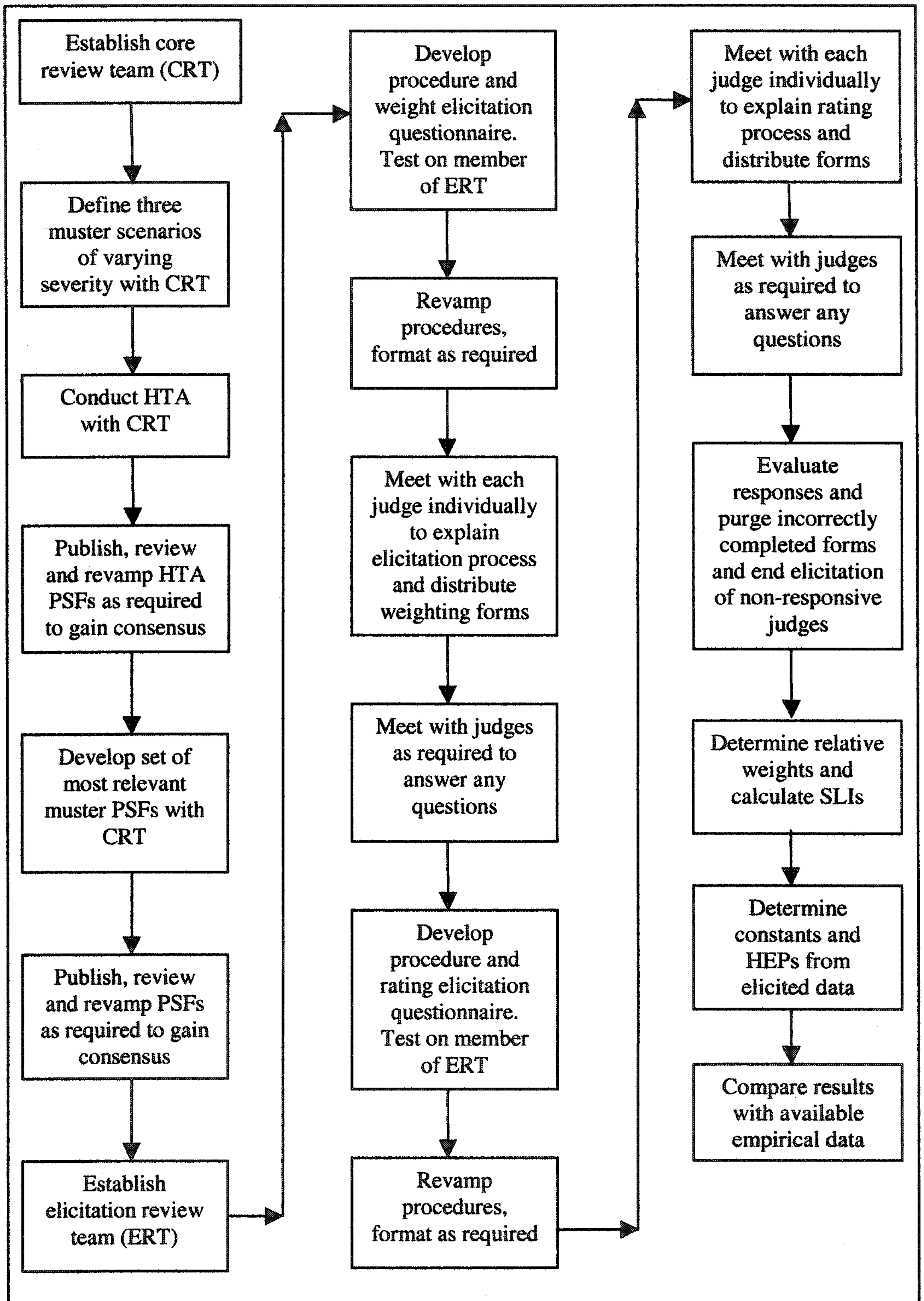

Figure 4.2 The SLIM process.

Table 4.1 Selection criteria for core review team members.

No.	Description
1	Is actively involved in offshore activities as a member of a producing company or regulator.
2	Has actively participated in platform musters or is involved in the design or evaluation of platform safety systems.
3	Has participated or led risk assessments in offshore related activities.
4	Has a minimum of 10 years of industrial experience in hydrocarbon processing.
5	Is capable of dedicating the required time to perform evaluations and is committed to participate as required in the development of HEPI.
6	Does not work directly for any other member of the CRT or with any member of the CRT on a daily basis.
7	Is available to meet in person during work hours.

4.3 Defining the Muster Scenarios

Three muster scenarios were established by the CRT to encompass the widest possible range of credible muster initiators. The five criteria used in the establishment of the muster scenarios are found in Table 4.2. The three muster scenarios become the reference sequences from which other scenarios are ranked through HEPI.

Table 4.2 Muster scenario criteria.

No.	Description
1	Credible muster scenarios that can occur on an offshore platform.
2	Provide a wide range of risk.
3	At least one scenario that has close relationship to empirical data.
4	At least one severe scenario that can be referenced through case history.
5	At least one scenario that has been experienced by the majority of the CRT.

The muster scenarios chosen as anchors were man overboard, gas release, and fire and explosion. The details of each anchor muster were developed in the process of establishing the PSF rating forms. The following two sections review the hierarchical task analysis (HTA) of a generic muster sequence and its review with the CRT.

4.4 Review of HTA with CRT

A preliminary hierarchical task analysis (HTA) of a muster sequence was developed by Judge A (author) and provided to each member of the CRT for review and comment. The goal was to identify actions that are common to non-control room personnel. Table 4.3 provides a summary of CRT responses to the preliminary HTA. The notation N/C indicates that there was no comment or that agreement was stated for the action in question. The comments were incorporated and the revised HTA shown in Table 4.4 was generated. The items utilized from the feedback from Judge B were to include an action for PA announcements and to report observations gathered enroute to the TSR, to incident command. The PA announcement action is an important factor in the muster sequence as valuable information can be provided by the control room through this means of communication.

The second item of providing pertinent information to incident command is also valuable in that it can help the incident commander (OIM) be more effective in dealing with the crisis and may provide for more timely rescue of individuals. A recommendation to amend the action for collecting one's survival suit was adopted. The survival suit is to be gathered if the individual is in their accommodations at time of muster. This task is part of the formal muster procedure and has benefits related to evacuation activities. Action 12 (assisting others while enroute to the TSR) was modified to include the phrase "or as directed". The initiation of this task can be generated by another individual or through direction by incident command.

Table 4.3 CRT comments on draft muster actions.

No.	Action (Judge A)	Judge B	Judge C	Judge D	Judge E
			Awareness Phase		
1	Detect alarm	N/C	N/C	N/C	N/C
2	Identify alarm	N/C	N/C	Make clear that this alarm is not a control room process alarm	Stop work immediately, identify alarm
3	Act accordingly	N/C	N/C	N/C	N/C
			Evaluation Phase		
4	Ascertain if danger is imminent	N/C	N/C	N/C	N/C
5	Muster if in imminent danger	N/C	N/C	N/C	N/C
6	Return process equipment to safe state	N/C	N/C	N/C	N/C
7	Make workplace safe	N/C	N/C	Be more clear (i.e. shut off equipment, engines)	Make workplace as safe as possible in limited time
			Egress Phase		
8	Evaluate potential egress paths and choose route	N/C	N/C	**NEW ACTION** **Respond to PA announcement**	N/C
9	Move along egress route	N/C	N/C	N/C	N/C
10	Assess quality of egress route while moving to TSR	**NEW ACTION** **Report observations to incident command staff if pertinent**	N/C	N/C	Be prepared to change route if fire, heavy smoke, gas etc are encountered. Walk smartly to TSR but do not run. Hold hand rails when descending stairs/ladders
11	Collect personal survival suit if possible	Collect suit if person is in their room	N/C	Collect suit if person is in their room	N/C
12	Assist others if needed	and as directed	N/C	N/C	N/C

Table 4.3 Cont'd. CRT comments on draft muster actions.

No.	Action (Judge A)	Judge B	Judge C	Judge D	Judge E
13	Register at TSR	N/C	N/C	This requires moving your T-card and remaining quiet in the TSR	Check-in with P.O.B. card coordinator
Recovery Phase					
14	Interpret the OIM's instructions	Interpret instructions correctly	Little room for interpretation; instructions will be clear	Follow OIM instruction	N/C
15	Don personal survival suit or TSR survival suit	Only don suits if ready to abandon	N/C	N/C	If instructed to prepare to abandon platform, put on survival suit and life jacket located in the TSR. Do not leave and return to accommodations to retrieve personal survival suit
16	Standown or enter survival craft	Emergency response team may abandon on 2nd survival craft	May not abandon via survival craft. May have to use skyscape of climb down	N/C	Upon instruction enter survival craft in an orderly and quiet fashion. Fasten safety belts and await launching and further instructions

Table 4.4 Original and revised HTA.

No.	Original HTA	No.	Revised HTA
	Awareness Phase		**Awareness Phase**
1	Detect alarm	1	Detect alarm
2	Identify alarm	2	Identify alarm
3	Act accordingly	3	Act accordingly
	Evaluation Phase		**Evaluation Phase**
4	Ascertain if danger is imminent	4	Ascertain if danger is imminent
5	Muster if in imminent danger	5	Muster if in imminent danger
6	Return process equipment to safe state	6	Return process equipment to safe state
7	Make workplace safe	7	Make workplace safe as possible in limited time
	Egress Phase		**Egress Phase**
8	Evaluate potential egress paths and choose route	**8**	**Listen and follow PA announcements***
9	Move along egress route	9	Evaluate potential egress paths and choose route
10	Assess quality of egress route while moving to TSR	10	Move along egress route
11	Collect personal survival suit if possible	11	Assess quality of egress route while moving to TSR
12	Assist others if needed	**12**	**Choose alternate route if egress path is not tenable***
13	Register at TSR	13	Collect personal survival suit if in accommodations at time of muster
	Recovery Phase	14	Assist others if needed or as directed
14	Interpret OIM's instructions		**Recovery Phase**
15	Don personal survival suit or TSR survival suit	15	Register at TSR
16	Standown or enter survival craft	16	Provide pertinent feedback attained while enroute to TSR
		17	Don personal survival suit or TSR survival suit if instructed to abandon
		18	Follow OIM's instructions

* new action

Judge C suggested adding a section for the emergency response team. As the goal of this work was to deal solely with the muster activities and not emergency response, this item was not included. Clarification was offered with regard to the action of interpreting the OIM's instructions. This action was redescribed as "follow OIM's instructions" because the orders would be clear and concise, requiring little interpretation. Clarification was also provided for action 16 (standown or enter survival craft) where it was noted that the escape chute (skyscape) may be used to evacuate the platform. As the muster sequence ends at the beginning of the evacuation phase, this item was not included in the action list. Action 16 was removed from the original list and the TSR activities that still pertained to the muster sequence were redescribed.

Judge D suggested rewriting the description for action 2 (identify alarm) to discern the difference between control room alarms and alarms annunciated by the PA and emergency lighting system. Control room actions are not considered in this study; this suggestion was not adopted. A suggestion to add an action for PA announcements was identical to Judge B. A suggestion for action 7 (make workplace safe) to be specific with regards to equipment was not adopted, as the muster actions are to apply to any individual performing any job. Clarification was provided for action 13 (register at the TSR). The actions of moving one's T-card and remaining quiet were not included as the T-card may be moved by another individual in charge of the T-card bank. Remaining quiet in the TSR is an action that goes to following the OIM's instructions and was not included in the action list. Judge E suggested that action 2 (identify alarm) be changed to "stop work and identify alarm". This was not included because the level of task decomposition was sufficient.

Further clarification on action 7 (make workplace safe) was provided through a re-description of the action to "make workplace safe in a limited amount of time", as muster actions are to be conducted in the most expedient fashion. For action 10 (assess quality of egress route) it was suggested that the individual may have to change egress routes because of event factors making the route untenable. This was incorporated as one of the actions in the revised task list. Further detailing of actions performed while enroute to the TSR was not included as the degree of decomposition would be excessive. Judge E suggested that one should walk quickly to the TSR and not run. Depending on the event factors, running may be perfectly appropriate in an attempt to gain safe haven in the TSR and hence the suggestion was not adopted. The comment is a reflection of a training protocol that does not promote innovative thinking during severe musters. The ability to deviate from muster procedures can be a crucial element in surviving the high exposure phases (awareness, evaluation and eggress) of the muster sequence.

Comments related to action 15 (don survival suit) included "prepare to abandon" and "do not return to accommodations to retrieve survival suit" (Judge E). These are incorporated in the intent of muster action 18 (follow OIM's instructions) and no modification was made. While there does exist a temptation to leave the TSR and acquire one's personal survival suit, this would generate more risk and is strictly prohibited in muster training. Further suggestions regarding the boarding of the life boat were not included as these are evacuation items not included in the scope of the work.

4.5 HTA of a Platform Muster Sequence

The result of the review of the original hierarchical task analysis is shown in Table 4.5. The actions are sufficiently generic in nature permitting the application to any muster event. The colors associated with each muster action represent the four muster phases (yellow - awareness phase, blue - evaluation phase, green - egress phase, purple - recovery phase). The muster sequence begins subsequent to the initiating event and does not concern itself with why the event occurred (Figure 4.3). The sequence ends with the completion of the muster actions in the temporary safe refuge (TSR) before standing down (return to normal activities) or evacuation actions begin.

The muster tasks were next classified by skill, rule and knowledge (SRK) behaviour. A logic tree has been used in a prior work (Hannaman and Worledge, 1988) to provide guidance in selecting SRK behaviour for specified actions. Figure 4.4 is a logic tree that helps assign SRK modes to the muster sequences considered in this work.

Table 4.5 Muster actions broken down by muster phase.

Awareness Phase	
1	Detect alarm
2	Identify alarm
3	Act accordingly
Evaluation Phase	
4	Ascertain if danger is imminent
5	Muster if in imminent danger
6	Return process equipment to safe state
7	Make workplace as safe as possible in limited time
Egress Phase	
8	Listen and follow PA announcements
9	Evaluate potential egress paths and choose route
10	Move along egress route
11	Assess quality of egress route while moving to TSR
12	Choose alternate route if egress path is not tenable
13	Collect personal survival suit if in accommodations at time of muster
14	Assist others if needed or as directed
Recovery Phase	
15	Register at TSR
16	Provide pertinent feedback attained while enroute to TSR
17	Don personal survival suit or TSR survival suit if instructed to abandon
18	Follow OIM's instructions

Table 4.6 summarizes the behaviour type for each muster action. Each task is classified and the behaviour types listed. Several of the egress actions move from rule-based behaviour to knowledge-based behaviour for the gas release and fire and explosion musters. It is under these unfamiliar, more severe musters that stress levels peak and event factors make routine tasks complex, requiring greater cognitive control.

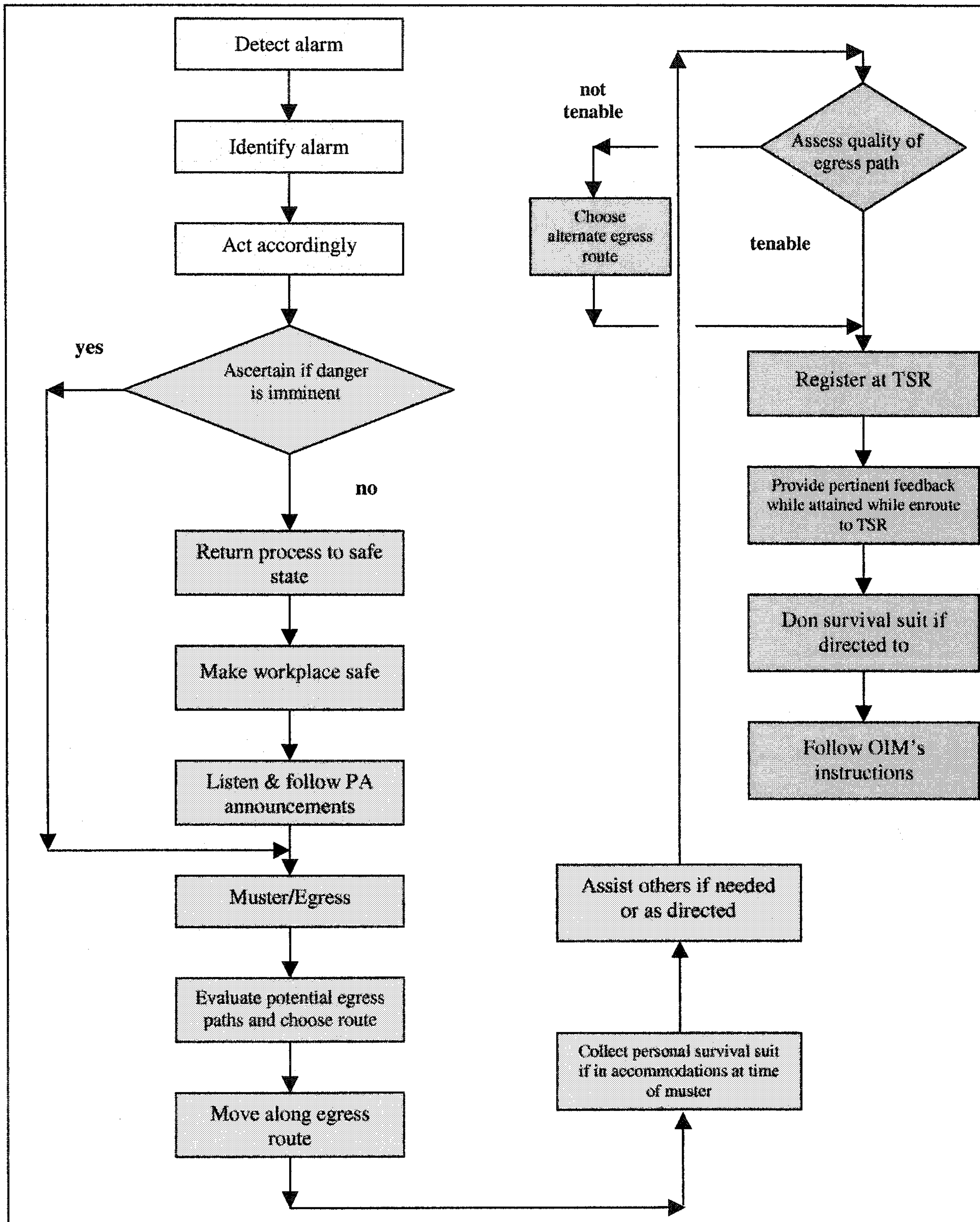

Figure 4.3 The muster sequence.

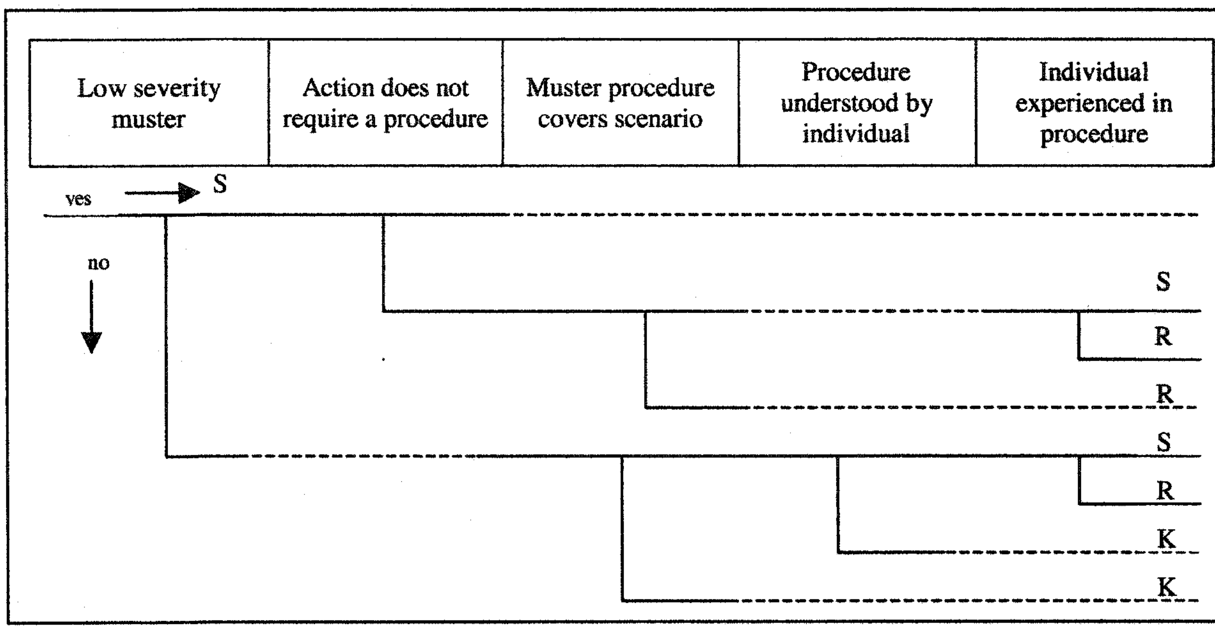

Figure 4.4 Logic tree to assist in selection of expected behaviour type (adapted from Hannaman and Worledge, 1988).

4.6 Review of PSFs with CRT

The original list of PSFs is given in Table 4.7. Each member of the CRT was asked to provide their feedback on the quality of the PSF and recommend other PSFs if they deemed it pertinent to a muster event. Judge B had no comments on the draft list of PSFs. Judge C had several PSF suggestions including level of emergency, weather, time of day, and to expand experience to actual and practice. The level of emergency and time of day suggestions were incorporated in event factors and weather was incorporated in the definition of atmospheric factors.

Judge D suggested including the location of the individual, confidence in the OIM, and age as additional PSFs. The location of the person is considered an event factor. Confidence in the OIM is an ambiguous PSF and should not play a role in the majority of muster actions. An individual's confidence in another person can have a multitude of causal factors. Aspects of an individual's personality (e.g. temper) are not included in the formation of these PSFs. Judge E provided feedback identical to Judge C for three PSFs: level of emergency, weather and time of day.

Table 4.6 Muster actions defined by SRK behaviour.

No.	Actions	MO*	GR^	F&E~
	Awareness Phase			
1	Detect alarm	S	S	S
2	Identify alarm	R	R	R
3	Act accordingly	S	S	S
	Evaluation Phase			
4	Ascertain if danger is imminent	K	K	K
5	Muster if in imminent danger	R	R	R
6	Return process equipment to safe state	R	K	K
7	Make workplace safe in limited time	R	K	K
	Egress Phase			
8	Listen and follow PA announcements	R	K	K
9	Evaluate potential egress paths and choose route	K	K	K
10	Move along egress route	R	K	K
11	Assess quality of egress route while moving to TSR	K	K	K
12	Choose alternate route if egress path is not tenable.	K	K	K
13	Collect personal survival suit if in accommodations at time of muster	R	R	R
14	Assist others if needed or as directed	K	K	K
	Recovery Phase			
15	Register at TSR	R	R	R
16	Provide pertinent feedback attained while enroute to TSR	K	K	K
17	Don personal survival suit or TSR survival suit if instructed to abandon	R	R	R
18	Follow OIM's instructions	R	R	R

*man overboard
^ gas release
~ fire and explosion

Table 4.7 Review of PSFs by CRT.

No.	Original PSFs	Feedback			
	Judge A (Author)	**Judge B**	**Judge C**	**Judge D**	**Judge E**
1	Procedure required	N/C	N/C	N/C	N/C
2	Event stress	N/C	N/C	N/C	N/C
3	Time pressure	N/C	N/C	N/C	N/C
4	Consequences	N/C	Level of emergency	NC	Level of emergency
5	Complexity	N/C	N/C	N/C	N/C
6	Degree of teamwork required	N/C	N/C	N/C	N/C
7	Training	N/C	N/C	N/C	N/C
8	Experience	NC	Actual and practice	N/C	N/C
9	Distractions	N/C	N/C	N/C	N/C
		Suggested PSFs			
10		---	Weather	---	Weather
11		---	Time of day	---	Time of day
12		---	---	Person's location	---
13		---	---	Confidence in OIM	---
14		---	---	Age	---

Prior applications of SLIM (Embrey et al., 1984) utilized six to eight PSFs. The review of PSFs with the CRT generated a set of 14 of which 11 were considered for use. A set of six PSFs was targeted to prevent the SLIM procedure from becoming too unwieldy. To determine the relevance of the PSFs developed by the CRT, each PSF was judged against the remaining PSFs in the set. This pairwise comparison is a simple qualitative method of determining the relative importance of each PSF. For each pair of PSFs one of the two PSFs was chosen to be more pertinent as illustrated in Table 4.8 (the stylized letters represent the PSFs). A PSF rank (λ) was determined by equation [4-1] and listed in Table 4.9. The higher the PSF rank, the more relevant the PSF. The top six PSFs were used in this study.

$$\lambda_i = \sum occurences\ of\ PSF_i \qquad [4\text{-}1]$$

Although the PSFs, time, pressure and consequences have equal weight with that of atmospheric factors, it was decided not to include them as separate items as they are defined by the stress PSF. The level of stress is generated by the severity of the event factor and the potential consequences from failure to complete muster tasks.

4.7 Most Relevant PSFs

The performance shaping factors utilized in this work that influence the probability of failure in conducting muster actions are:

- stress
- complexity
- training
- experience
- event factors
- atmospheric factors

Table 4.8 Pairwise comparison of PSFs.

PSF		*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*
Procedural	*A*	---	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*
Stress	*B*	---	---	*B*	*B*	*B*	*B*	*G*	*H*	*B*	*J*	*B*
Time pressure	*C*	---	---	---	*C*	*E*	*C*	*G*	*H*	*C*	*J*	*K*
Consequences	*D*	---	---	---	---	*E*	*D*	*G*	*H*	*D*	*J*	*D*
Complexity	*E*	---	---	---	---	---	*E*	*G*	*H*	*E*	*J*	*E*
Degree of teamwork	*F*	---	---	---	---	---	---	*G*	*H*	*I*	*J*	*K*
Training	*G*	---	---	---	---	---	---	---	*H*	*G*	*G*	*G*
Experience	*H*	---	---	---	---	---	---	---	---	*H*	*J*	*H*
Distractions	*I*	---	---	---	---	---	---	---	---	---	*J*	*K*
Event factors	*J*	---	---	---	---	---	---	---	---	---	---	*J*
Atmospheric factors	*K*	---	---	---	---	---	---	---	---	---	---	---

Table 4.10 provides a description of each PSF which was supplied with the PSF weight and rating questionnaires to ensure a common interpretation by all judges. It should be noted that traditionally, training and experience have been coupled as one PSF. While an improved training level can come from greater experience, offshore operations fall into a class where the workspace is unique and where emergency situations arise at infrequent intervals. Individuals may have a substantial amount of training but have little actual muster experience. Conversely, individuals may have limited work experience but may have actual muster experience.

Table 4.9 Ranking of PSFs from pairwise comparison.

No.	PSF (i)	Letter Designation	Rank* (λ)
1	Experience	*H*	9
2	Training	*G*	9
3	Event factors	*J*	9
4	Stress	*B*	7
5	Complexity	*E*	6
6	Atmospheric factors	*K*	4
7	Time pressure	*C*	4
8	Consequences	*D*	4
9	Distractions	*I*	2
10	Degree of teamwork	*F*	1
11	Procedural	*A*	0

*Rank defined by equation [4-1]

4.8 Establishment of Elicitation Review Team

Thirty individuals, including the CRT members, were solicited to be part of the elicitation review team (ERT). Each individual was met with separately to explain the requirements of being on the ERT. A wide range of experience and background was sought in the formation of this group of judges. Of the 30 individuals contacted, 28 became judges. The remaining individuals were unable to provide feedback due to time constraints.

Of the 28 judges, the responses of three were inconsistent with the given instructions and were discarded. One judge completed the work correctly but responded too late to be included in this study. Each judge is identified by a capital letter ranging

Table 4.10 PSF descriptions.

PSF	Description
Stress	PSF to complete actions as quickly as possible to effectively muster in a safe manner. The effect from muster initiator on the consequences of not completing the task.
Complexity	PSF that affects the likelihood of a task being completed successfully because of the intricacy of the action and its sub-actions. This, combined with a high level of stress, can make actions that are normally simplistic in nature complicated and/or cumbersome. Can cause individuals to take short cuts (violations) to perform task as quickly as possible or not to complete the task.
Training	PSF that directly goes to an individual's ability to most effectively identify muster alarm and perform the necessary actions to complete muster effectively. Training under simulation can provide a complacency factor as a highly trained individual may lack a sense of urgency because of training's inherent repetitiveness.
Experience	PSF related to real muster experience. Individual may not be as highly trained as other individuals but will have experienced real muster(s) and the stressors that accompany real events. Strong biases may be formed through these experiences.
Event factors	PSF that is a direct result from the muster initiator and the location of the individual with respect to the initiating event. Distractions that can affect the successful completion of a muster include smoke, heat, fire, pressure wave and noise.
Atmospheric factors	PSF that influences actions due to weather. High winds, rain, snow or sleet can affect manual dexterity and make egress paths hazardous by traversing slippery sections. Extremely high winds negatively impact hearing and flexibility of movement.

from A to X (24 judges), consistent with the method of identifying CRT members. The CRT judges retain their designations of A through E with the author remaining as Judge A. Table 4.11 provides a breakdown of the ERT members by profession. The engineers in this group are made up of a mixture of disciplines while the operations group is comprised of control room operators, trainers and supervisors. The ERT is categorized by a series of subgroups as defined by their backgrounds. The quality of the judges is an important factor as the basis of the HEP predictions for muster actions is the PSF weight and rating responses of the judges. In order to discriminate between judges based on

Table 4.11 ERT judges defined by job type.

Job Type	No. of Judges
Engineering	14
Operations	6
Health and Safety	3
Administrative	1
Total	24

their level of experience and training, a numerical ranking system was devised (Table 4.12). Judges whose rank was less than 35 were grouped separately due to their relative lack of experience and training as compared to other ERT judges. This subgroup is designated as the <35 group (<35). The subgroups that made up the ERT are engineers, operators, CRT members, non-CRT members and >35 group (>35).

A comparison of PSF weights and ratings determined by members of each of these subgroups was conducted to determine if any subgroup's results varied extensively from the ERT as a whole. If any significant deviation was apparent it was deemed prudent to exclude that data. The analysis of data, which is detailed in Chapter 5, revealed that no subgroup deviated extensively from the ERT. Appendix A provides example rankings for two ERT judges.

The complete rankings of each of the ERT judges can be found in an accompanying data book. A separate data book is utilized as the volume of elicited data cannot be properly presented or summarized in this thesis. The data book also contains calculations derived from the SLIM process. Table 4.13 summarizes the rankings for each ERT judge and Table 4.14 identifies the judges by their respective subgroups. A comparison of results from the elicitation of weights and ratings as made by subgroups is outlined in Chapter 5.

Table 4.12 Ranking system for ERT judges.

Years of Industry Experience	Rank	Years of Offshore Experience	Rank
0 to 2	2	0 to 1	5
3 to 5	5	1 to 3	10
6 to 10	10	3 to 10	15
11 to 20	15	10 to 20	20
greater than 20	20	greater than 20	25
Safety Training	**Rank**	**Muster Experience**	**Rank**
basic risk assessment	5	participated in drills	5
advanced risk assessment	10	participated in actual musters	10
BST*	2	**Variety of Experience**	**Rank**
WHMIS**	2	single platform	3
incident investigation	2	multiple platforms, same project	6
confined space	2	multiple platforms, various projects	10
rescue	5	multiple platforms, different geographical location	15
Safety Experience	**Rank**	**Job Type**	**Rank**
HAZOP	5	engineer	2
Tap Root ©	2	offshore operator	5
concept/design risk assessment	5	regulatory authority	3
		health and safety	10
		offshore supervisor	12
		administrative	1
		maintenance	5

* Basic Survival Training
** Workplace Hazardous Materials Information System

Table 4.13 Ranking of ERT judges and relevant background.

Judge	Rank	Classification
A*	71	Engineer, Facility Engineer
B*	49	Engineer, Regulatory Engineer
C*	60	Operations, Control Room Operator
D*	79	Operations (supervisory background)
E*	103	Health and Safety (operations background)
F	31	Engineer, Facility Engineer
G	47	Engineer, Facility Engineer
H	44	Engineer, Facility Engineer
I	26	Engineer, Facility Engineer
J	18	Engineer, Facility Engineer
K	28	Administrative
L	62	Engineer, Facility Engineer
M	96	Health and Safety (operations background)
N	49	Engineer, Contract Process Engineer
O	81	Engineer, Facility Engineer
P	65	Operations (survival training background)
Q	50	Operations, Maintenance Planner
R	31	Engineer, Facility Engineer
S	34	Engineer, Reservoir Engineer
T	84	Operations, Trainer
U	86	Engineer, Materials Engineer
V	108	Health and Safety (operations background)
W	115	Operations (supervisory background)
X	96	Engineer, Contract Instrumentation and Control Engineer

*Core Review Team member

Table 4.14 Summary of ERT subgroups and judge's ranking.

Judge	Rank	Sub–Groups by Judge (shading indicates member of sub-group)					
		CRT	Non CRT	>35	<35	Operators	Engineers
A	71	A	A	A	A	A	A
B	49	B	B	B	B	B	B
C	60	C	C	C	C	C	C
D	79	D	D	D	D	D	D
E	103	E	E	E	E	E	E
F	31	F	F	F	F	F	F
G	47	G	G	G	G	G	G
H	44	H	H	H	H	H	H
I	26	I	I	I	I	I	I
J	18	J	J	J	J	J	J
K	23	K	K	K	K	K	K
L	62	L	L	L	L	L	L
M	96	M	M	M	M	M	M
N	27	N	N	N	N	N	N
O	81	O	O	O	O	O	O
P	65	P	P	P	P	P	P
Q	50	Q	Q	Q	Q	Q	Q
R	31	R	R	R	R	R	R
S	34	S	S	S	S	S	S
T	84	T	T	T	T	T	T
U	86	U	U	U	U	U	U
V	108	V	V	V	V	V	V
W	115	W	W	W	W	W	W
X	96	X	X	X	X	X	X

4.9 Determination of PSF Weights

The weighting (importance) of the six PSFs was conducted for each of the 18 muster actions (the PSF weight data can be found in the accompanying data book). The form utilized to conduct weighting elicitation for man overboard is found in Table 4.15. Appendix B contains the questionnaires for the gas release and fire and explosion scenarios. The forms were initially provided to a small number of judges who were

Table 4.15 PSF weighting questionnaire for man overboard scenario.

Weighting of Performance Shaping Factors PSFs are weighted in increments of 10 from 0 to 100, 100 having the greatest influence and 0 having least influence							
Scenario		Performance Shaping Factors					
Man Overboard							
No.	Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm						
2	Identify alarm						
3	Act accordingly						
4	Ascertain if danger is imminent						
5	Muster if in imminent danger						
6	Return process equipment to safe state						
7	Make workplace as safe as possible in limited time						
8	Listen and follow PA announcements						
9	Evaluate potential egress paths and choose route						
10	Move along egress route						
11	Assess quality of egress route while moving to TSR						
12	Choose alternate route if egress path is not tenable						
13	Collect personal survival suit if in accommodations at time of muster						
14	Assist others if needed or as directed						
15	Register at TSR						
16	Provide pertinent feedback attained while enroute to TSR						
17	Don personal or TSR survival suit if instructed to abandon						
18	Follow OIM's instructions						

Directions: Assume all PSFs are as severe as possible in their own right. Take the PSF that if improved would afford the greatest possibility of completing the task successfully. Give that PSF a value of 100. Next weight each of the remaining PSFs against the one valued at 100, from 0 to 90. The 5 remaining PSFs may be of duplicate value. Consider the scenario when weighting PSFs for each task.

for feedback based on ease of use and clarity. It was decided, based on this feedback, to provide directions on the bottom of each page on how to conduct the PSF weighting. A meeting was then held individually with each judge to go over the rules associated with the elicitation of PSF weights. Subsequent meetings were held if questions arose during the work phase to clarify the process and ensure a common approach. Despite this effort, three judges completed the forms incorrectly and their results were discarded as opposed to offering more coaching which may have biased their results. Twenty-four judges responded correctly within the time frame of this work.

Judges were instructed to first consider all PSFs to be as severe as possible for each scenario. Then they were to choose the PSF that, if improved, would afford the greatest possibility of completing the task successfully. That PSF was given a value of 100 and is denoted as PSF_{100}. The remaining PSFs were weighted against PSF_{100}, from 0 to 90; that is, if PSF_i is deemed to be 50% as important as PSF_{100} then PSF_i is given a weight of 50, and so on. The five remaining PSFs may be of duplicate value.

The results were tabulated and categorized by their respective PSF and can be found in the accompanying data book. Table 4.16 provides an example by listing the mean PSF weights for stress in the man overboard muster scenario. Appendix C contains the complete list of the average (mean) weights for each PSF and muster scenario. A discussion of the results and a comparison between judges is given in Chapter 5.

The next section overviews how PSF ratings were elicited. The ratings are a measure of the quality of the PSFs. As a reminder, a PSF weight is a measure of importance. A PSF rating is a grade based on the details (e.g. individual's years of experience) of the muster scenario.

Table 4.16 Mean PSF weights - stress (MO).

No.	Action	Stress
1	Detect alarm	39
2	Identify alarm	45
3	Act accordingly	57
4	Ascertain if danger is imminent	54
5	Muster if in imminent danger	59
6	Return process equipment to safe state	60
7	Make workplace safe as possible in limited time	63
8	Listen and follow PA announcements	58
9	Evaluate potential egress paths and choose route	59
10	Move along egress route	55
11	Assess quality of egress route while moving to TSR	60
12	Choose alternate route if egress path is not tenable	60
13	Collect personal survival suit if in accommodations at time of muster	60
14	Assist others if needed or as directed	67
15	Register at TSR	50
16	Provide pertinent feedback attained while enroute to TSR	63
17	Don personal survival suit or TSR survival suit if instructed to abandon	65
18	Follow OIM's instructions	73

4.10 Determination of PSF Ratings

The rating (quality) of the six PSFs was conducted for each of the 18 muster actions (the PSF rating data can be found in the accompanying data book) within each of the 3 muster scenarios. Table 4.17 is an example of the questionnaire used to solicit the PSF ratings. Appendix D contains the questionnaires for the gas release and the fire and explosion scenarios. The scenarios are defined on the form and guidance is provided with regard to each PSF scale. Judges were asked to rate each of the six PSFs for each muster task for each of the three muster scenarios. Ratings could be of equal value in the

Table 4.17 Questionnaire for rating of PSFs (MO).

Rating of Performance Shaping Factors							
Scenario		**Performance Shaping Factors***					
Man Overboard (15 yrs experience as an operator, daylight, summer, no wind, calm seas, man falls O/B on different deck)		**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
No.	Actions Operator does not witness or hear the event, operator was draining/skimming a vessel	100 = no stress associated with action 50 = some stress 0 = highly stressed	100 = not a complex action 50 = somewhat complex 0 = very complex	100 = highly trained in action 50 = some training 0 = no training	100 = very experienced in action 50 = somewhat experienced 0 = no experience	100 = no effect on action 50 = some effect 0 = large effect	100 = no effect on action 50 = some effect 0 = large effect
1	Detect alarm						
2	Identify alarm						
3	Act accordingly						
4	Ascertain if danger is imminent						
5	Muster if in imminent danger						
6	Return process equipment to safe state						
7	Make workplace as safe as possible in limited time						
8	Listen and follow PA announcements						
9	Evaluate potential egress paths and choose route						
10	Move along egress route						
11	Assess quality of egress route while moving to TSR						
12	Choose alternate route if egress path is not tenable						
13	Collect personal survival suit if in accommodations at time of muster						
14	Assist others if needed or as directed						
15	Register at TSR						
16	Provide pertinent feedback attained while enroute to TSR						
17	Don personal or TSR survival suit if instructed to abandon						
18	Follow OIM's instructions						

* Scales are provided as a guide. Ratings are in increments of 10 from 0 to 100

range of 0 to 100 in increments of 10. This scale is identical to the one used by Embrey et al. (1984). Instruction was provided on an individual basis and follow up meetings were conducted when required.

Table 4.18 is a summary of the PSF scales used to rate each of the muster actions. The scales were applied in an identical manner to all three of the muster scenarios. A rating of one hundred represents the optimal condition of the PSF. Conversely, a rating of 0 is the least optimal condition for each PSF. PSFs were permitted to have the same rating for a given action. The rating scales were placed directly in the questionnaire, which provided the ERT judges with a consistent reference point and helped to avoid misinterpretation. A complete list of ERT mean ratings can be found in Appendix E. Ratings are not provided for action 13 (collect personal survival suit if in accommodations at time of muster) as the reference muster scenarios do not occur in the accommodations module. Performance shaping factor weights were provided by the ERT for action 13 as the muster scenarios were not detailed at that stage of the elicitation of data.

Table 4.18 PSF rating scales for each muster action.

Rating Scale	Performance Shaping Factors					
	Stress	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
100	no stress	not complex	highly trained	very experienced	no effect	no effect
50	some stress	somewhat complex	some training	somewhat experienced	some effect	some effect
0	highly stressed	very complex	no training	no experience	large effect	large effect

4.11 Determination of Human Error Probabilities

The HEPs for each action (j), under each muster scenario, were determined from the solicited weights and ratings provided by the ERT. The replies from each judge were reviewed to ensure procedures were followed before proceeding with HEP calculations.

If there was a discontinuity observed, a followup meeting was held to determine if the point in question required editing. This occurred on only four occasions. A set of weights for a muster action can be written as equation [4-2] (Embrey et al., 1984).

$$\theta_j = \sum_{i=1}^{6} w_{ij} \qquad [4\text{-}2]$$

where
i = PSFs (1 to 6)
j= muster actions (1 to 18)
w = weight provided to each PSF
θ_j = sum of weights for action j

The weights were normalized (σ_{ij}) for each action as shown in equation [4-3] (Embrey et al., 1984). The sum of the normalized weights is unity, equation [4-4] (Embrey et al., 1984).

$$\sigma_{ij} = \frac{w_{ij}}{\theta_j} \qquad [4\text{-}3]$$

$$\sum_{i=1}^{6} \sigma_{ij} = 1 \qquad [4\text{-}4]$$

where
σ_{ij} = normalized weight of PSF (i)
w_{ij} = weight of PSF (i) for action (j)

The success likelihood index (SLI) is the product of the normalized weight and the rating for each PSF, equation [4-5] (Embrey et al., 1984).

$$\psi_{ij} = \sigma_{ij} \times \delta_{ij} \qquad [4\text{-}5]$$

where
δ_{ij} = rating for PSF (i) and action (j)
ψ_{ij} = SLI for PSF (i) and action (j)

The sum of the SLIs for a given action, equation [4-6], is utilized in determining the probability of success (POS) for each action (Embrey et al., 1984).

$$\Omega_j = \sum_{i=1}^{6} \psi_{ij} \qquad [4\text{-}6]$$

where
Ω_j = total of SLIs for a given action

The POS is determined through a logarithmic relationship, equation [4-7], as developed by Pontecorvo (1965) and as has been the foundation for all versions of SLIM in the determination of HEPs .

$$\log(\kappa_j) = a\Omega_{jm} + b \qquad [4\text{-}7]$$

where
κ = probability of success (POS) or (1 - HEP)
Ω_{jm} = arithmetic mean of SLIs for action j
a, b = constants

The arithmetic mean of the calculated SLIs is utilized as opposed to the geometric mean as the geometric mean cannot be used in conjunction with data that are less than or equal to 0. As the weight and rate scales run from 0 to 100 there exists the possibility that the calculated SLI (Ω_j) is zero for any judge and given action. This result occurred several times in the determination of the F&E SLIs (see data book).

The arithmetic mean was checked against the geometric mean for the fire & explosion (F&E) SLI sets that contained non-zero values as well as the SLI sets for man overboard (MO) and gas release (GR) scenarios. The arithmetic mean was found to be the same or extremely close to the geometric mean. The arithmetic mean of the calculated SLI values is a good estimate of this value (note: the arithmetic mean can never be less than the geometric mean).

The geometric mean is also useful for data that are severely skewed. The median values were calculated for each set of SLIs and found to be similar to the arithmetic mean. The skewness was also checked for each group of determined SLI values (see data book). There was little skewness (skewness less than 1) associated with thirty-four of the fifty-four sets; six sets of SLIs had a skewness value of unity and eleven had a skewness of -1. There were no sets of SLIs with skewness outside this range.

In order to determine the constants (*a*, *b*) in equation [4-7], the HEPs of the actions with the greatest and lowest SLIs must be obtained or estimated. These base HEPs (BHEPs) permit the solution of the constants a and b. The remaining 16 HEPs may then be determined. To solve for *a and b*, two approaches were taken: estimates based on THERP data tables and empirical muster data.

To determine the applicability of the logarithmic relationship, the SLI (ψ) for each task was graphed against the log of its HEP (κ). Embrey et al. (1984) indicated that as the correlation coefficient (ρ) of a linear regression approached unity, the better the data agreed with equation [4-7]. The mean of the SLIs was used to confirm the logarithmic correlation for all three muster scenarios, as Embrey et al. (1984) had performed. The variance associated with the log (κ) takes the general form of equation [4-8].

$$\text{variance}(x) = \frac{n\sum_{k=1}^{n} x^2 - \left(\sum_{k=1}^{n} x\right)^2}{n(n-1)} \qquad [4\text{-}8]$$

where

x = log of POS for an action (j) by a judge (k), log (κ_{jk})
n = total number of judges (24)

The general form of variance in terms of predicted POS for a given action is represented by equation [4-9] (Embrey et al., 1984).

$$\text{variance}(\log \kappa_j) = \frac{n\sum_{k=1}^{n} \log {\kappa_{jk}}^2 - \left(\sum_{k=1}^{n} \log \kappa_{jk}\right)^2}{n(n-1)} \qquad [4\text{-}9]$$

The standard deviation (υ) of the HEPs is the square root of the sample variance, equation [4-10] (Embrey et al., 1984).

$$\upsilon = \sqrt{\frac{n\sum_{k=1}^{n}\log \kappa_{jk}^{2} - \left(\sum_{k=1}^{n}\log \kappa_{jk}\right)^{2}}{n(n-1)}} \qquad [4\text{-}10]$$

The upper and lower uncertainty bounds are equivalent to the log of the POS ± 2 standard errors (s.e.), equation [4-11] and equation [4-12] (Basra and Kirwan, 1998).

$$\log \kappa \pm 2s.e. \qquad [4\text{-}11]$$

where

$$s.e. = \sqrt{\frac{\text{variance}(\log \kappa_j)}{n}} \qquad [4\text{-}12]$$

The following chapter discusses the results from the elicitation phase for both weights and ratings. Included are the HEP determinations for each muster scenario. Statistical analysis was conducted on the PSF weights and ratings to determine the effect of muster actions and muster scenarios on the elicited results. An ANOVA was conducted among the three muster scenarios for each of the six PSFs and within each scenario for the 18 muster actions. The purpose of doing this analysis was to determine if the judges viewed the muster scenarios as a factor in their PSF weights and ratings. Second, the analysis revealed whether the muster actions affected the PSF weights and ratings for a given muster scenario.

As a check to ensure the ANOVA prerequisite of a nearly normal distribution, normal probability charts were produced for a selection of both PSF weights and ratings. The population distributions were found to be fairly symmetrical and the sampling distribution of the mean was approximately normal as the sample size was greater than fifteen (Levine et al., 2001). A non-parametric test (Kruskal-Wallis) was also performed on each muster action to compare against the ANOVA results for each muster scenario. A list of the statistical tests is given in Table 4.19.

Table 4.19 Statistical tests performed on ERT PSF data.

No.	Test Name	Description	Reason for Test
1	ANOVA	Comparing the mean PSF weights and ratings for each action between muster scenarios.	Determine if muster scenarios affected judges' PSF weights and ratings for each action.
2	ANOVA	Comparing the mean weights and ratings for each action within a muster scenario.	Determine if muster actions affected judges' weights and ratings within a given muster scenario.
3	ANOVA	Comparing the SLI values with muster actions and scenarios.	Determine if muster actions and scenarios affected SLI determinations.
4	Kruskal-Wallis	Identical to test #1 and #2 using a non-parametric ranking technique (for PSF weight data only).	Check of test no. 1 and no. 2 results; independent of distribution form.

Chapter 5
DISCUSSION OF ELICITATION DATA AND PREDICTING HUMAN ERROR PROBABILITIES

In this chapter the results of the elicitation phase are reviewed. Comparisons are made on the basis of muster actions and muster type. The elicited results for the ERT subgroups are also compared for both PSF weights and ratings and a summary of the statistical analysis is presented. A presentation of the calculated SLI values and HEPs complete the chapter. The discussion of the PSF weights and ratings are based on the actions within each muster phase as listed in Table 4.5 (awareness actions 1 to 3, evaluation actions 4 to 7, egress actions 8 to 14 and recovery actions 15 to 18). As a reminder, the PSF weights and ratings are based on a scale of 0 to 100. The larger the PSF weight value, the more important the PSF is in successfully completing a task. The larger the PSF rating value, the higher the quality of that PSF. For example, a training rating of 80 for a given action indicates that the individual is well trained for the task in question. If the training weight is 70 this indicates that training is 70% as important as the most important PSF (weight = 100) also known as PSF_{100}. The graphs in this and subsequent chapters have the points connected by lines to illustrate the continuity of the muster sequence. These lines do not provide interpretative values between muster tasks.

5.1 Man Overboard PSF Weight Results

As previously discussed, the elicitation of PSF weights was conducted first, followed by the elicitation of PSF ratings. The mean PSF weights for all actions within the man overboard scenario are shown in Figure 5.1. This scenario is the result of an accident involving a fall from height or a slip on the deck or stairs. Stress weights increase throughout the muster sequence as the muster progresses from the awareness phase to the recovery phase in the TSR.

The importance of low stress levels in completing these tasks increases as the muster progresses and the evaluation phase ends. Stress weights through the egress phase do not vary because muster conditions were seen not to be deteriorating under this scenario. There is a notable increase in stress weight in the egress phase at action 14 (assist others). This action is rarely practiced during muster drills and slows progress to the TSR. The increased weight is a reflection of the importance of remaining calm to assist others effectively. There is a notable drop in stress weight in the recovery phase at action 15 (register at TSR). This action requires little skill to complete and no decision making is associated with this relatively simple act. Stress weights increase through the final three recovery actions as lower levels of stress will improve a person's ability to provide feedback and prepare for potential evacuation from the facility.

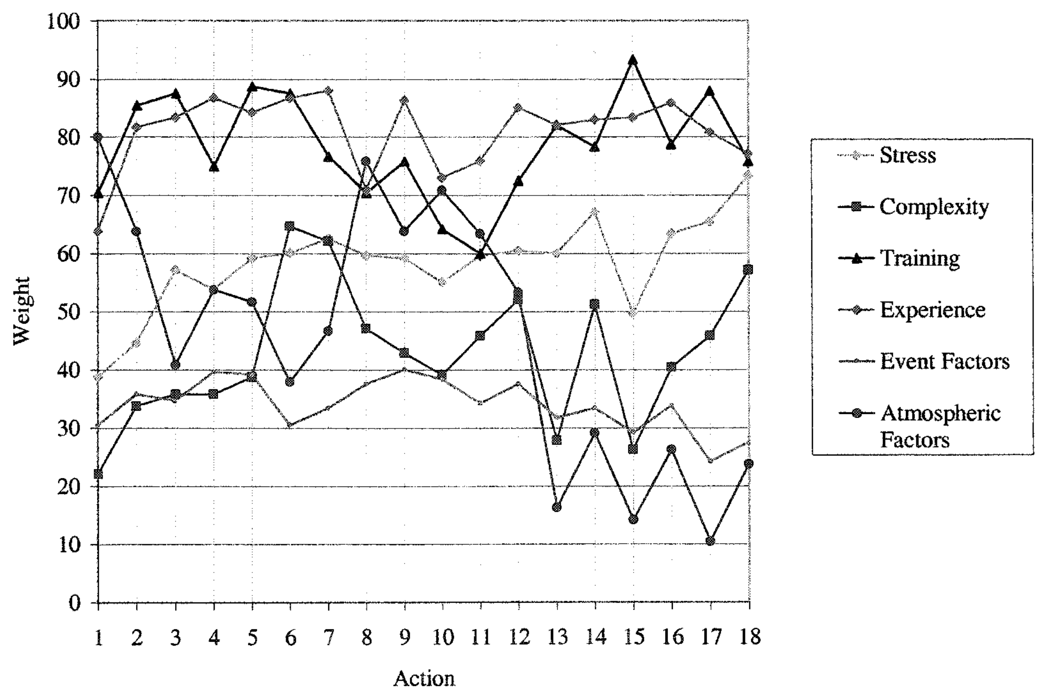

Figure 5.1 PSF weights (MO).

Complexity weight is low at the beginning of the awareness phase as detection of the muster alarm in a man overboard scenario is a simple task. The importance of complexity increases through the awareness and evaluation phases, peaking at actions 6 (return process equipment to safe state) and 7 (make workplace as safe as possible in limited time). If the complexity of these tasks is reduced, then the time to move into the egress phase is shorter. Complexity weights increase sharply with actions 12 (choose alternate route if egress path is not tenable) and 15 (assist others). In both cases the probability of success is significantly lowered if these actions are intricate in any way. The importance of this PSF is shown again in the final recovery phase action (follow OIM's instructions). The ability to complete this action in preparation for abandonment or possibly moving to another safe location is highly dependent on how simple the instructions are.

Training weights are high through the awareness and evaluation phases and begin to drop in importance at action 6 (make workplace safe) through to the lowest weight at action 11 (assess quality of egress route). There is also a notable drop in weight at action 4 (ascertain if danger is imminent). Under this muster scenario, training is not seen to be very important in these actions because the scenario does not present much risk. Actions at the beginning and at the end of the muster have the highest training weights. These actions are clearly defined in the muster procedure and good training can improve their likelihood of being completed successfully. The egress actions (6 to 14) are more ad hoc and traditional muster training does not enhance the likelihood of completing these tasks successfully.

Experience was determined to be important in all aspects of the muster. Weights are high throughout this muster scenario with less of a fall off in the egress phase as compared to training. Experience was seen to be more important than training in the progression to the TSR once the workplace was made safe. This could be a reflection of the quality of training for these tasks.

Event factors are not seen to be important at any stage in the man overboard muster scenario. This PSF has lower weights as compared to the other five PSFs for all actions except those performed in the TSR. Its weight does not change significantly throughout the awareness, evaluation and egress phases. Peak weight is associated with action 9 (evaluate potential egress paths and choose route). The cause of the man overboard scenario may generate a blockage in an egress path requiring individuals to choose an alternate route. There is a drop in weight in the recovery phase as any event factor associated with a man overboard is diminished in the confines of the TSR.

Atmospheric factors was weighted heavily for action 1 (detect alarm) and for the actions in the egress phase. Poor weather conditions will hamper an individual's ability to clearly hear the muster alarm and interpret PA announcements. Extreme winds or ice on the deck can slow progress through the egress phase and make decisions on the quality of the egress path difficult. The importance of atmospheric factors drops to the lowest of all PSFs once the safety of the TSR is achieved.

5.2 Gas Release PSF Weight Results

The mean PSF weights for all actions within the gas release scenario are shown in Figure 5.2. Gas releases can be small in nature, localized, and detected through local instrumentation. They can also be very severe and lead to expanding vapour clouds with the potential for detonation or jet fire if the leak is from a high pressure source through a flange break. Gas releases on offshore platforms are more common than the man

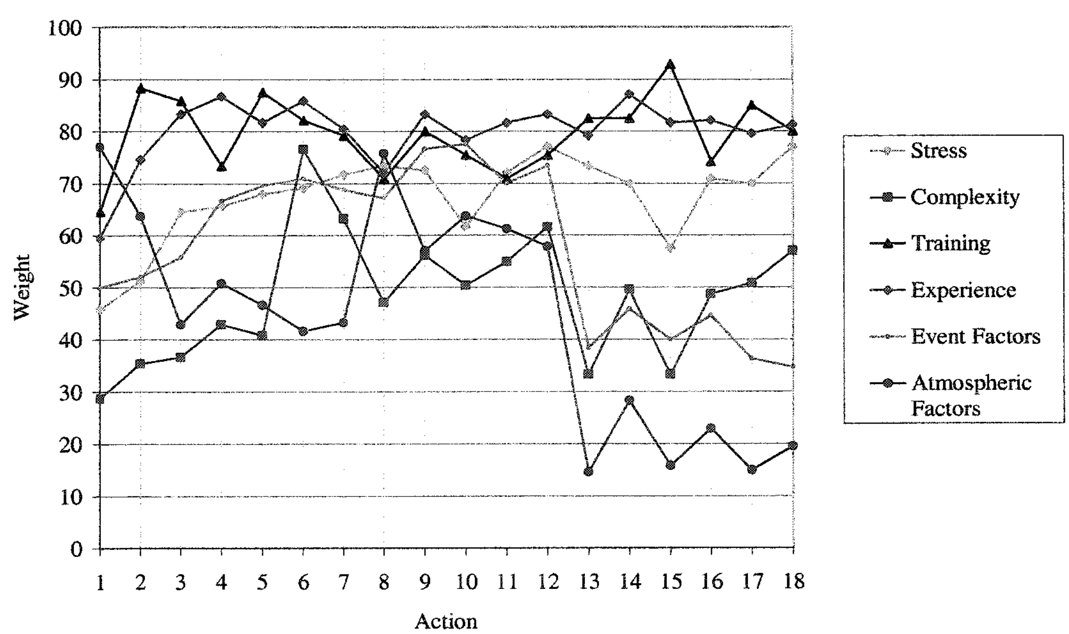

Figure 5.2 PSF weights (GR)

overboard scenario and it can be reasonably expected that experienced offshore personnel have gone through actual gas release muster events.

Stress weight is lowest at the beginning of the awareness phase at action 1 (detect alarm). Stress weight increases through the muster sequence and peaks in the egress phase at action 12 (choose alternate route while moving to TSR) and again at the concluding recovery phase action (follow OIM's instructions). Stress is most important in decision based tasks and lowest in the physical actions of moving along an egress path and registering at the TSR. Stress can be a debilitating factor when making decisions as performance usually deteriorates as the stressor increases or persists (Miller and Swain, 1987). The ability to move effectively between skill-based and knowledge-based modes of behaviour can be severely compromised. Training programs that promote knowledge-based behaviour during muster events may help provide a basis from which individuals can deal more effectively with unfamiliar circumstances. Through job observation, individuals who require additional training to overcome stress effects can be identified and their potential to negatively affect others during a muster can be reduced.

Complexity weights are the lowest among all PSFs for the first five muster actions of the awareness and evaluation phases. Complexity weights increase sharply with actions in the evaluation phase at actions 6 and 7 (return process equipment to safe state, make workplace as safe as possible in a limited time). Complexity was determined to be more important with the physical actions of the evaluation phase. The decision based action of choosing an alternate egress route in the egress phase, action 12, is also weighted heavily. The ability to choose another route correctly can be complex because of unfamiliarity due to a lack of training. Complexity weights decrease for actions that take place within the accommodations and at the initial registration in the TSR. Complexity weights increase as tasks require higher degrees of communication and physical activity in preparation to possibly abandon the platform.

Training weights are high throughout all phases of the muster and do not drop off significantly at any point in the sequence. Training importance is lowest at the beginning of the awareness phase at action 1 (detect alarm) and highest in the recovery phase at action 15 (register at TSR). Experience weights mirror training weights as the importance of this PSF remains high throughout the chain of actions. As with training, experience is ranked lowest at the beginning of the muster and peaks for actions 4 (ascertain if danger is imminent) and 14 (assist others if needed or as directed).

Event factor weights increase throughout the first three phases and drop significantly once safe refuge is attained in the TSR. Event factor importance is highest in the egress phase at action 10 (move along egress path) and lowest at the end of the muster (follow OIM's instructions), which is expected as the influence from event factors is greatest in the awareness, evaluation and egress phases.

Peak weights for atmospheric factors occur at actions 1 and 8 (detect alarm, and, listen and follow PA announcements, respectively). In its worst state, atmospheric factors influence actions associated with communication, lowering the probability of success associated with these components of the muster. Atmospheric factors are least important throughout the recovery phase where protection is afforded in the TSR.

5.3 Fire and Explosion PSF Weight Results

The fire and explosion scenario presents the most severe of the three muster sequences. The mean PSF weights for all actions within the F&E scenario are shown in Figure 5.3. This scenario provides the greatest level of risk through all phases of the muster scenario and can lower local area tenability including that in the TSR.

Stress weights show little variance from action to action and remain high throughout the muster sequence. Complexity weights vary significantly through the muster cycle, peaking sharply in the egress phase at action 6 (return process equipment to safe state). Complexity climbs again in importance with the final action (follow OIM's instructions). The more straightforward the OIM's directions are, the greater the likelihood of a successful abandonment if conditions warrant this step.

Training and experience exhibit almost identical weights throughout the muster sequence. Event factor weights remain high through the first three phases of the muster but drop in importance after the egress phase with actions that occur in the

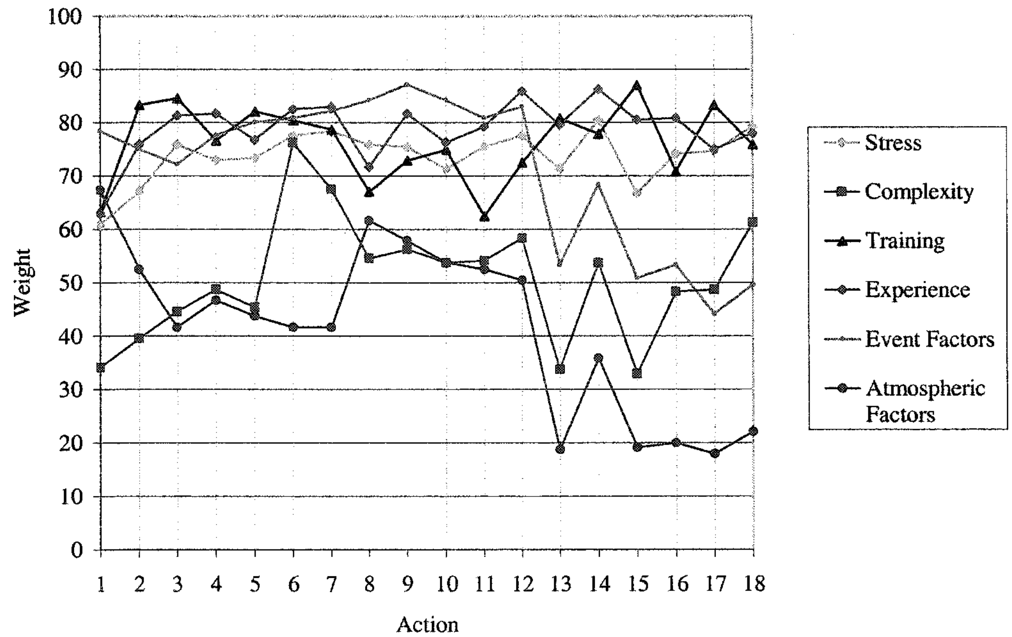

Figure 5.3 PSF weights (F&E).

accommodations and TSR. The drop in weight for the recovery phase exhibits a level of confidence by the ERT that once behind the facility blast wall and in the pressurized environment of the TSR, local area tenability is sustained despite the severity of the muster initiator.

The importance of atmospheric factors is greatest in action 1 (detect alarm) and decreases quickly through the evaluation phase before becoming important again in the egress phase. As with any scenario, atmospheric factors in their worst state not only negatively impact communication based actions, but also negatively influence mobility and bias decision making while progressing to the TSR. The integrity of the TSR protects the mustering complement and is seen to be of minimal importance on actions in the recovery phase and while gathering one's personal survival suit in the accommodations module.

5.4 PSF Weights defined by SRK Behaviour

Table 4.6 is re-presented (Table 5.1) as a reminder of the breakdown of the muster actions by skill, rule and knowledge behaviour as previously explained in Chapter 4. As a reminder, no PSF ratings were determined for Action 13 (collect survival suit if in accommodations at time of muster) as the muster scenarios do not occur in the accommodations.

Table 5.1 Summary of muster actions as defined by SRK behaviour.

No.	Actions	MO	GR	F&E
1	Detect alarm	S	S	S
2	Identify alarm	R	R	R
3	Act accordingly	S	S	S
4	Ascertain if danger is imminent	K	K	K
5	Muster if in imminent danger	R	R	R
6	Return process equipment to safe state	R	K	K
7	Make workplace as safe as possible in limited time	R	K	K
8	Listen and follow PA announcements	R	K	K
9	Evaluate potential egress paths and choose route	K	K	K
10	Move along egress route	R	K	K
11	Assess quality of egress route while moving to TSR	K	K	K
12	Choose alternate route if egress path is not tenable.	K	K	K
13	Collect personal survival suit if in accommodations at time of muster	R	R	R
14	Assist others if needed or as directed	K	K	K
15	Register at TSR	R	R	R
16	Provide pertinent feedback attained while enroute to TSR	K	K	K
17	Don personal survival suit or TSR survival suit if instructed to abandon	R	R	R
18	Follow OIM's instructions	R	R	R

Recalling the SRK Generic Error Modelling (GEMS) system, from Chapter 3, individuals move from one mode of behaviour to another based on their level of experience, training and external factors that influence their ability to complete actions. As muster severity increases, actions 6, 7, 8 and 10 transition from rule to knowledge behaviour as environments become unfamiliar and more severe in nature. As an example (Figure 5.4), when comparing the MO and F&E scenarios, the mode of behaviour changes from rule to knowledge-based for action 10 (move along egress route) . The severity of the muster has increased and the individual's experience has decreased (i.e. 15 years for the MO scenario, six months for the F&E scenario).

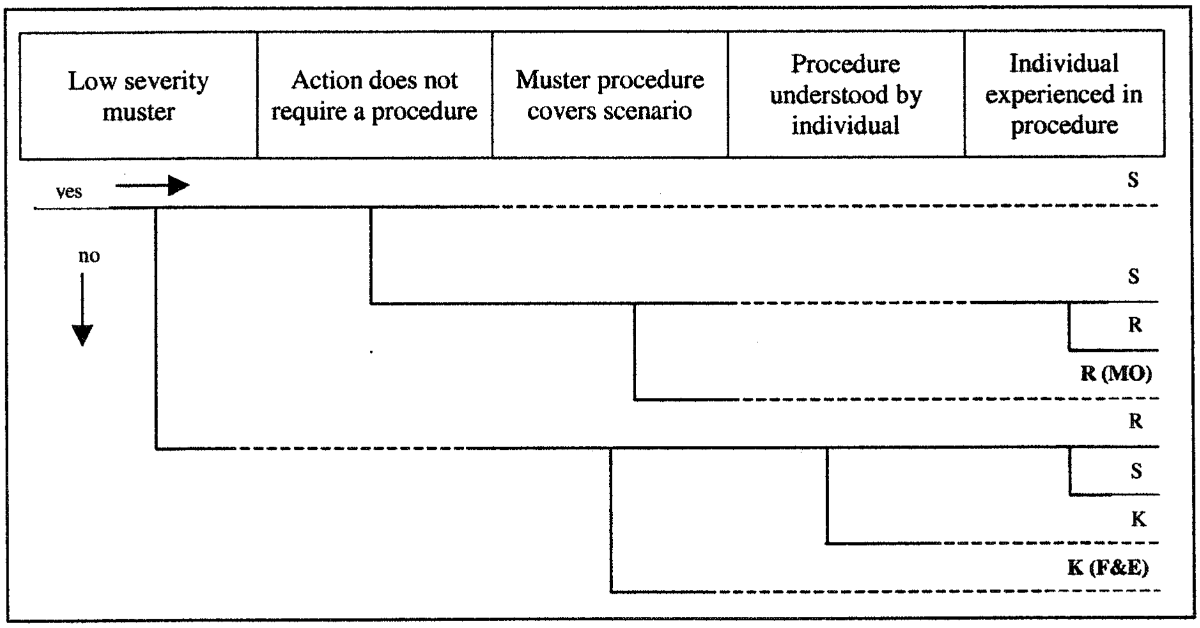

Figure 5.4 Application of logic tree for action 10 (move along egress route) for MO and F&E scenarios.

This level of unfamiliarity requires personal to acquire local information to help them make decisions that would otherwise be simple in a routine muster drill. This does not imply that other actions (e.g. don personnel survival suit or TSR survival suit if instructed to abandon) will not occur in a knowledge-based mode if the individual has difficulty in suiting up. As task complexity increases, a higher level of cognitive processing is necessitated. Figures 5.5 to 5.7 are identical to Figures 5.1 to 5.3,

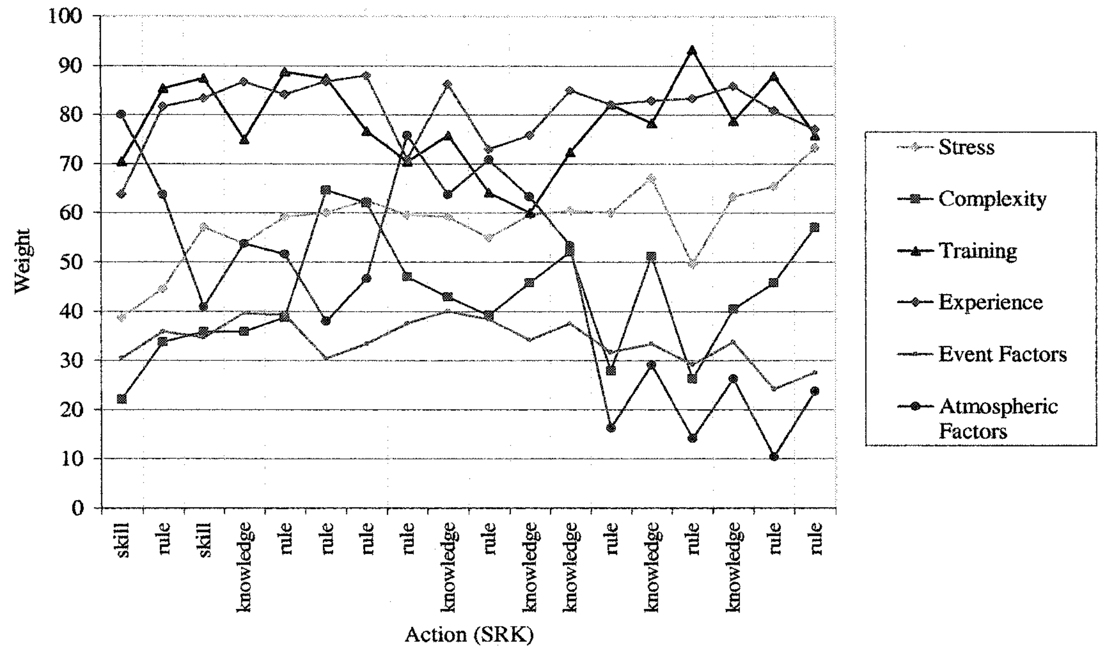

Figure 5.5 PSF weights described by SRK behaviour (MO).

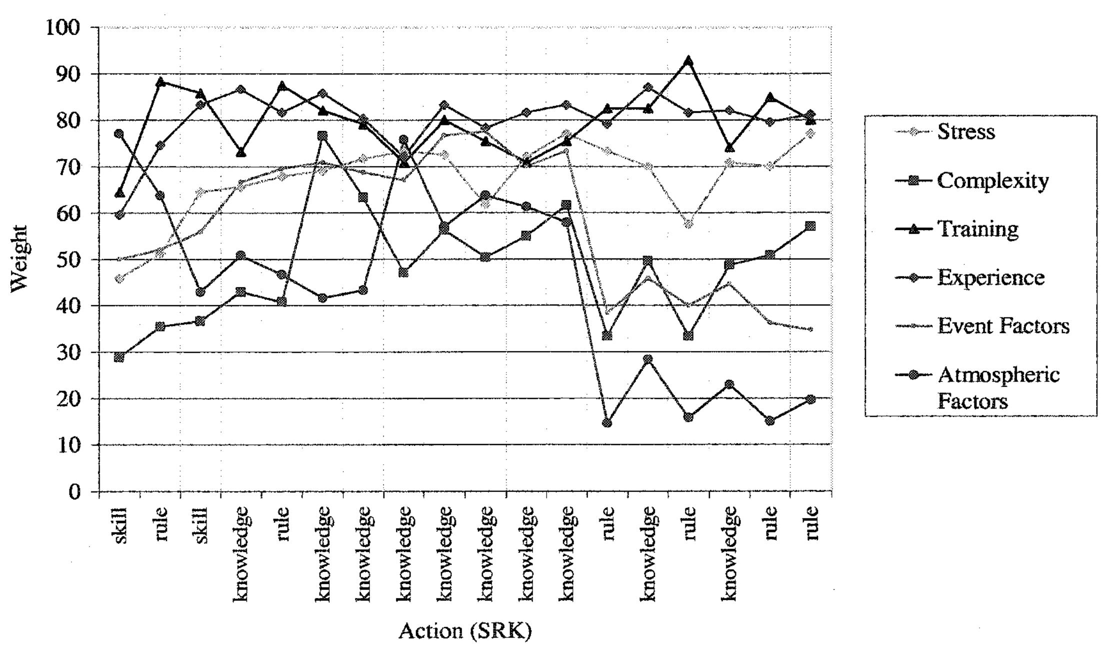

Figure 5.6 PSF weights described by SRK behaviour (GR).

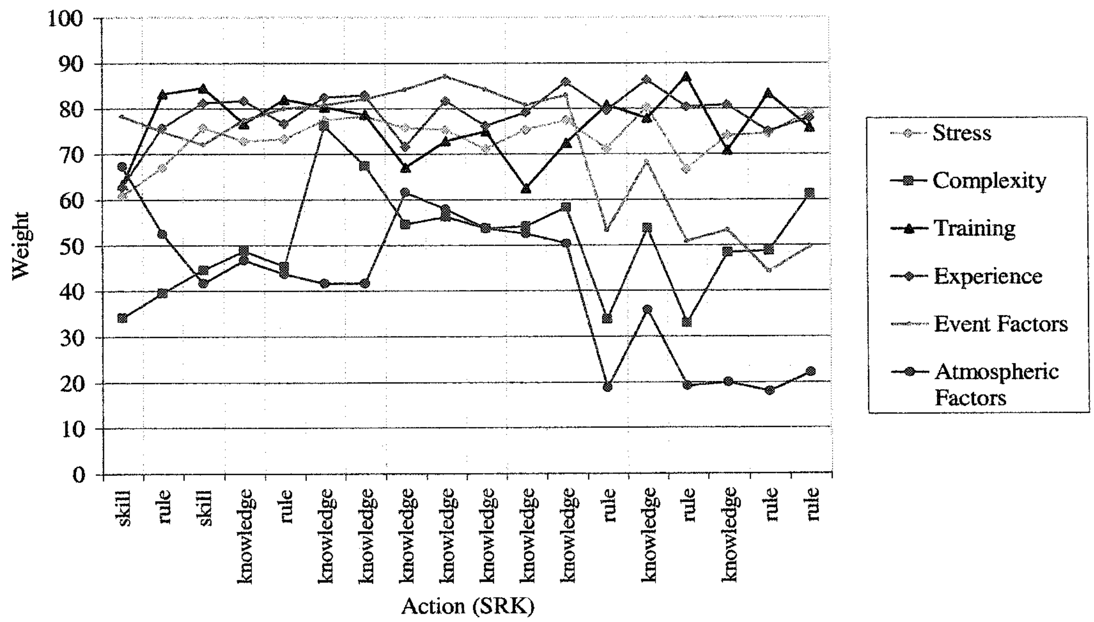

Figure 5.7 PSF weights described by SRK behaviour (F&E).

except that the actions are identified by the SRK behaviours. Table 5.1 does not imply that these actions take place solely in the behaviour indicated. Rather, Table 5.1 is a prediction of which behaviour will dominate in the performance of each task. For more severe musters, performing actions in the knowledge-based mode will be a necessity as environments can be unfamiliar and confusing.

Actions that are skill and rule-based may still become knowledge-based actions if individuals are not successful in initially completing the task. The higher the probability of failure, the more likely the actions will be performed in the knowledge-based mode. In the MO scenario (Figure 5.5) the PSF weights do not show any prevailing trends associated with SRK behaviour. In the GR muster (Figure 5.6) PSF weights are generally higher for the knowledge-based actions which predominate the evaluation and egress phases. The PSF weights in the F&E scenario (Figure 5.7) do vary significantly with SRK behaviour although the trends indicate that collectively the PSF weights are greatest in the egress phase (actions 8 to 14).

The next section reviews the mean PSF weights among the three muster scenarios followed by a comparison among the five ERT subgroups.

5.5 Comparison of PSF Weights between Muster Scenarios and ERT Subgroups

Figure 5.8 to 5.13 compare the elicited PSF weights on a muster scenario basis. Figure 5.8 illustrates how the importance of stress increases with muster severity

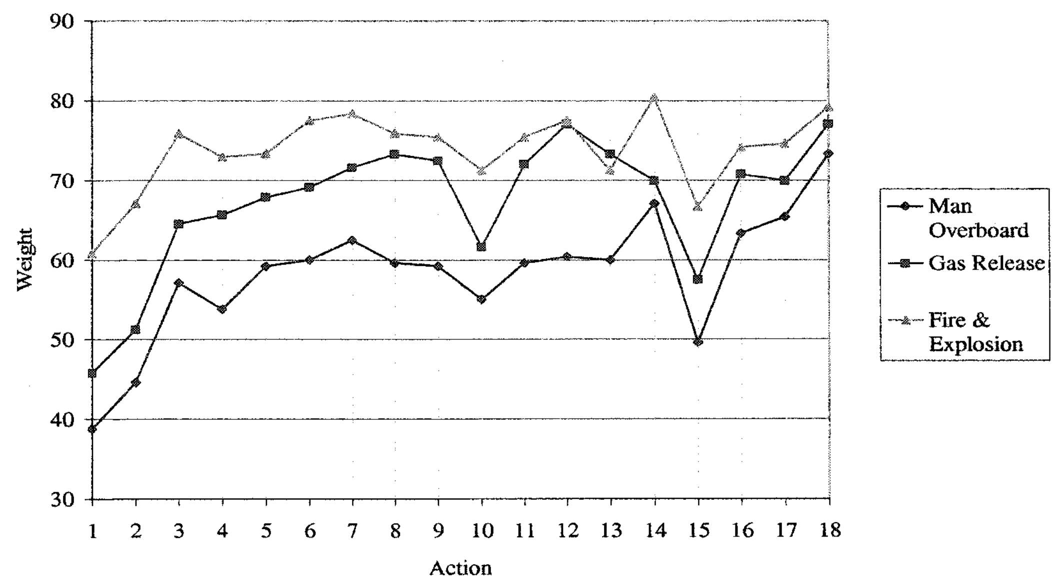

Figure 5.8 Comparison of stress weights for all three muster initiators.

for all actions except for egress actions 12 (choose alternate route if egress path is not tenable) and 13 (collect personal survival suit if in accommodations module at time of muster initiation). In these two actions, stress weights are nearly equal for both GR and F&E. Stress is less sensitive to the differences in muster severity in the egress and recovery phases for GR and F&E musters except for egress action 9 (evaluate potential egress paths and choose route), where stress is weighted more significantly in the F&E scenario. Actions which take place in the TSR during the recovery phase show less of a difference in stress weights among all three scenarios. This implies that the importance of stress is diminished when in the protective environment of the TSR.

Figure 5.9 compares PSF complexity weights across the muster scenarios. The generally tight grouping of the weight data for all actions throughout the awareness, evaluation, egress and recovery phases indicates a level of independence from the initiating event. There is

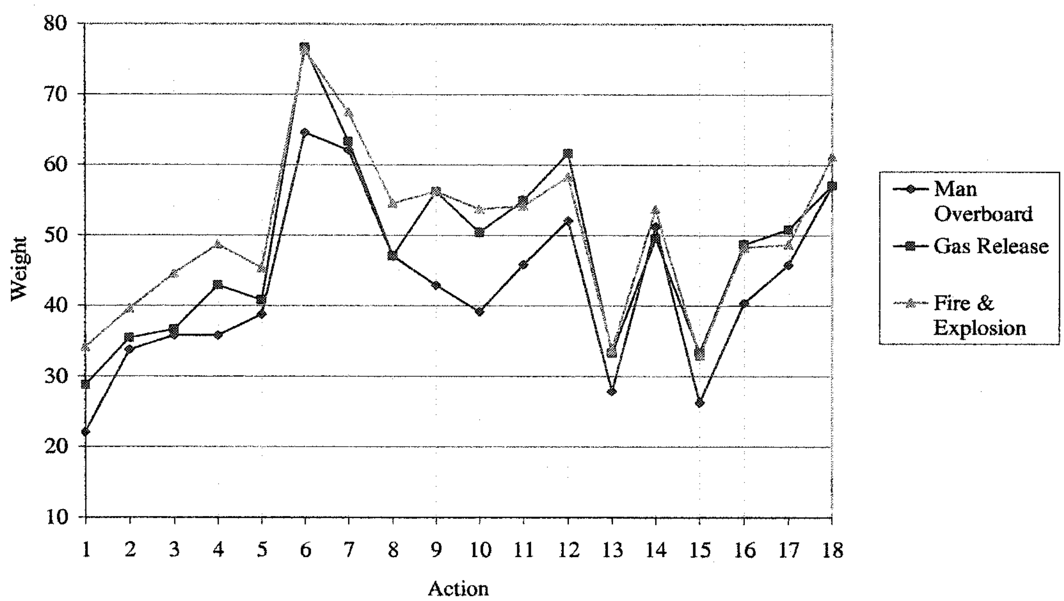

Figure 5.9 Comparison of complexity weights for all three muster initiators.

some variance in the egress phase between the man overboard scenario and the two more severe circumstances for actions 9 through 12. Complexity is higher for the GR and F&E scenarios for these egress actions. In all three muster scenarios, the peak weights are achieved in action 6 (return process equipment to safe state). The complexity of this action has a strong influence on whether this action is completed successfully. Of note, complexity is equally important across all scenarios for action 14 (assist others if needed or as directed).

Figure 5.10 (training) and Figure 5.11 (experience) show a very tight scatter of weight data for both PSFs throughout all phases of the muster. The ERT did not

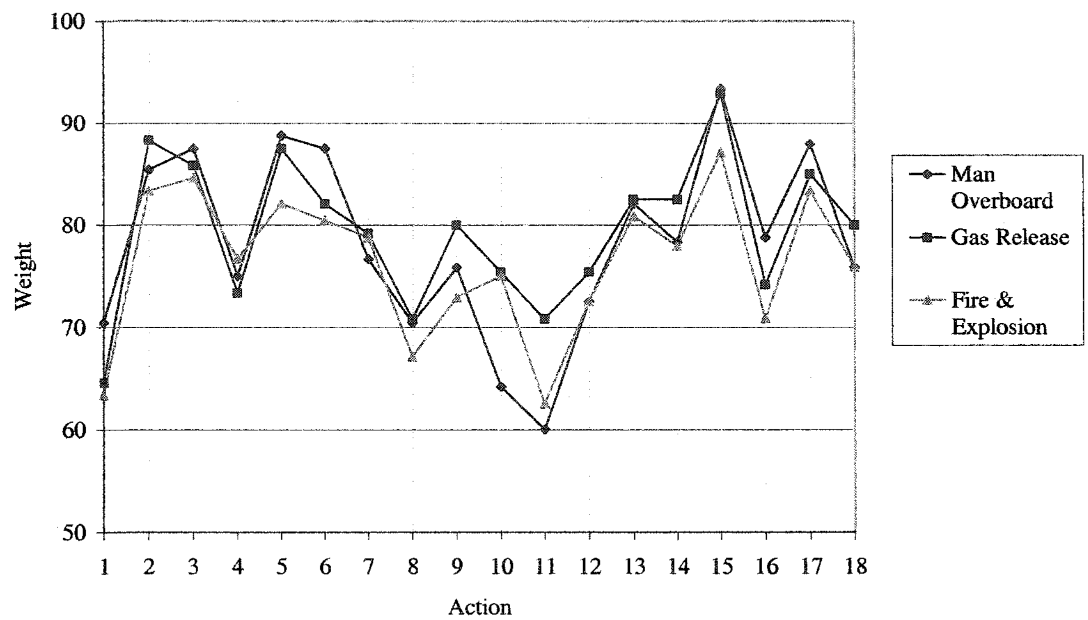

Figure 5.10 Comparison of training weights for all three muster initiators.

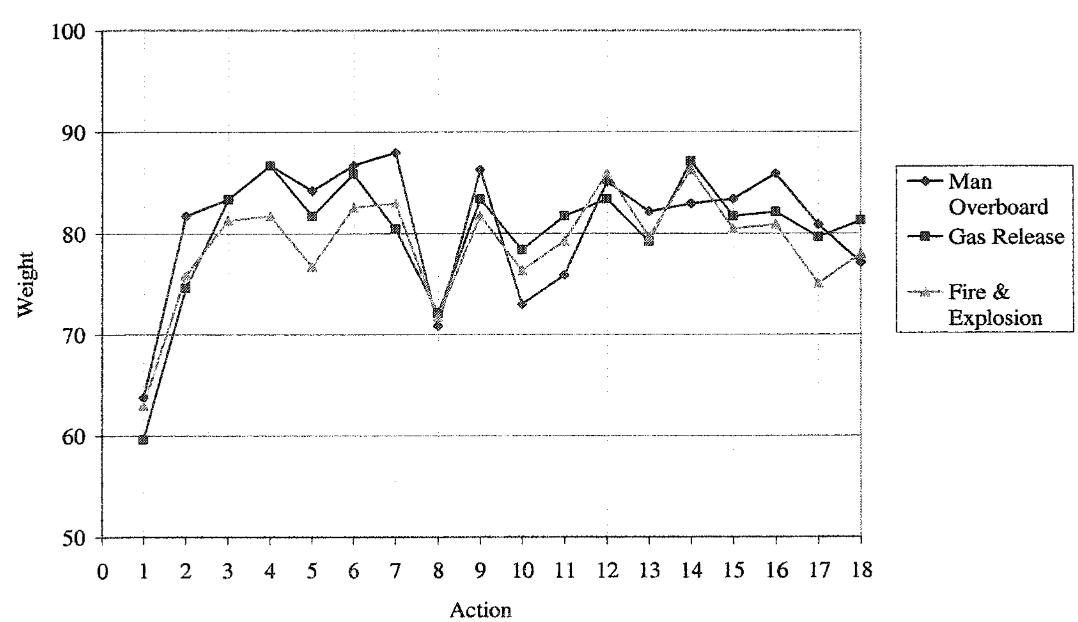

Figure 5.11 Comparison of experience weights for all three muster initiators.

distinguish between the muster initiators in weighting these factors. Interestingly, experience weights were least important for certain F&E actions (i.e. 3, 4, 5 and 6). As muster initiators become more severe, the importance of experience becomes less of a factor. The message is that individuals have less of an ability to control their likelihood of success as event factors dominate and chance becomes ever more important to survival.

Figure 5.12 illustrates the influence of event factors. This PSF shows the widest range of results in weight among all six PSFs. The widest gap falls in the awareness, evaluation and egress phases; there is then a narrowing of the range in the final stage of muster recovery. Gas release and fire and explosion weights are more closely weighted and follow the same trends, showing a step change in importance from the more benign man overboard event. The man overboard event resembles the least severe form of muster, a drill, where event factors play little significance in completing tasks successfully.

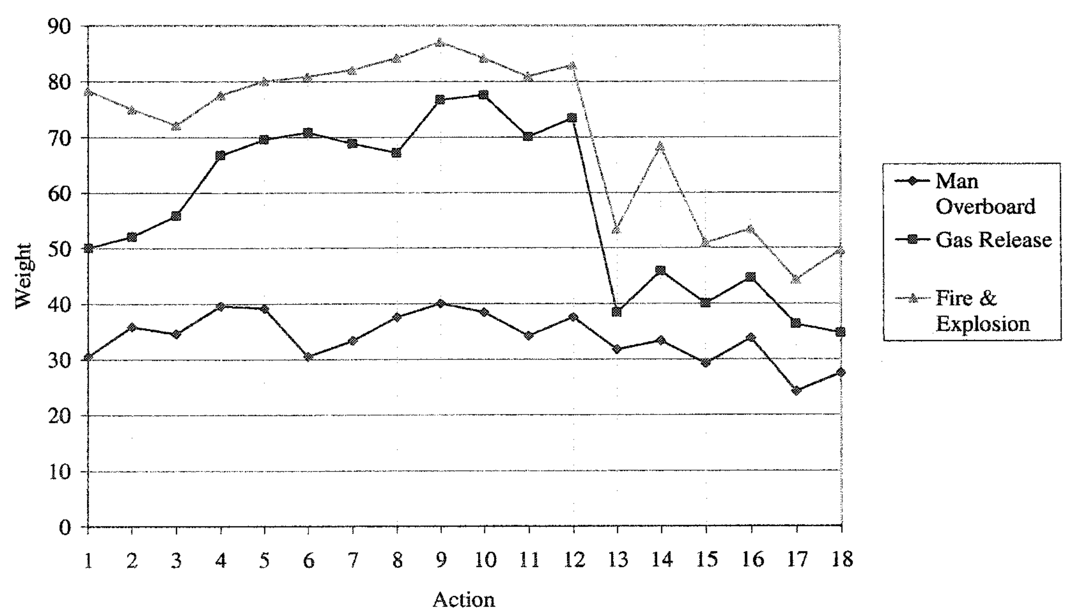

Figure 5.12 Comparison of event factor weights for all three musters initiators.

Figure 5.13 compares the weights among muster scenarios for atmospheric factors. There is no clear distinction that can be made based on muster initiator. Atmospheric factors are independent of muster severity and act in conjunction with the initiating event, making actions more complex if weather conditions are harsh.

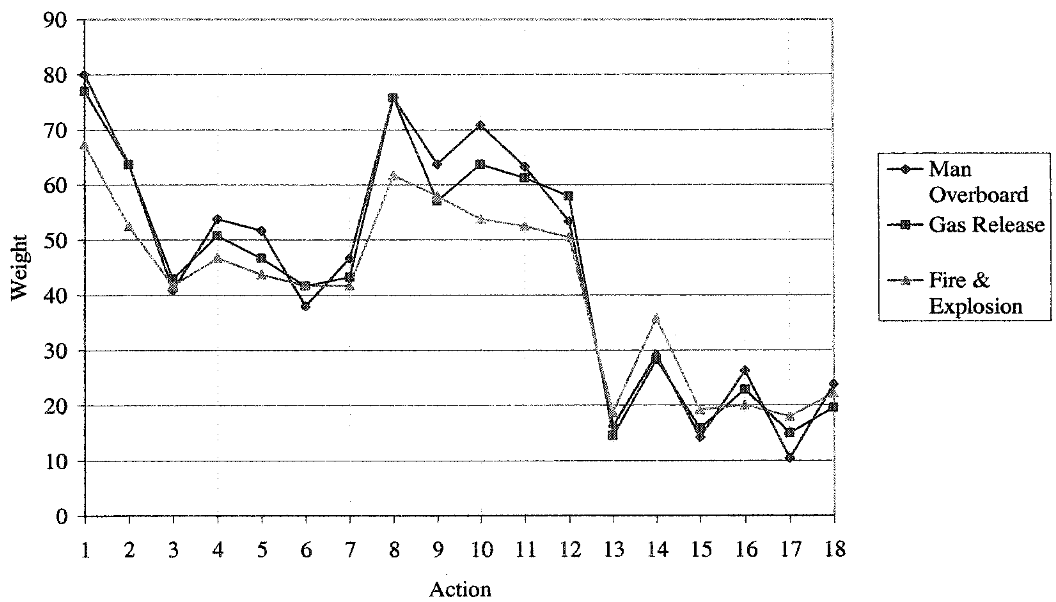

Figure 5.13 Comparison of atmospheric factors weights for all three muster initiators.

Under its worst conditions, weather complicates actions and detrimentally affects chances of success. The atmospheric factor weights show a high level of influence on actions related to communication and egressability for all three muster scenarios.

Figure 5.14 summarizes the mean weights for all actions within each muster scenario. Experience is found to be most important (mean weight of approximately 80) for all three scenarios with little variation among them. This PSF is closely followed by training with an average weight of 77 across all three events. This close relationship implies that the ERT members viewed training and experience as equally important and clearly more important than any other PSF. The mean weight for stress increases as

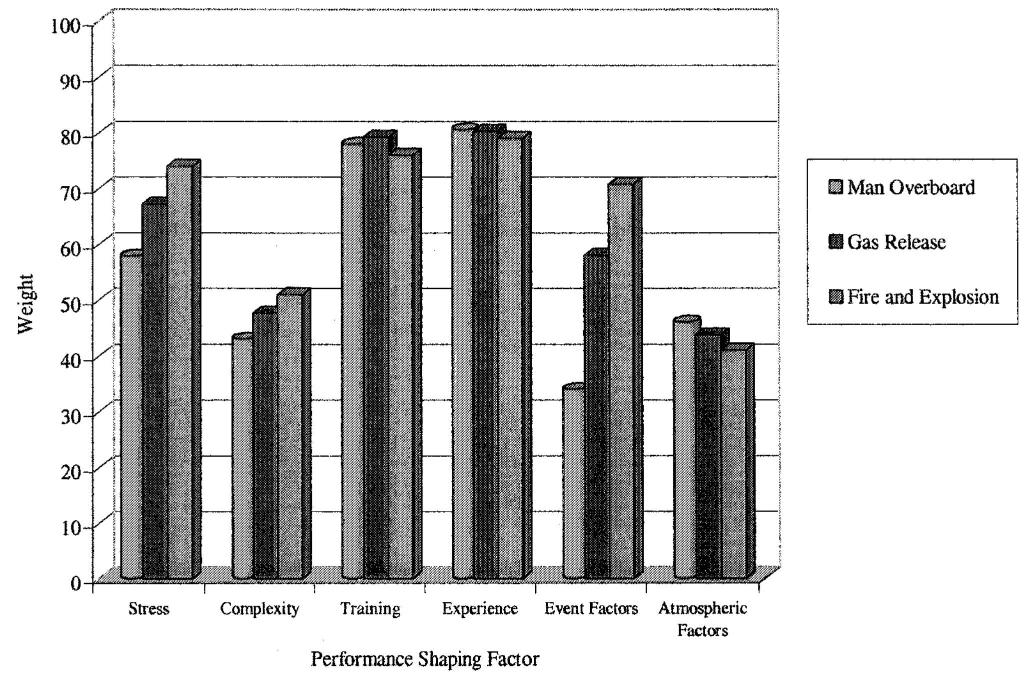

Figure 5.14 Mean PSF weights for all actions and muster initiators.

muster severity increases and stress plays a greater role in the likelihood of completing a task successfully as conditions worsen.

Complexity also increases with muster severity but to a lesser degree than stress. It is, on average, ranked fourth among the PSFs as being influential in the likelihood of completing muster tasks successfully. As the elicitation of weights was based on PSFs in their worst state, the complexity of muster actions is not significantly influenced by the type of muster. Atmospheric factor weights are similar to complexity weights, but show a slight decline in importance as muster conditions worsen. Atmospheric conditions are more important, on average, than event factors for the man overboard scenario but reverse positions as event factors make weather conditions (atmospheric factors) less relevant in the F&E and GR scenarios.

Figures 5.15 through 5.17 compare the mean weights among ERT subgroups for each PSF and muster scenario. The variation in weights among subgroups is not great in most cases, indicating that there is no significant bias provided by a subgroup except by the CRT subgroup in the MO scenario. The CRT mean PSF weights vary notably from the other groups. The 5-person CRT is the most varied in experience and expertise. The small size of the group permits the mean value of the PSFs to be influenced more readily by any one judge who varies significantly from the rest of the group. Though different in background, the larger subgroups mean PSF weights agree more closely.

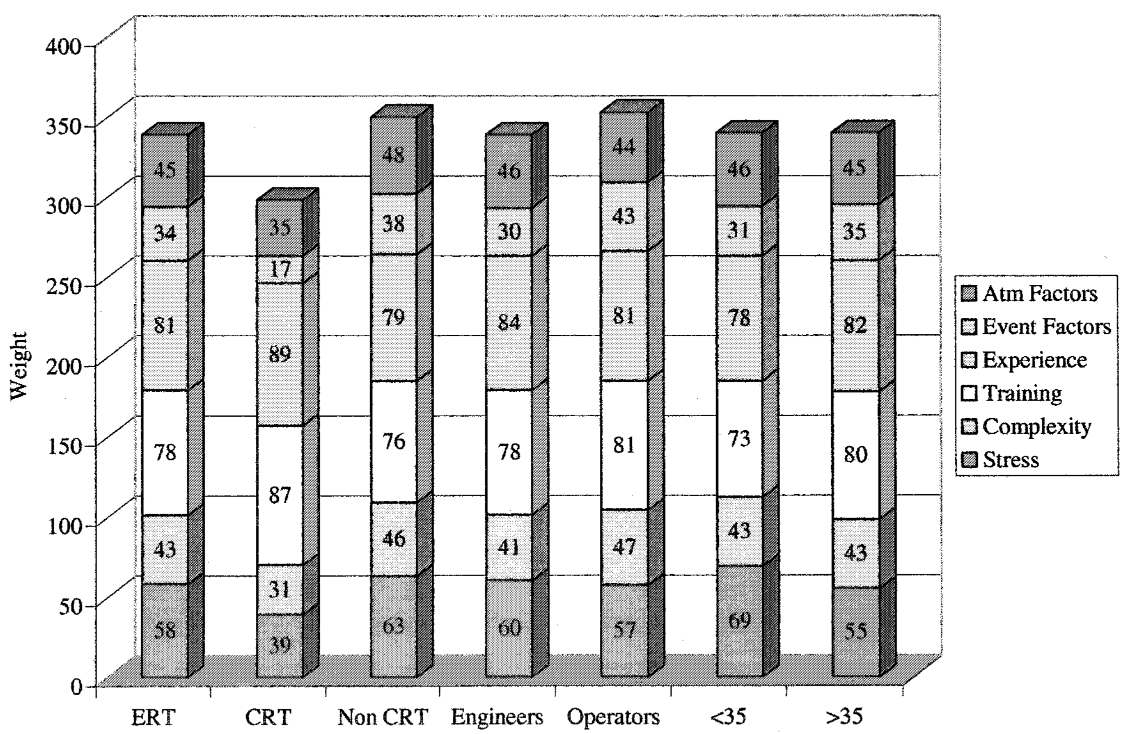

Figure 5.15 Comparison of PSF weights by ERT subgroups (MO).

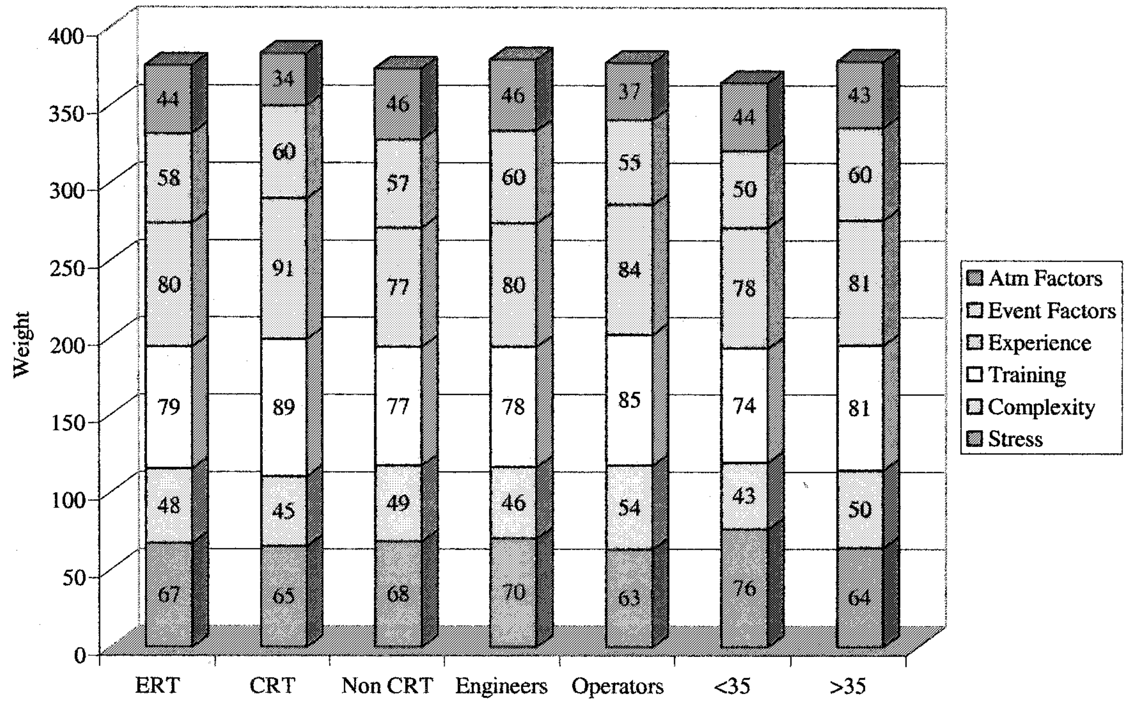

Figure 5.16 Comparison of PSF weights by ERT subgroups (GR).

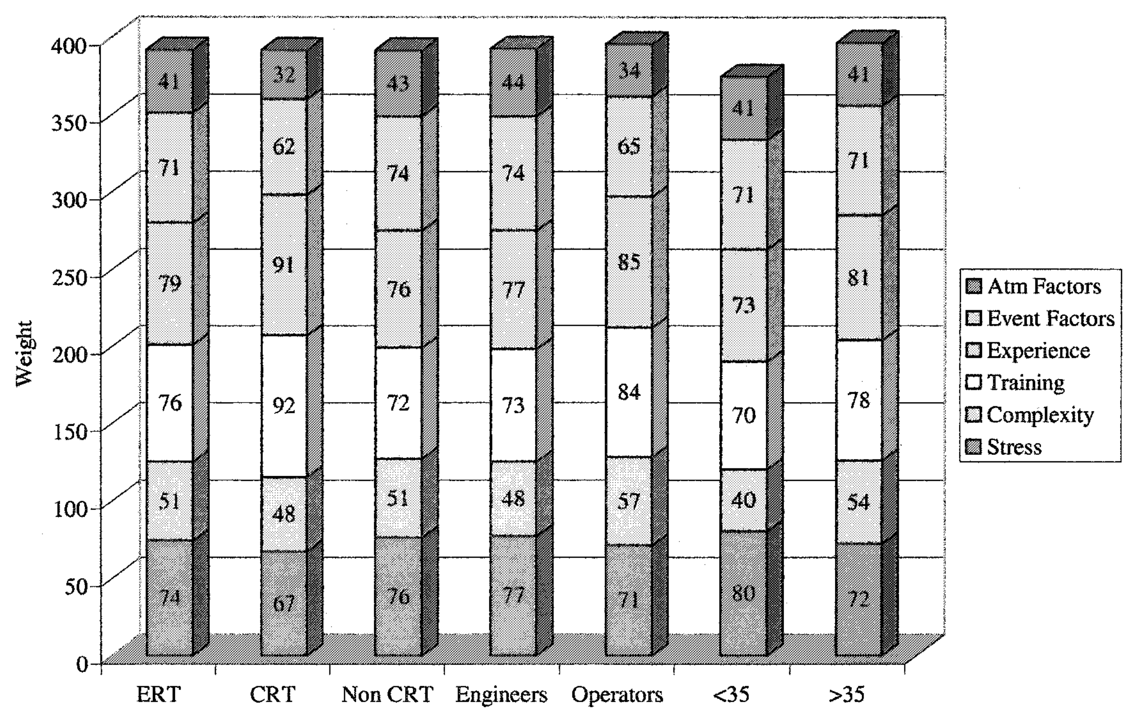

Figure 5.17 Comparison of PSF weights by ERT subgroups (F&E).

5.6 Statistical Analysis of PSF Weight Data

To this point the PSF weight data have been presented and reviewed graphically. A statistical review will determine to what degree, if any, the effect of the muster scenarios and the muster actions had on the elicitation of the PSF weight data. In order to achieve this, hypothesis testing (i.e. null hypothesis, H_o) was conducted on the mean weights. The null hypothesis in its general form states that the variable in question has no effect on the measurement being analyzed. The null hypothesis tested for the muster scenarios is: muster scenarios have no effect on PSF weights and ratings. The null hypothesis tested for the muster actions is: muster actions have no effect on PSF weights and ratings within each muster scenario.

One of the most important statistical tests for hypothesis testing is the ANOVA F-test named after its developer R.A. Fischer (Pagano, 1990). The F-test generates an F-statistic, which is the ratio of two independent estimates of the same population variance. These variances are termed the within-group variance (how different each of the scores in a given sample is from other scores in a same group) and the between-group variance (how different the means of the samples are from one another). The ANOVA F-test is fairly robust against departures from normality and is not affected to a great extent when larger sample sizes are applied (Levine et al., 2001). Further, as the sample sizes in this analysis are equal for all groups tested by ANOVA, the results will not be seriously affected by unequal variances (Levine et al., 2001).

If H_o is true, the F statistic will be approximately 1 (i.e. the variance between the groups is approximately equal to the variance within the groups). If H_o is false (i.e. muster initiators affect the elicited PSF weights), the F statistic can be substantially greater than unity. For a given level of significance (e.g. $\alpha = 0.05$) the decision rule is:

$$Reject \rightarrow H_o \ if \ F > F_c$$

where F_c is the F statistic at the chosen level of significance (Figure 5.18).

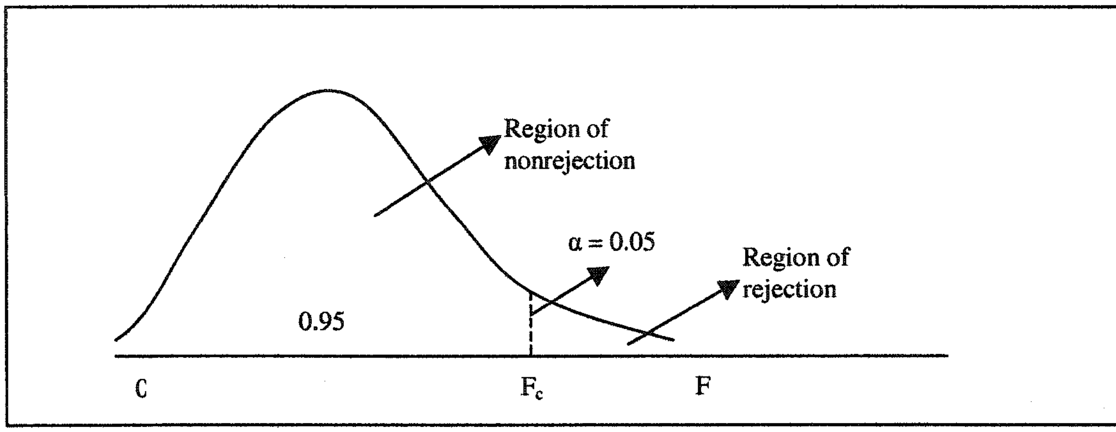

Figure 5.18 F distribution showing regions of rejection and non-rejection when using ANOVA to test null hypothesis (H_o).

A measure of probability is provided by the P-Value, which provides the probability of obtaining a value equal to or greater than the determined F statistic. When H_o is true, the P-Value will be greater than the specified level of significance (0.05). To avoid Type I errors (rejecting H_o when H_o is true), only strong F_c results are considered to be valid to reject H_o. Conversely, Type II errors (accepting H_o when H_o is false) are mitigated by the use of larger populations (more judges). The number of judges in this work (24) is larger than that applied by Embrey et al. (1984) and Zimalong (1992) who used three and six judges, respectively.

As a check on the ANOVA results, the non-parametric, rank order technique (Kruskal-Wallis) was utilized. The Kruskal-Wallis rank test (KW) is an alternative to the one-way ANOVA test and applies an H statistic to test the null hypothesis (H_o). The KW test can be more powerful than the F test when assumptions of the ANOVA are violated (i.e. near normal distribution). The KW test compares the average of the ranks (a rank of 1 is given to the smallest value and increases to a rank of n corresponding to the largest value) in each of the groups against the overall average rank based on all observations. The test statistic H can be approximated by the chi-square distribution, χ_u^2 (Levine et al, 2001). For a given level of significance ($\alpha = 0.05$) the decision rule is:

$$Reject \rightarrow H_o \ if \ H > \chi_u^2$$

The KW p-value provides the probability of obtaining a value equal to or greater than the determined H statistic. When H_o is true, the p-value will be greater than the specified level of significance (0.05). The KW test provides an additional check on the validity of the ANOVA decision on the null hypothesis, especially in cases where there is not a strong F statistic to reject H_o.

Analysis of variance (ANOVA) statistics have previously been applied by Embrey et al. (1984) and Zimalong (1992) to determine the effect of judges and actions on calculated HEPs. Embrey et al. (1984) sought to check the consistency of his judges through an ANOVA and applied an interclass coefficient as a measure of consistency. Of the twelve judges Embrey et al. utilized, only three took part in all of the SLIM working sessions. As such, Embrey et al.'s consistency analysis was applied to only those three judges. Not surprisingly, Embrey et al. found that most of the variability lies in the differences between the actions evaluated, and not the judges. No check or comment was performed, in either work, on the normality of the data (which is a prerequisite of ANOVA). The small sample in Embrey et al.'s 1984 work provides less flexibility for variations from normality.

Zimalong (1992) found through ANOVA that the PSFs had statistically significant effects on the predicted HEPs for the 12 tasks in his study, but found poor correlation among the judges for the one ANOVA performed on the PSF rating results. As with Embrey et al. (1984), Zimalong did not report on the distribution quality of the data. With small samples, the experimental results of Embrey et al. and Zimalong may be viewed as questionable without further understanding the normality of the data. In neither work was there an analysis performed on the elicited PSF weights despite the critical nature of the weights in determining HEPs. Even with the utilization of 24 judges in the current work, it is still important to check the normality of the data used in an ANOVA.

The software used for the statistical review of elicited PSF weights was conducted utilizing the PHStat (Version 1.4) software add-in for Microsoft Excel. Details of the experiments are found in the accompanying data book, which includes results from parametric (one-way ANOVA) and non-parametric (Kruskal-Wallis) tests. The analysis provides commentary on the effect of muster initiators and the muster actions on the PSF weights. Another prerequisite of ANOVA experiments is that the data must be based on an interval or ratio scale. The weight data are based on a range of 0 to 100 on an interval scale of 10, and thus satisfy this prerequisite.

Distributions that contain at least 30 samples can be considered to have a normal distribution (Levine et al., 2001). The current study utilized 24 judges and does not fit this criterion. A graphical approach is acceptable to determine normality if there are at least twenty observations (Levine et al., 2001). The assumption of normality for an ANOVA was checked through the use of normal probability charts (NPCs) for a group of randomly chosen PSFs and actions. A normal distribution is indicative of a linear relationship generated in an NPC. The level of deviation from linearity is considered to be a deviation from normality. Figures 5.19 to 5.21 are NPCs that show reasonably good linearity based on the Z values (standard normal score) and their associated cumulative percentage (percent of values less than Z). The first test was a check on whether the type of muster initiator had any effect on the elicited PSF weights.

A one-way ANOVA was conducted to determine if the null hypothesis, severity of muster initiator does not affect PSF weight, was true or false (Table 5.2). A complete set of tables can be found in Appendix F. Included in these tables are the results from the non-parametric Kruskal-Wallis test. Through the analysis of variance between and within the groups, it can be determined whether if the muster initiators generated statistically different mean PSF weights for each action within the muster sequence.

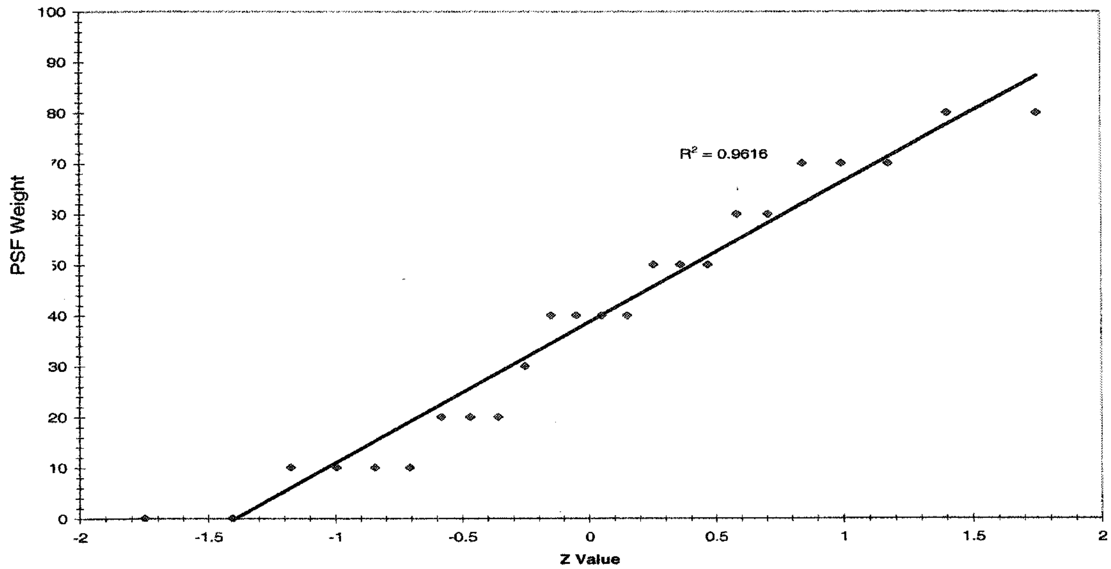

Figure 5.19 NPC for stress weights, action 1 - detect alarm (MO).

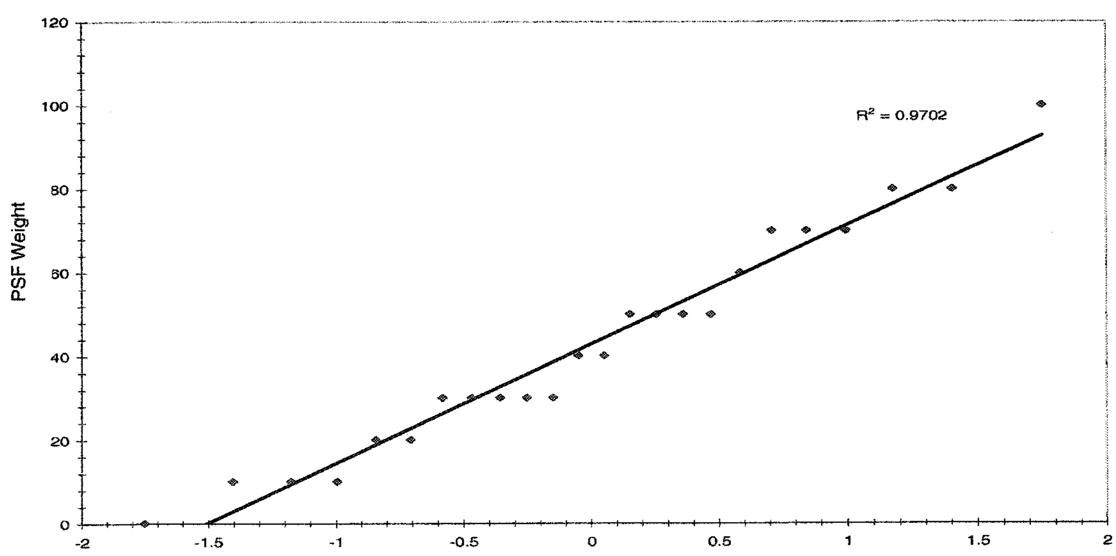

Figure 5.20 NPC for experience weights, action 15 - register at TSR (GR).

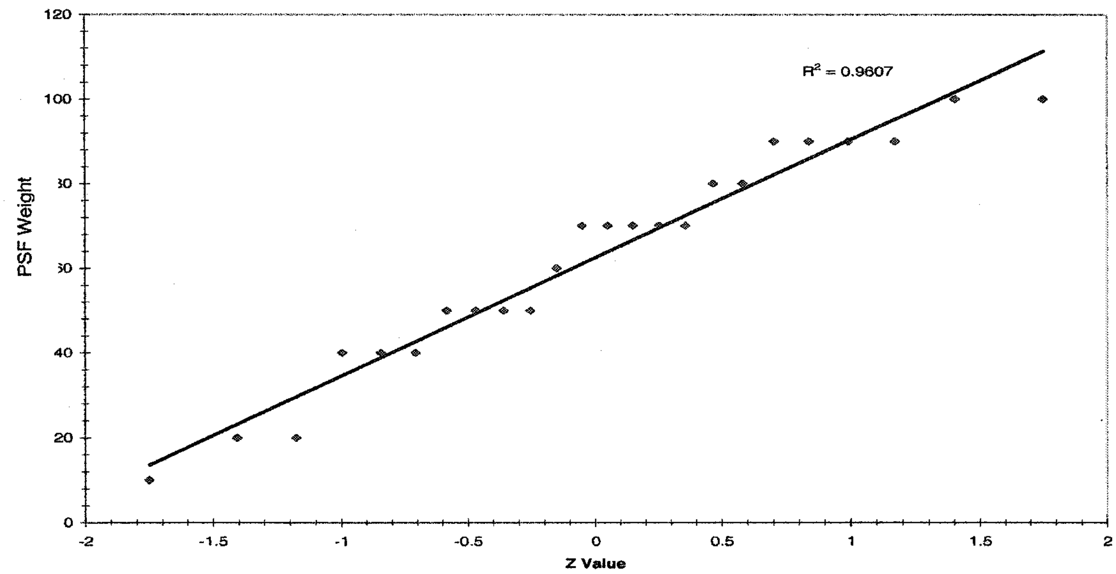

Figure 5.21 NPC for training weights, action 11 - assess quality of egress route while moving to TSR (F&E).

Table 5.2 Effect of muster initiator on action 1 PSF weights.

Action 1 – detect alarm (H_o = severity of muster initiator does not affect PSF weights, α = 0.05)									
Test no.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
1a	stress	4.19	3.13	0.019	*reject*	5.56	5.99	0.06	accept
1b	complexity	1.26	3.13	0.289	accept	1.33	5.99	0.51	accept
1c	training	0.26	3.13	0.767	accept	2.16	5.99	0.39	accept
1d	experience	0.12	3.13	0.879	accept	0.71	5.99	0.70	accept
1e	event factors	13.36	3.13	$1.34*10^{-5}$	**reject**	15.60	5.99	0.0004	**reject**
1f	atmospheric factors	1.10	3.13	0.338	accept	5.86	5.99	0.05	accept

A total of six ANOVA and six KW tests were performed for each muster action, representing each PSF. This generated a total of 216 individual statistical results. A strong rejection of H_o is signified in bold (i.e. **reject**) and a weak rejection is identified by italicized text (i.e. *reject*).

The results indicate that the null hypothesis is true for the complexity, training, and atmospheric factor weights for all actions. There is a rejection of H_o for experience in action 4, ascertain if danger is imminent (Table F.3). In this case the ANOVA result accepts the null hypothesis while the KW test provides an extremely weak rejection ($p = 0.047$). The p-value is essentially equal to the stated level of significance (0.05) and as such does not provide a strong statistic to reject H_o.

ANOVA and KW statistics for stress are contradictory in certain cases. The ANOVA results provide a weak rejection of H_o for actions 1 through 4, 6 through 9, and 12. The other actions which make up the total 18 muster actions accept the null hypothesis. The actions which reject H_o have weak F statistics that are marginally greater than F_c in all cases. The corresponding ANOVA probability is close to the stated level of significance (0.05) for all rejected cases. Coupled with an acceptance of H_o in the corresponding KW test, it is determined that muster initiators have no effect on the mean stress weights.

Event factor test results show strong rejection of the null hypothesis for actions 1 though 12, and weak rejections for actions 14, 15, 17 and 18. Event factors have a large effect through the first three phases of the muster sequence but do not play as significant a role in recovery actions that are performed in the TSR. The statistical analysis indicates that PSFs in their worst state (criteria set in PSF weight questionnaires) are independent of the muster initiator except for the PSF that is a direct result of the type of muster initiator (i.e. event factors). This confirms that the ERT understood the elicitation directions for PSF weights. The ERT was not influenced by the muster initiator for PSFs that are not a direct result of the type muster.

The next set of statistical work centered on the effect the muster actions have on the elicited PSF weights. The null hypothesis for this experiment for each muster scenario is: the muster actions have no effect on PSF weights. Table 5.3 summarizes the ANOVA results for the MO scenario. In all cases, the null hypothesis is rejected except

Table 5.3 Effect of muster actions on PSF weights (MO).

(H_0 = actions do not affect PSF weights, $\alpha = 0.05$)				
PSF	**ANOVA**			
	F	**F_c**	**P-Value**	**Result**
stress	1.76	1.65	0.030	*reject*
complexity	4.59	1.65	$6.96*10^{-9}$	**reject**
training	3.60	1.65	$2.06*10^{-6}$	**reject**
experience	2.24	1.65	0.0031	**reject**
event factors	0.52	1.65	0.94	accept
atmospheric factors	15.82	1.65	$1.88*10^{-35}$	**reject**

for event factors. This infers that the event factor weights are independent of the muster actions. In the case of man overboard the event factors may have little significance on the probability of failure (POF) to complete muster actions. The likelihood of completing the muster tasks successfully is not dependent on this type of muster initiator.

The same experiments were conducted for the gas release and fire and explosion scenarios (Appendix F). In the gas release scenario, the muster actions are seen to have a strong effect on the PSF weights in all cases. In the fire and explosion scenario, the muster actions are seen to have an effect on the PSF weights in all cases except for stress. In this scenario, muster actions were seen not to influence the importance of stress as stress levels are likely to be influenced more by the muster initiator than by the muster tasks.

5.7 PSF Ratings Results

This section reviews the results from the elicitation of ratings for all three muster scenarios. The rating elicitation phase was successful in obtaining replies from all 24 judges who provided valid weight data. Here the muster scenario is defined in more detail by providing particulars about the weather at the time of muster, the location of the individual in relation to the initiating event and the individual's years of work experience. As previously mentioned, a summary of PSF ratings can be found in Appendix E.

A comparison of each PSF within each muster scenario was conducted first. This was followed by a discussion of the ratings through SRK behaviour and then another comparison of the ratings was made based on the three muster scenarios to illustrate the effect of muster severity. There are no ratings for action 13 because the defined scenarios (Tables 5.4, 5.6 and 5.8) did not include this action (i.e. gather personal survival suit if in accommodations at time of muster). Table 5.18 can be used as reference for rating scales.

5.8 Man Overboard PSF Rating Results

The man overboard scenario (Table 5.4) was set up so that the muster sequence provided no obstacles during the event. The muster is not seen or heard by a very experienced operator (i.e. 15 years) who is in the process units conducting a regular activity (i.e. skimming a vessel). The event occurs during the daylight in good weather and calm seas. Table 5.5 relates the set-up components of the muster with the PSFs. This scenario was set up so that the PSFs were in their best possible condition (i.e. good weather, daytime, low severity muster, individual is highly experienced, work activity is routine).

Table 5.4 MO scenario description.

Component	Description
Situation	A person falls overboard resulting in the activation of the muster alarm
Muster person in question	A very experienced (15 year) operator who at the time of muster alarm is in the process units skimming a process vessel
Weather	The incident occurs in good weather and calm seas
Time of day	The muster is conducted during daylight hours
Location of muster initiator	The operator is on a different deck than the person who has fallen overboard. The operator does not see or hear the muster initiator

Table 5.5 MO scenario components and related PSFs.

PSF	Muster Scenario
Stress	• muster initiator is a man overboard • mustering individual is an operator who does not hear or see incident
Complexity	• muster initiator is a man overboard • job at time of muster is skimming a vessel
Training	• mustering individual has 15 years of offshore experience • mustering individual is an operator
Experience	• mustering individual has 15 years of offshore experience
Event Factors	• muster occurs during daylight hours • muster initiator occurs on a different deck
Atmospheric Factors	• muster event occurs in the summer with no wind and in calm seas

The mean ratings for all actions in the MO muster are shown in Figure 5.22. A low rating infers that the PSF is appraised to be poor (e.g. a stress rating of 0 indicates a very high stress level) while a high rating is regarded as being positive (e.g. a stress rating of 100 is equivalent to no stress).

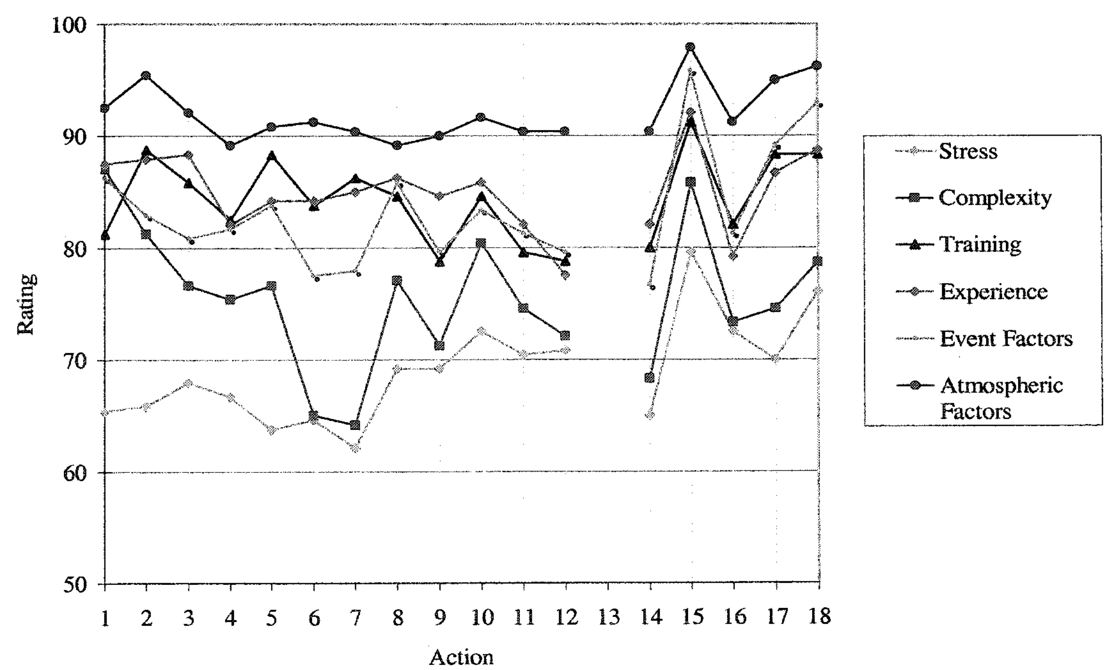

Figure 5.22 PSF ratings (MO).

Stress is rated the lowest among the PSFs. Stress levels are highest in the awareness and evaluation phase and begin to decrease through the egress phase. Stress is at its lowest level (i.e. high rating) during the recovery phase actions in the TSR. Both actions 6 (return process equipment to a safe state) and 7 (make workplace as safe as possible in limited time) were rated to be the most stressful of all actions.

These actions delay the start of egress and may generate higher stress levels because they are the most difficult of the sequence. Complexity increases from the point of alarm until the end of the evaluation phase. Once the egress phase begins, complexity ratings improve and peak once the TSR is achieved in action 15. The most complex actions are seen to be making the workplace safe and returning process equipment to a safe state. As local area tenability is not degrading, actions that are process related are seen to be the most complex (i.e. low complex rating).

Training is rated highly through the awareness and evaluation phases and falls off through the egress phase. Training is rated lowest at action 14 (assist others if needed or as directed) and highest for actions in the recovery phase. Despite the level of experience (i.e. 15 years), egress actions that involve decision making (i.e. 9, 11 and 12) are rated lowest of all actions. Once in the recovery phase, registering at the TSR is rated most highly among all muster actions indicating the high level of training associated with this action. Registering at the TSR is emphasized in muster drills, as it is crucial to have a proper and expedient count of all personnel to determine if there are any missing individuals. Muster training does not traditionally address the decision based actions in the egress phase and hence these are not highly rated.

Experience is rated highly (i.e. much experience) throughout the muster sequence and, like training, is rated lowest (i.e. little training) for the actions that require evaluation and decision making during the egress phase. These are rule-based actions (9, 11 and 12) in this muster scenario and are not difficult to complete successfully. Experience is most highly rated for action 15 (register at TSR). The event factors PSF is rated at over 75 throughout the muster event (a rating of 100 indicates no effect on action). There is little variance among the actions for this PSF as the scenario is set up such that there is little influence from the muster initiator. Atmospheric factors was rated the highest among all PSFs for this muster scenario. Essentially all actions are rated at over 90 indicating that the weather has little effect on muster actions.

5.9 Gas Release PSF Ratings Results

The GR scenario (Table 5.6) was setup such that all six PSFs were of lower quality than the MO scenario. The muster sequence occurred during the day in less than optimal weather conditions. The mustering individual has notable but not extensive experience (i.e. three years) and is changing filters on a solids removal unit at the time of muster initiation. The muster event is a gas release which occurs on the same deck as the operator, thus providing a heightened level of danger. Table 5.7 relates the components of the muster with the PSFs.

Table 5.6 GR scenario description.

Component	Description
Situation	A hydrocarbon gas release in the process units
Muster person in question	An experienced (three years) operator who at the time of muster alarm is changing filters in a solids removal unit
Weather	The incident occurs in cold, wet weather
Time of day	The muster is conducted during daylight hours
Location of muster initiator	The operator is on the same deck as the gas release

Table 5.7 GR scenario components and related PSFs.

PSF	Muster Scenario
Stress	• muster initiator is a gas release • mustering individual is on the same deck as the gas release
Complexity	• muster initiator is a gas release • job at time of muster is changing filters on a solids filter
Training	• mustering individual has three years of offshore experience • mustering individual is an operator
Experience	• mustering individual has three years of offshore experience
Event Factors	• muster occurs during daylight hours • muster initiator occurs on the same deck
Atmospheric Factors	• muster event occurs in the winter with some wind and it is raining

The mean ratings for all actions in the gas release muster are shown in Figure 5.23. Stress quickly drops (rating of 0 is highly stressed) from the detection of the alarm through the awareness, evaluation and egress phases. In the recovery phase actions, the stress rating sharply increases - indicating that once the TSR is achieved, stress levels are greatly reduced. Stress levels peak for actions 7 (make workplace as safe as possible in limited time) and 12 (choose alternate route if egress path is not tenable). Action 7 is an action that delays the start of egress and extends the time spent in the evaluation phase. If this action is not completed and the egress paths are impeded, the effect on others is detrimental and increases the time before the total platform complement has safely mustered. This may hinder the expediency of a potential evacuation.

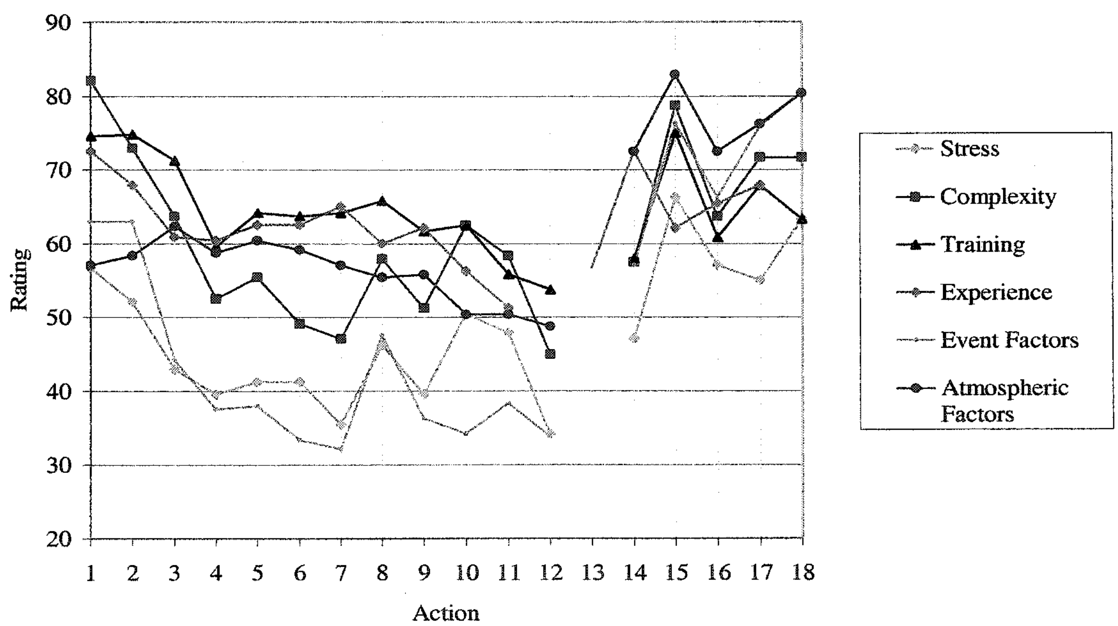

Figure 5.23 PSF ratings (GR).

As with stress, complexity starts at a low level at muster initiation (i.e. a high complexity rating) and degrades quickly through the first three phases of the muster, recovering for the actions that take place in the TSR. Complexity was rated to be highest (i.e. low rating) for action 12 (choose alternate route if egress path is not tenable) in the egress phase. The flexibility of alternate routes is limited on offshore platforms and depending on the individual's location at the time of muster; there may be few options to choose from for an egress path. If the TSR is not achievable, an alternate safe haven must be chosen. This can be an escape site that permits evacuation to the sea. These types of locations are generally open to the environment and may not be situated behind a blast wall. The surroundings of such an area are generally not protected from the effects of the muster initiator, and it is therefore not a desirable location to muster.

Training ratings decrease through the awareness, evaluation and egress phases. Training was rated lowest (i.e. poor training) for action 12. Again, this decision-based action of choosing another egress route was rated poorly, as muster training drills do not focus on this decision making step. Consistent with expectations actions that are outside the routine muster drills (i.e. 4, 11, and 12) have lower ratings than other actions. During a drill, evaluation and decision making are not required at any significant level. Skill and rule-based behaviour govern because unconscious type behaviour dominates during muster exercises. This makes these actions more difficult to complete successfully in a degraded scenario.

Ratings for experience decline through the first two phases. As with the other PSFs in this scenario, experience is rated lowest in assessing the quality of the egress path and choosing an alternate route if needed. Experience in conducting such actions would be limited despite the relevant amount of experience for the operator. Event factors were rated lowest of all PSFs through the evaluation and egress phases. This scenario places the operator at risk as the gas release occurs on the same deck as the individual. This presents a possibility that the individual's local environment may be degrading and that the escaping gas is blocking egress paths. The effect of event factors increases at action 3 (act accordingly) and remains significant through the evaluation and egress phases. The event factors of the gas release have potentially degraded the tenability of the surroundings, reducing the chance of being successful in all actions that are performed outside the safe refuge.

The atmospheric factors set up in this muster scenario were not optimal as the event occurred in winter conditions. Risk from ice on the deck and cold weather effects make physical actions more difficult as dexterity is reduced (Rohles and Konz, 1987). This PSF was the only factor that was ranked lower at muster initiation and improved through the awareness phase as the winter conditions may affect one's ability to detect the muster alarm. The effects from weather are relatively constant through the evaluation phase but degrade throughout the egress phase.

The ratings associated with atmospheric conditions are highest in the recovery phase. Though protected from the weather once in the TSR, effects are not eliminated because individuals who are cold and wet are likely to have increased difficulty with donning their TSR survival suits. This procedure can be very awkward because the suits are a "one-size-fits-all" design and they limit the ability for free hand movement.

5.10 Fire and Explosion PSF Rating Results

The F&E scenario (Table 5.8) was set up so that the muster sequence occurred during the night time in very poor weather conditions. This is the most severe of the three muster events. The mustering individual has little offshore experience (i.e. six months). The muster event is a fire and explosion which occurs on the same deck as the operator, providing an extreme level of danger. The fire and explosion (F&E) scenario

Table 5.8 F&E scenario description.

Component	Description
Situation	A fire and explosion in the process units
Muster person in question	An inexperienced (six months) operator who at the time of muster is in the process units working valves to isolate a vessel
Weather	The incident occurs during a winter storm
Time of day	The muster is conducted during night time hours
Location of muster initiator	The operator is on the same deck as the fire and explosion

provided the most significant issues during the muster scenario because of the nature of the incident and the location of the individual at the time of muster initiation. Table 5.9 relates the components of the muster with the six PSFs. There is considerable potential for a direct effect on the operator's surroundings, lowering the tenability of their environment.

Table 5.9 F&E scenario components and related PSFs.

Relevant PSF(s)	Muster Scenario
Stress	• muster initiator is a fire and explosion • mustering individual is an operator who is in close proximity to the muster initiator
Complexity	• muster initiator is a fire and explosion • job at time of muster is in the process units working valves to isolate a vessel
Training	• mustering individual has six months of offshore experience • mustering individual is an operator
Experience	• mustering individual has six months of offshore experience
Event Factors	• muster occurs during the nighttime • muster initiator occurs on the same deck
Atmospheric Factors	• muster event occurs during a winter storm

The mean ratings for all actions in the fire and explosion muster are shown in Figure 5.24. Stress was rated low (i.e. high stress) at the beginning of the muster incident and improves through the awareness and evaluation phases. The stress associated with the actions of returning the process equipment to a safe state and making the workplace safe are rated lowest (i.e. highest stress)`. Stress levels were rated more favourably as the egress phase is entered but fall sharply at action 12 (choose alternate route if egress path is not tenable). If this action was required, the implication is that the situation in this area of the platform has degraded significantly. Stress ratings are more favourable for the actions that take place in the TSR, although a high level of stress is still associated with these tasks.

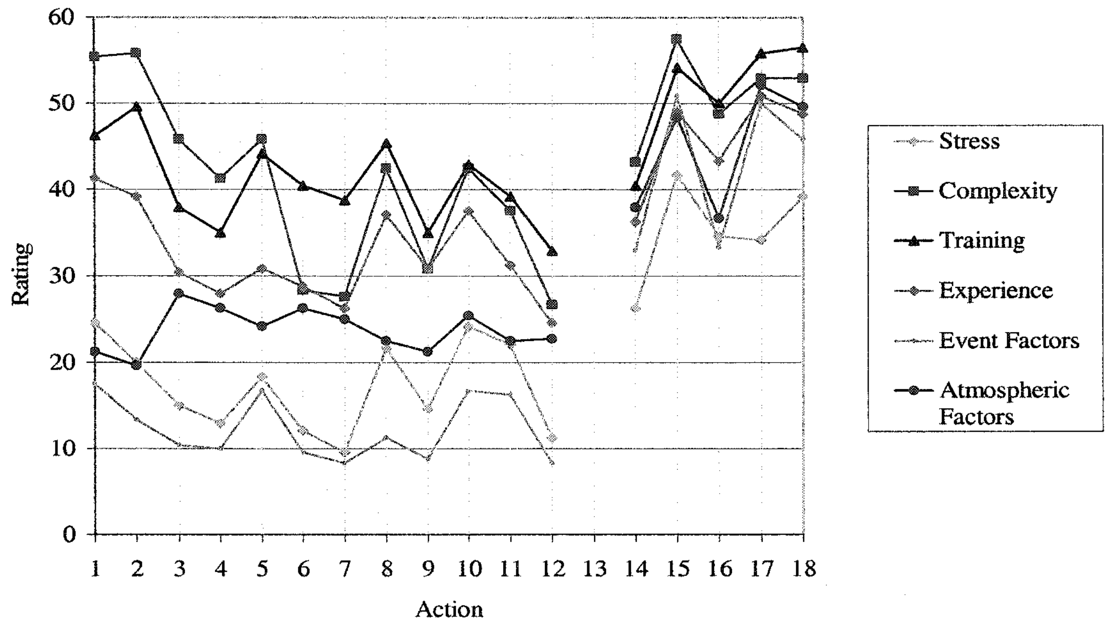

Figure 5.24 PSF ratings (F&E).

Complexity was rated highest (i.e. least complex task) among all PSFs at muster initiation. In this scenario the detection and identification of the alarm is not crucial to the initiation of muster actions. The event factors will provide an instigation to muster prior to the activation of the alarm. Complexity ratings degrade through the evaluation and egress phases. Complexity is highest (i.e. lowest rating) for actions 6 (return process equipment to safe state), 7 (make workplace as safe as possible in limited time), and 12 (choose alternate route if egress path is not tenable).

The ability to correctly choose an alternate egress path under adverse conditions can be difficult as time pressures increase. A decision not to move to the TSR may be forced and an alternate safe refuge required. In the event of entrapment, escape to the sea may be the only choice that provides an opportunity for survival. Escape to the sea can be performed by climbing down a platform leg to the sea floor and jumping, controlled descent by rope and harness, or by simply jumping. The technique for jumping to sea is taught as a component of the prerequisite survival training of all personnel working on platforms in the North Sea (U.K.) and Canada. A jump to sea (typically over one hundred feet) without a survival suit presents risk from impact and from cold water shock.

Weak ratings (i.e. low rating value) were given for training in decision based actions in the first three phases of muster. Training was also rated low in the evaluation phase for actions 6 (return process equipment to safe state) and 7 (make workplace as safe as possible in limited time). These physical actions are rated low as the mustering individual will have had limited training in six months of experience. Under the adverse conditions of a fire and explosion, an individual's uncertainty is likely to increase. Progress during the egress phase may be impeded and the ability to determine the tenability of an escape path may be more instinctive than knowledge-based without extensive training. The ability to make a reasonable diagnosis to generate a correct decision is likely difficult. As uncertainty increases, individuals tend to become poor judges of probability. Decision making can become biased through an over- or under-estimation of the likelihood of certain events occurring or the estimation of the quality of an egress route (Wickens, 1987). An individual with a low level of training is more likely to be a poor decision maker because their uncertainty will be high. The ratings, as with all PSFs, improved in the recovery phase.

Guidance through PA announcements is beneficial in helping to choose egress routes and avoid dangerous areas of the platform. If the PA announcements are contradictory, the result can be more confusion. If PA announcements during drills are not clear, a bias may be formed to ignore this support. This type of response is also found in the evacuation of buildings, where contradictory PA announcements provided confusion to a mustering population (Proulx, 1999). In Proulx's work, debriefing of individuals involved in a 25-storey building fire revealed that this bias had developed. Many individuals stated they would ignore future PA announcements because risk was increased by following the directions given during the building fire. The high frequency of offshore muster drills provides ample opportunity to form strong biases that may influence an individual's willingness to follow direction via PA announcements. In the event that poor direction is provided during muster drills, debriefing of personnel is useful in recognizing the errors and the actions needed to correct them. It is a recovery tool that provides valuable feedback on performance and can help restore confidence in the muster procedure.

Muster training should be geared to generate errors so that weaknesses in critical areas (i.e. early recognition, accurate evaluation, quick access to egress route, and efficient travel to TSR) can be discovered prior to real events. Observation of personnel during training is essential in areas where error promotion is generated (e.g. blocking access to the accommodations module on one of the production decks). Observation of muster sequences has been adopted and documented for onshore buildings providing valuable data on muster times under various muster scenarios (Ashe and Shields, 1999).

The experience of the mustering individual is minimal at six months. The actions that were rated highly (i.e. much experience) are those that are practiced in all muster drills, namely detect alarm, identify alarm, listen and follow PA announcements and move along egress path. Actions in the recovery phase are rated highest, although there is a significant drop for action 16 (provide pertinent feedback). The operator's low level of experience may not permit the recognition of important facts while enroute to the TSR. The low ratings in the evaluation and egress phases are dominated by actions that are both physical (i.e. make workplace as safe as possible in limited time) and decision based (i.e. choose alternate route if egress path is not tenable). The operator was deemed likely to have limited experience in these actions.

While inexperienced operators may be somewhat restricted in their work activities during an early stage of their career, muster training regimes should be formulated to recognize these individuals as being at high risk and requiring guidance in the event of a severe muster. Individuals can be made distinguishable through a specific color of hard hat or coverall. If the individual works in the accommodations module (i.e. cook, housekeeper) their work cloths can also be made distinguishable from experienced co-workers. The recognition of the complement's experience level is an ongoing metric that can be managed through the setup of shift rosters that maintain a low concentration of inexperienced personnel at any one time.

Event factors (e.g. smoke, heat) were rated the lowest (i.e. poor) among all PSFs through the first three phases of F&E muster and hence have a large effect on those actions. The ability to complete actions in these phases is significantly influenced by the tenability of the immediate surroundings. As fire and explosion is regarded as the most severe of all possible muster scenarios, early detection and protection systems are critical to surviving such incidents.

Atmospheric factors in this scenario were rated consistently low (i.e. poor weather conditions) among all actions preceding the recovery phase. The winter storm in this scenario can make egress actions difficult due to snow and ice and reduced visibility. The ability to ascertain egress route quality may be diminished because areas may be partially hidden under snow or ice. Under severe weather conditions, the OIM may restrict personnel to the accommodations module, thereby limiting the exposure of individuals in the event of a muster.

The following section compares the PSFs ratings by SRK behaviour. This is similar to the previous SRK analysis given for the PSF weights.

5.11 PSF Ratings Defined by SRK Behaviour

This section compares the PSF ratings against each action's mode of operation (i.e. skill, rule and knowledge). The PSF ratings for the man overboard scenario as defined by the SRK classification are given in Figure 5.25. There is no clear difference in rating between skill, rule and knowledge-based tasks for the man overboard scenario except for actions 6 and 7 (return process equipment to safe state, and make workplace as safe as possible in limited time). These actions have been classified as rule-based because the muster conditions would not place an individual in an unfamiliar circumstance, and the muster events do not adversely affect the ability of the individual

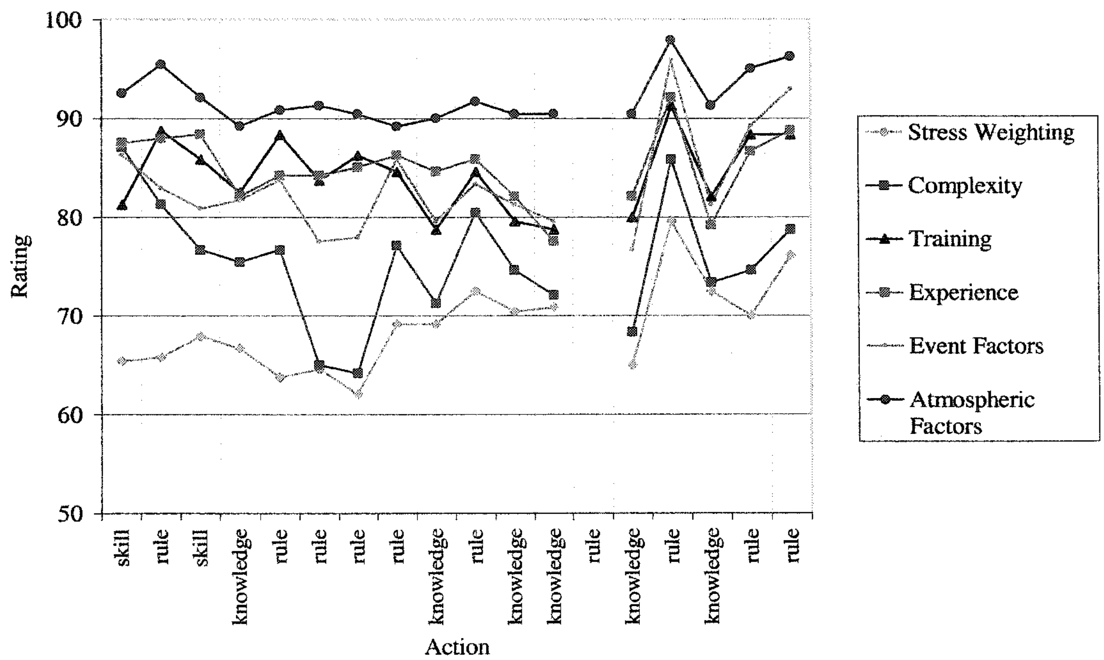

Figure 5.25 PSF ratings described by SRK behaviour (MO).

to complete the tasks. Although the lower ratings might imply a knowledge-based mode of behaviour, the ratings for these actions are still relatively high when compared to the other muster scenarios.

In general, the conditions of this muster are good (i.e. rated highly) for all PSFs through all phases of the MO scenario. The GR and F&E scenarios, Figures 5.26 and 5.27, respectively, show a clear trend to lower ratings for the knowledge-based tasks which predominate actions 6 through 12 in the evaluation and egress phases. As muster severity increases, knowledge-based actions dominate in the first three muster phases as circumstances become unfamiliar and actions become more complex. PSF behavior modes in the recovery phase do not vary with muster severity.

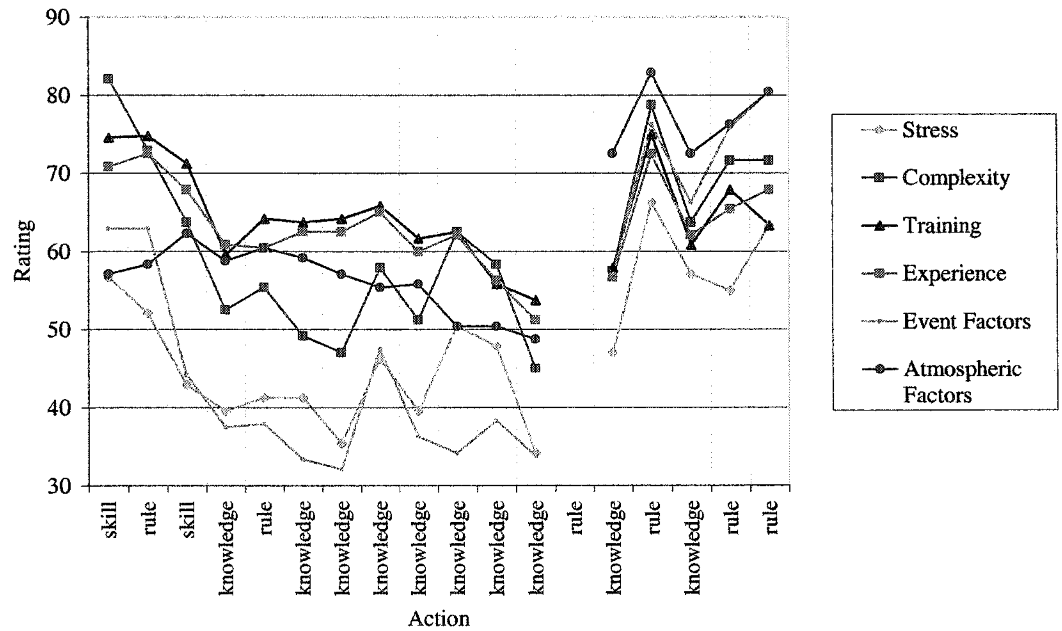

Figure 5.26 PSF ratings described by SRK behaviour (GR).

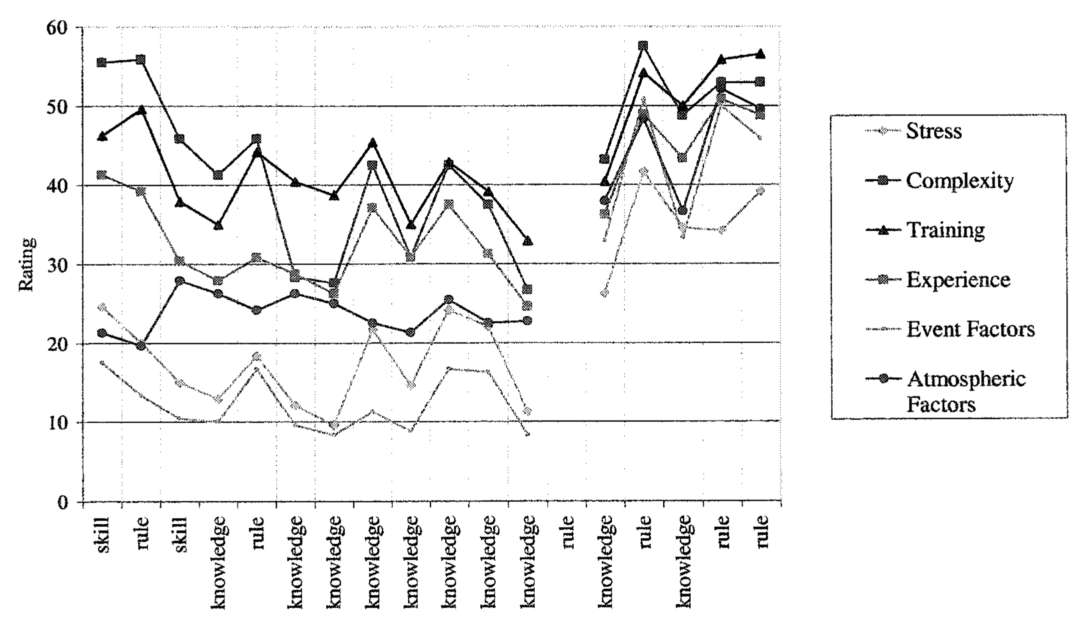

Figure 5.27 PSF ratings described by SRK behaviour (F&E).

The actions in the TSR retain their SRK designations through all muster scenarios because event factors have less of an influence once in the safe refuge. The ratings noticeably improve for the TSR actions in the GR and F&E scenarios. The knowledge-based actions show a decline in PSF rating for all three scenarios.

The following section compares the PSF ratings between the three muster scenarios to determine the degree to which the muster scenarios influence PSF ratings.

5.12 Comparison of PSF Ratings between Muster Scenarios and ERT Subgroups

In this section the PSF ratings are compared between muster initiators. Unlike the elicited PSF weights, there is a clear separation of results between these muster scenarios. In all cases, MO is rated highest across all actions followed by GR with F&E rated the lowest as the most severe muster scenario. All PSFs show an improved rating in the recovery phase actions.

The range in PSF ratings (RIR) (i.e. highest rating – lowest rating) for any muster is a measure of the influence of the muster scenarios and the individual's skill on the probability of completing the actions successfully. The range in PSF ratings is discussed for each muster setting. To reflect the differences between the three muster conditions, the MO ratings are subsequently normalized by dividing them by the GR and F&E ratings. The larger the ratings ratio, the greater is the difference in PSF ratings. The closer the ratio value is to unity, the more similar are the PSF ratings. This form of comparison was not conducted for the PSF weights because there was little difference between the weights based on muster scenario, except for event factors.

In the MO scenario, stress ratings (Figure 5.28) show an upward (improving) trend through the awareness, evaluation and egress phases, indicating that stress levels are decreasing (i.e. high rating values) as the individual nears the TSR. In the GR and F&E scenarios, stress ratings decrease sharply from the time of muster alarm through the evaluation phase and then fluctuate in the egress phase before falling off at action 12 (choose alternate route if egress path is not tenable). The more severe muster scenarios

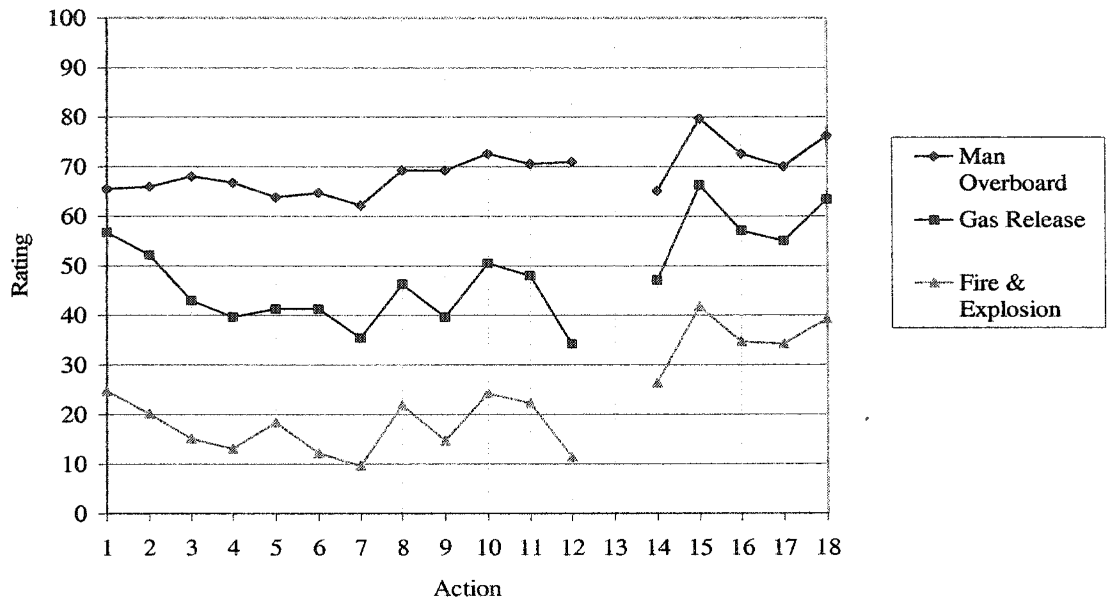

Figure 5.28 Comparison of stress ratings for all three muster scenarios.

(i.e. GR and F&E) exhibit a different rating trend (a sharp decrease in PSF ratings for actions 9, 11 and 12) in the egress phase due to the more difficult knowledge-based actions. The remaining PSFs in Figures 5.29 to 5.33 show similar trends through all muster actions, with the F&E scenario showing a higher degree of rating variability from action to action when compared to the MO and GR scenarios.

Complexity rating trends (Figure 5.29) vary in a similar fashion between the muster scenarios throughout the muster sequence. The range of complexity ratings is greatest for the GR scenario (range of 37) from actions one through twelve. The comparable rating ranges for MO and F&E are 20 and 26, respectively. The ratings for training (Figure 5.30) do not vary significantly between muster initiators. The range-in-ratings (RIR) for GR is greater than MO and F&E, at 20, 9 and 17, respectively. Experience ratings (Figure 5.31) exhibit similar trends to training and again show a higher variability, with a GR RIR of 21 versus an RIR for MO and F&E of 11 and 16, respectively.

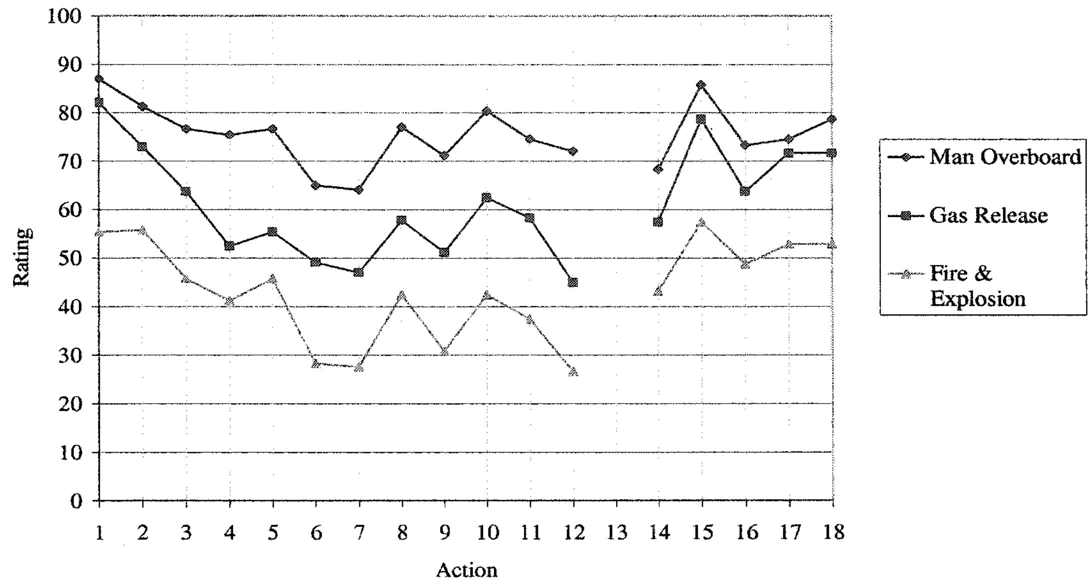

Figure 5.29 Comparison of complexity ratings for all three muster scenarios.

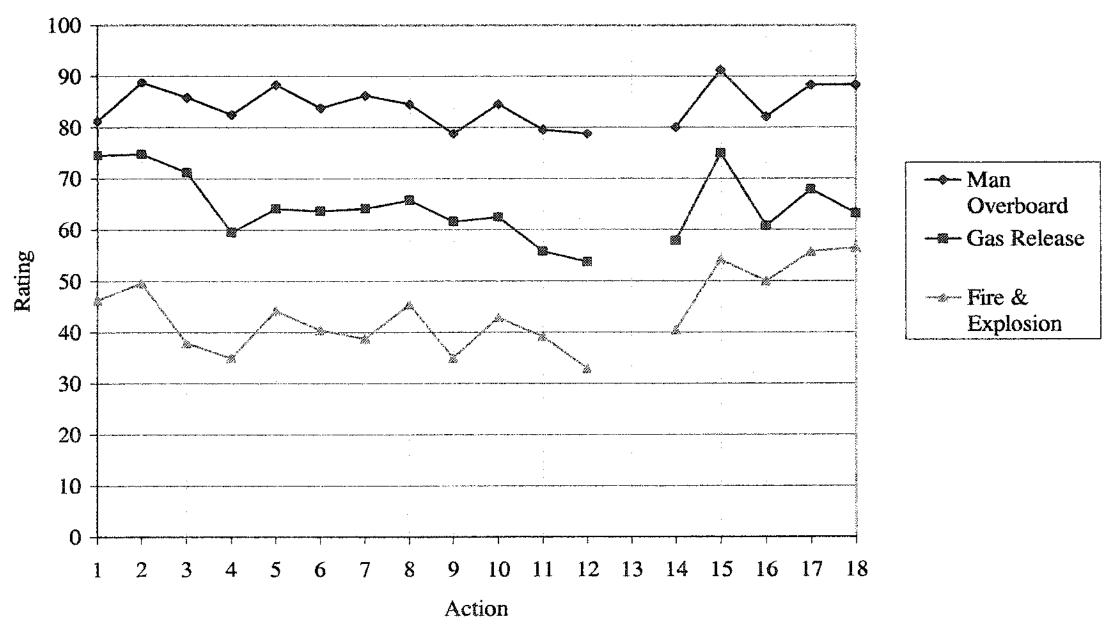

Figure 5.30 Comparison of training ratings for all three muster scenarios.

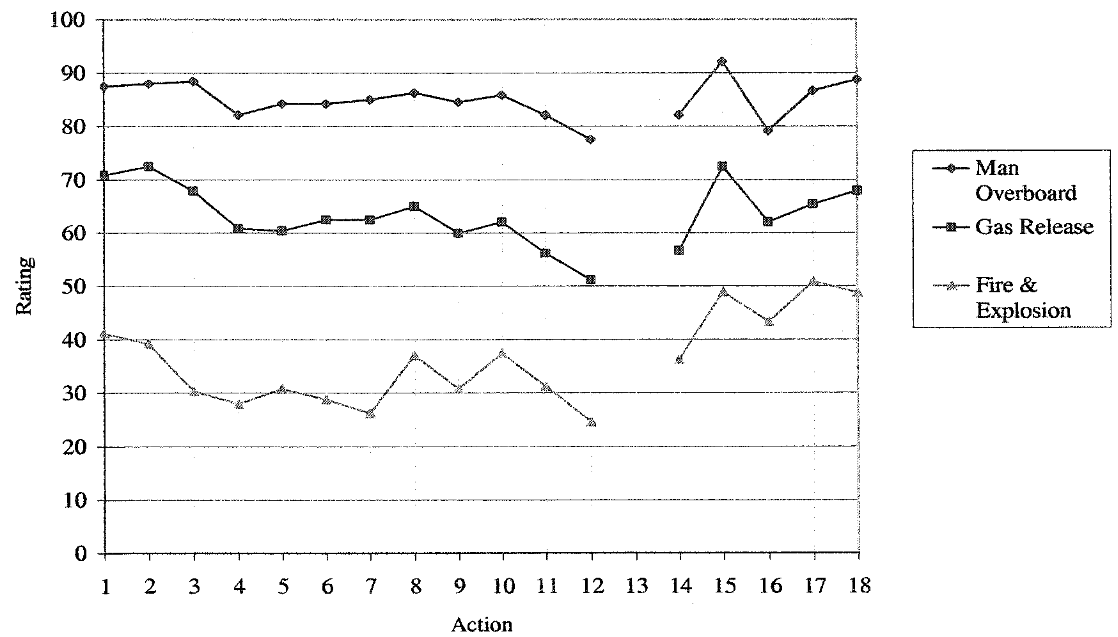

Figure 5.31 Comparison of experience ratings for all three muster scenarios.

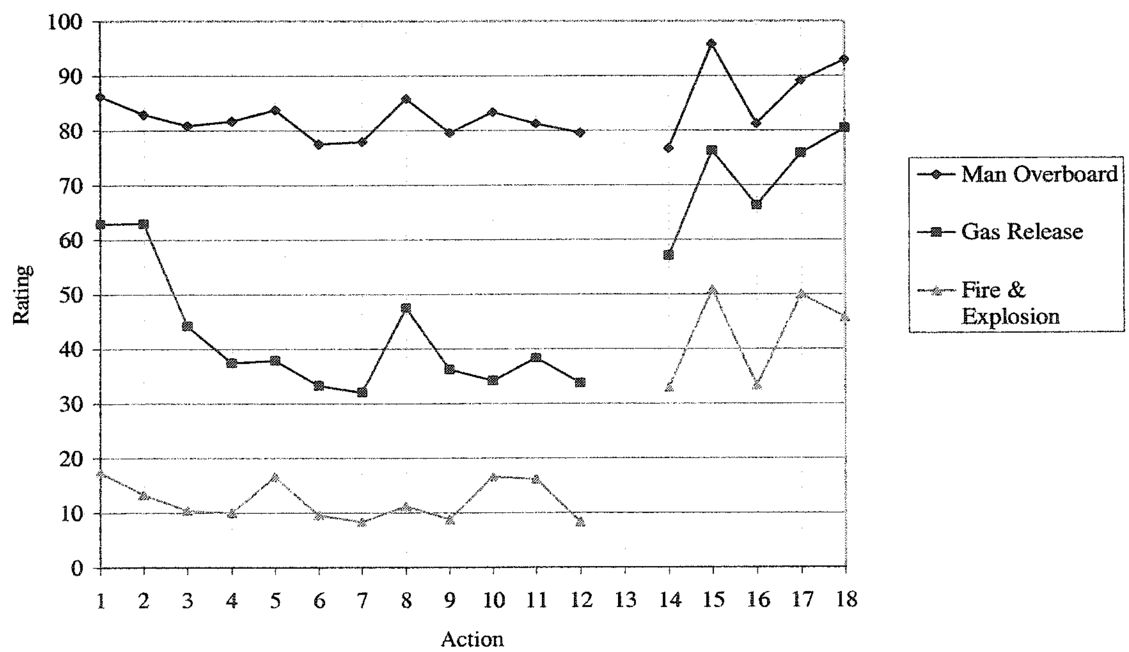

Figure 5.32 Comparison of event factors ratings for all three muster scenarios.

Event factors (Figure 5.32), interestingly, show a unique rating trend among the muster scenarios. There is little variation in ratings for the MO and F&E scenarios through the awareness, evaluation and egress phases. The GR scenario shows a higher degree of rating variability with an RIR of 39 versus an RIR of 10 for both the MO and F&E. This is expected as these two scenarios (MO and F&E) represent the muster extremes (MO is the most benign of the credible scenarios and F&E the most severe). In the former case, event factors are almost inconsequential, providing little risk to individuals, while the latter scenario provides overwhelming danger and can make the best efforts to muster less influential on the likelihood of success. Efforts to limit human error during a muster are most meaningful for events that generate circumstances where there is significant risk but also where human efficiency and reliability can overcome the effects of the muster initiator in the first three phases of the muster sequence where survivability is most at risk.

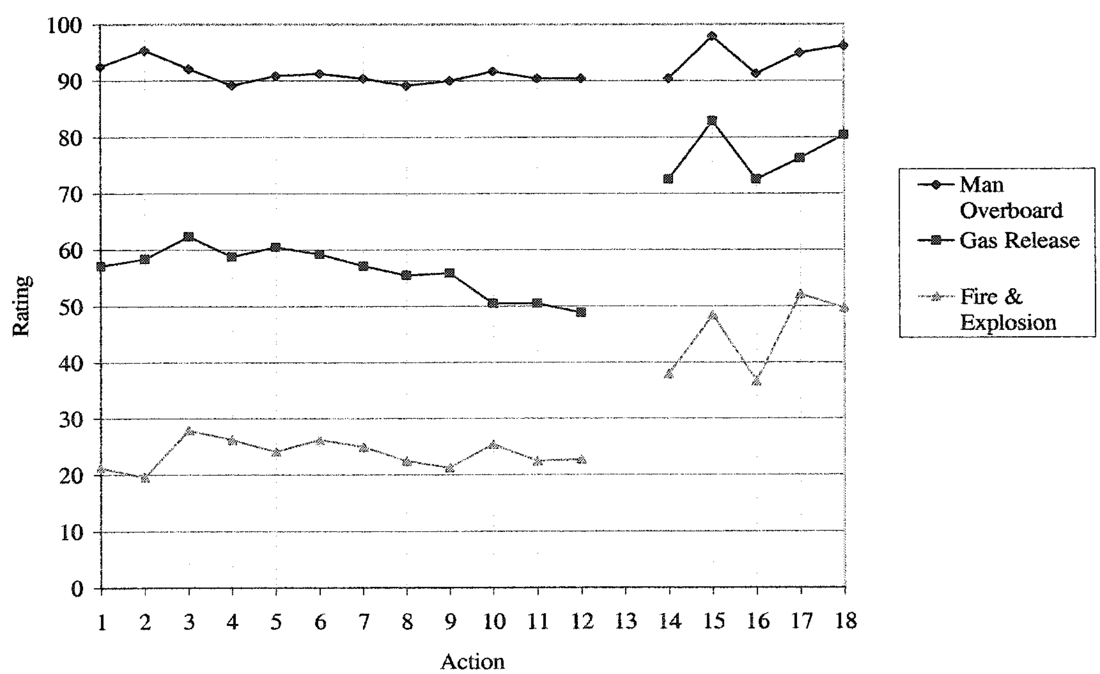

Figure 5.33 Comparison of atmospheric factors ratings for all three muster scenarios.

Atmospheric factors (Figure 5.33) provide the least variability between muster actions across all muster scenarios. The MO RIR is 5, while the F&E RIR is 8 and the GR RIR is 13. Again, the GR scenario shows the highest degree of rating variability among the groups.

The relative MO to GR ratings (MOGR) ratios shown in Figure 5.34 are near unity for all PSFs except for event factors. The MOGR ratio varies from 1 to 1.8 through all muster phases for the PSFs of stress, complexity, training, experience and atmospheric factors. The MOGR ratio for event factors is very different through actions 3 to 12, which encompass part of the awareness, evaluation and egress phases. The MOGR ratio for this PSF is greatest in the evaluation phase, peaking at nearly 3 at action 7 (make workplace as safe as possible in limited time) and then decreasing to an average of 2 through the egress phase and returning to within the range of the other PSFs at action 14 (assist others if needed or as directed).

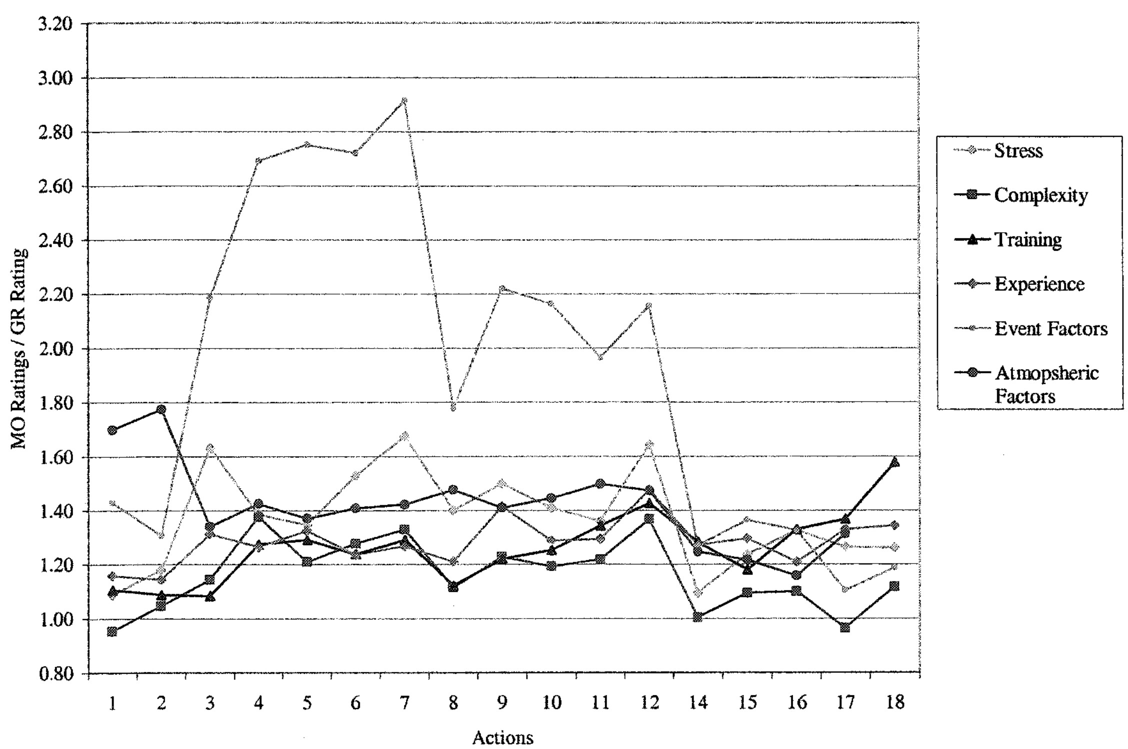

Figure 5.34 MO ratings relative to GR ratings.

The relative MO to F&E ratings (MOFE) ratios are shown in Figure 5.35. The PSFs of complexity, training and experience have similar MOFE ratios ranging from 1.2 to 2.5 through all four muster phases. Atmospheric factors have a distinctly higher range at 2.2 to 3.7, while stress ranges from 1.7 in the recovery phase to 5.1 in the evaluation phase. The MOFE ratio for event factors has the widest range of results (1.7 to 7.1) and the greatest level of variability, exhibiting large swings from action to action in the first three muster phases. The magnitude of MOGR and MOFE ratios provides a clear measure of the difference in PSF ratings for each muster scenario

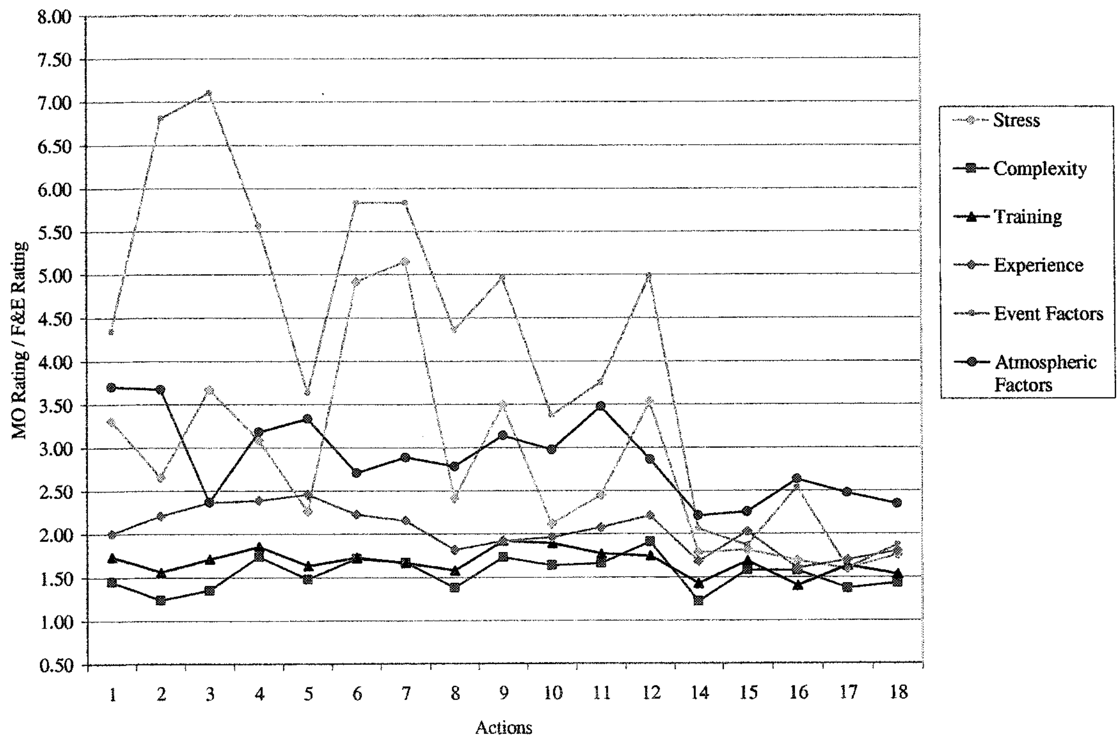

Figure 5.35 MO ratings relative to F&E ratings.

Fluctuations in the MOGR and MOFE ratios provide a measure of how the GR and F&E scenarios influence the muster actions. F&E influences are significantly greater than GR, but also show more variation. The F&E scenario shows three distinct peaks at actions 3 (act accordingly), 6 (return process equipment to a safe state) and twelve (choose alternate route if egress path is not tenable). It is difficult to maintain composure, effect physical motion and make decisions in this scenario because of the event factors and the individual's lack of training and experience.

A check was conducted to determine if any of the major subgroups of the ERT deviated significantly and consistently from the other subgroups across all three muster types. As with PSF weights, the average rating for the various ERT subgroups are compared in Figures 5.36 to 5.38. No subgroup showed a consistent deviation in

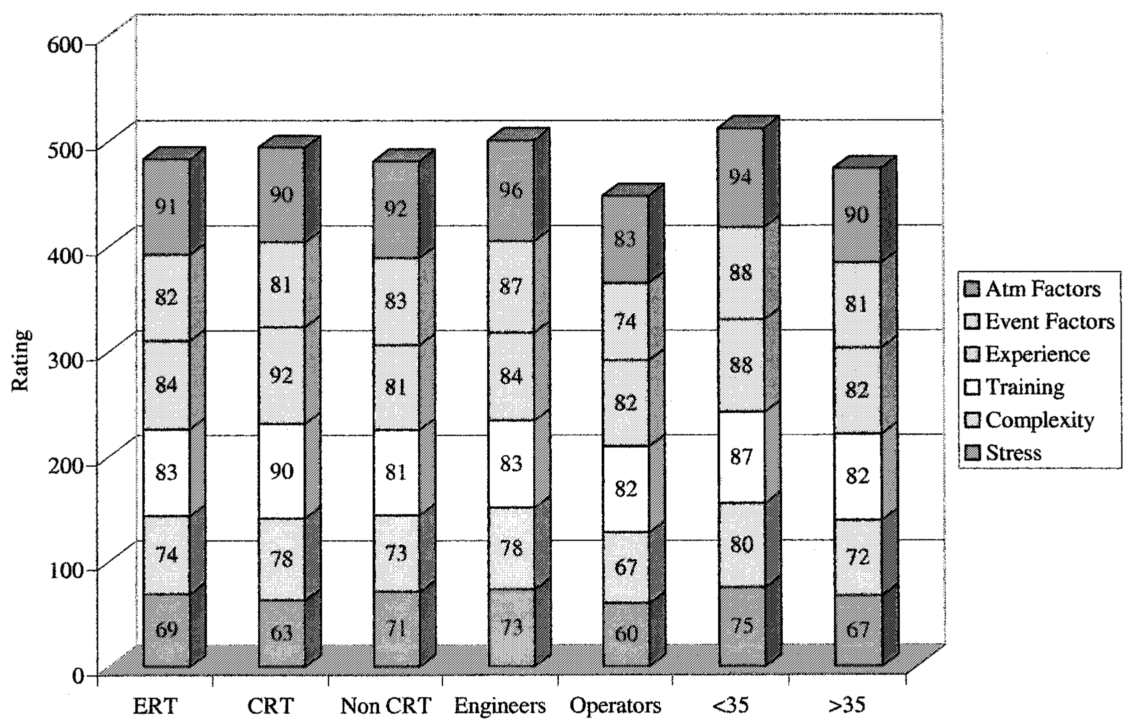

Figure 5.36 Comparison of PSF ratings by ERT subgroup (MO).

ratings from the other subgroups across all three muster scenarios. The Operators group provided the lowest total rating (420) of the subgroups. Operators rated complexity, event factors and atmospheric factors lower than the other groups for the man overboard scenario.

The CRT's total rating for the gas release muster was the lowest among the groups at 320, with a noticeably average lower rating (49) for atmospheric factors. The <35 group provided the most notable deviation among the subgroups for the F&E muster. The average ratings for event factors (15) and atmospheric factors (20) are lower than the

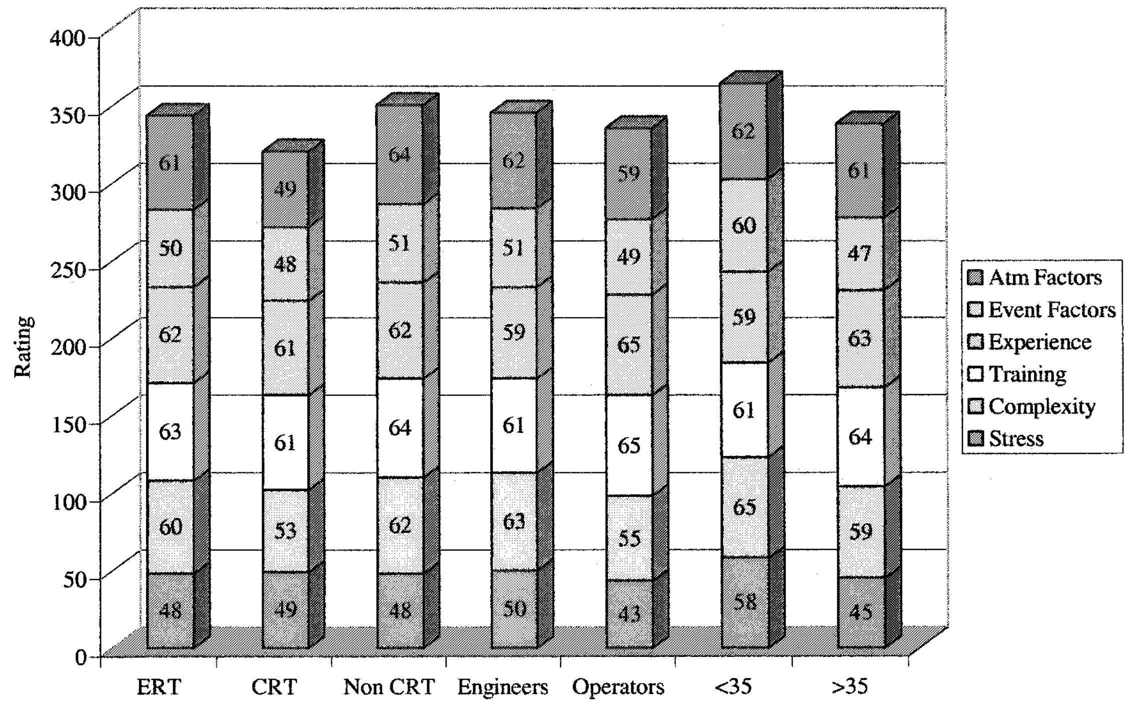

Figure 5.37 Comparison of PSF ratings by ERT subgroup (GR).

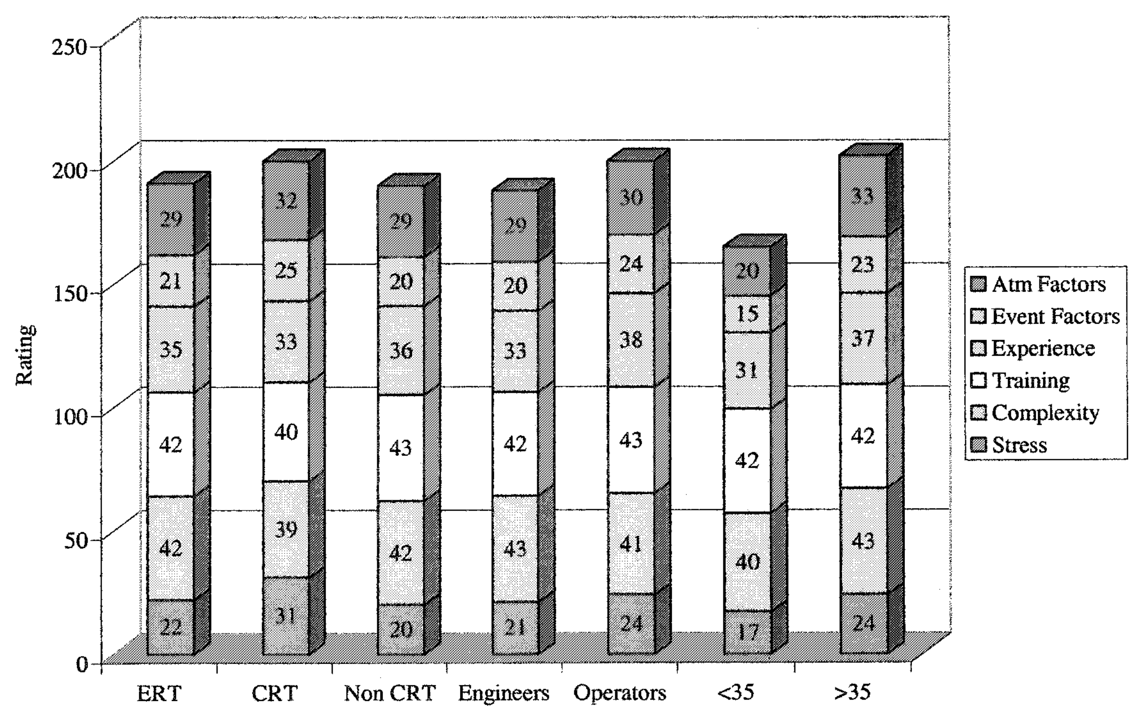

Figure 5.38 PSF ratings by ERT subgroup (F&E).

average ratings among the other subgroups. The total of the PSF ratings for each subgroup does decrease as muster severity increases, showing a consistent understanding of the rating process.

The next section gives the results of a statistical analysis of the PSF ratings. The ANOVA experiments check the effects of muster scenario and muster actions on PSF ratings.

5.13 Statistical Analysis of PSF Rating Data

As just discussed, the rating data show that the muster scenarios have a clear effect on the PSF ratings; as muster severity increases, the ratings notably decrease. Before conducting the ANOVA work, the normality of the rating data was checked for various actions through the use of normal probability charts (Figures 5.39 to 5.41). As with the weight data, the ratings data are not perfectly normal and show some asymmetry. As mentioned previously, the sample populations were relatively large so that deviations from normality do not have a significant effect on the validity of the ANOVA results. This was checked through a non-parametric Kruskal-Wallis (KW) test for one of the ANOVA results (highlighted in red) given in Table 5.10. The KW confirmation of the ANOVA test is shown in Table 5.11.

The ANOVA results for action 1 in Table 5.10 confirm the significant effect the muster scenario has on all six PSF ratings. The Kruskal-Wallis test confirmed the ANOVA result with a very strong rejection of the null hypothesis. ANOVA experiments were performed for the remaining muster actions; similarly strong rejections of the H_o (that muster initiators have no effect on PSF ratings) were determined. These results can be found in Appendix G.

Table 5.12 provides a summary of the ANOVA results to determine if the muster actions affected the PSF ratings for the MO scenario. The ANOVA results for the GR and F&E scenarios are also found in Appendix G. The null hypothesis, H_o (muster actions have no effect on PSF ratings) is accepted for the MO scenario for all PSFs except complexity and event factors. The ANOVA results show a weak rejection (*reject*)

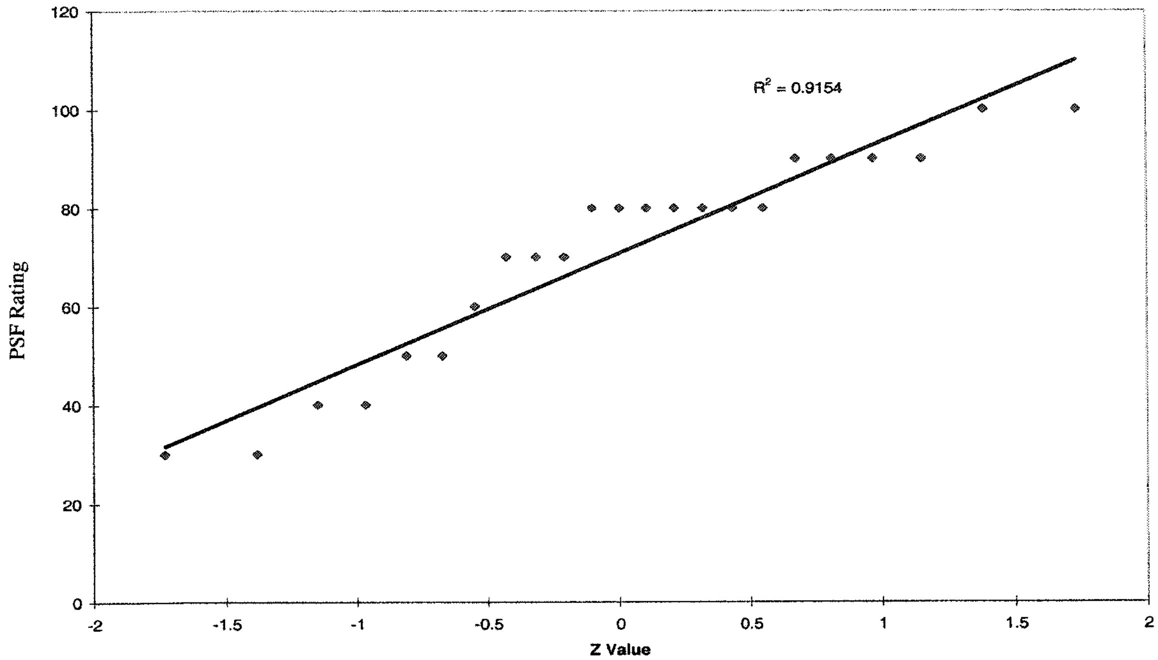

Figure 5.39 NPC for complexity ratings, action 9 – evaluate potential egress paths and choose route (MO).

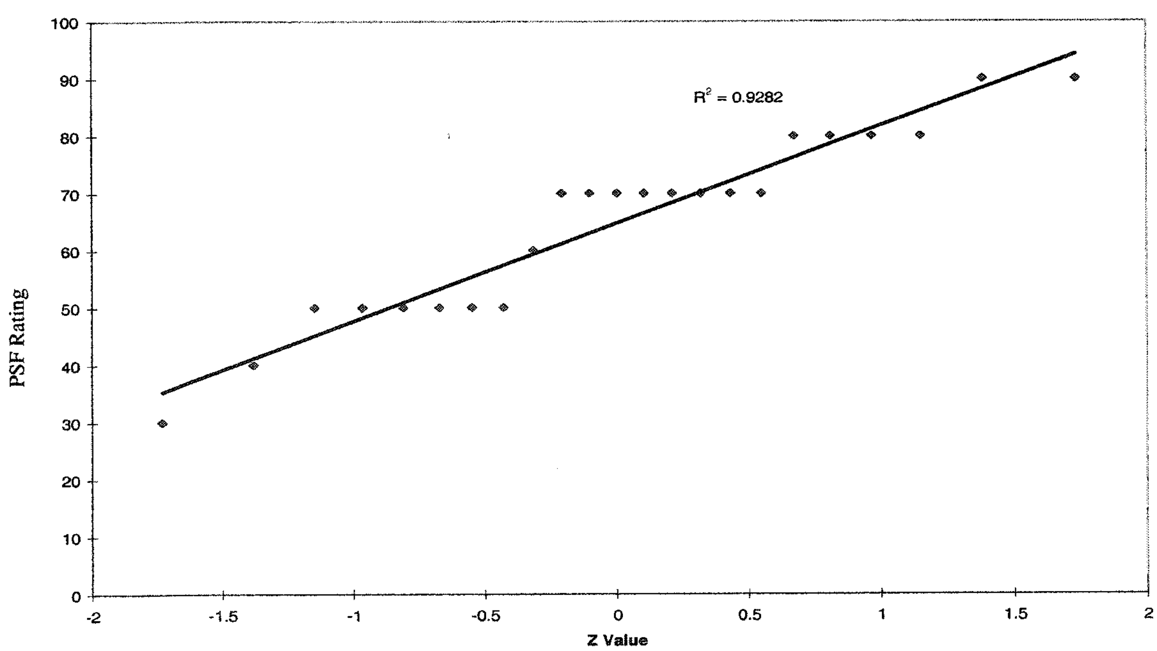

Figure 5.40 NPC for training ratings, action 5 – muster if in imminent danger (GR).

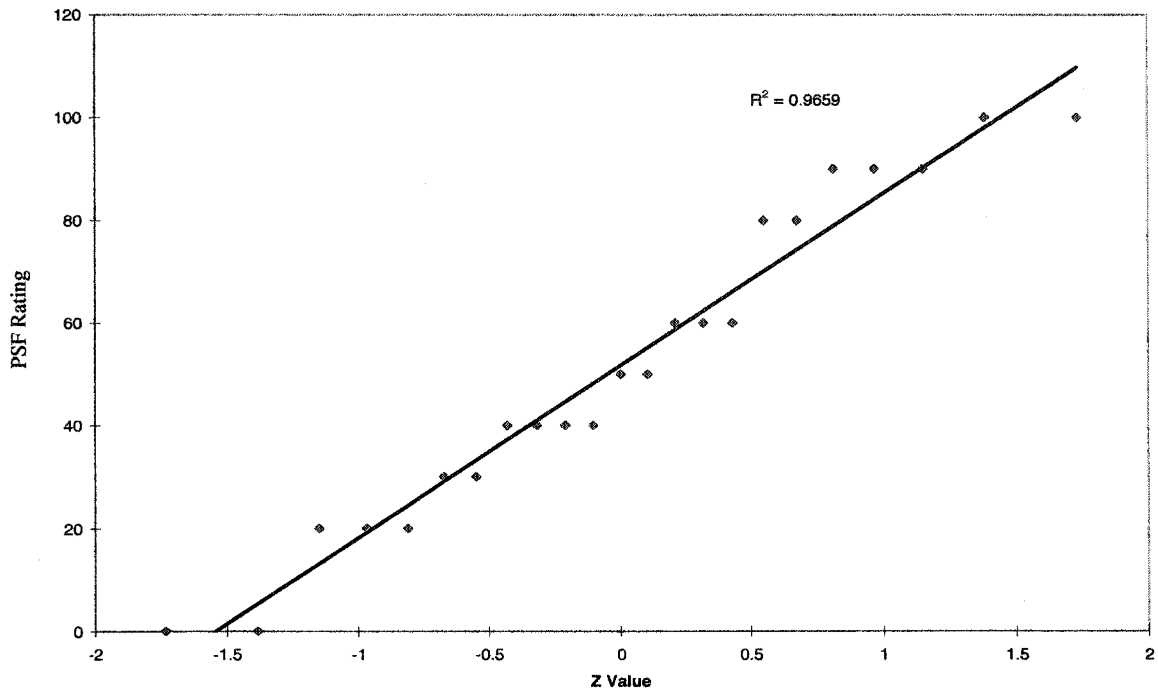

Figure 5.41 NPC for training ratings, action 15 – register at TSR (F&E).

of the H_0 for these two PSFs. As the MO scenario presents near optimal conditions (i.e. low stress, highly trained, good weather) for all PSFs, these results are not unexpected. For example, stress levels are rated equally for actions inside and outside the TSR as risk (e.g. potential for injury) levels are essentially the same for all tasks.

ANOVA tests for the GR and F&E scenarios resulted in strong rejections (**reject**) of H_0. Under these scenarios the PSFs are less than optimal (i.e. high stress, high complexity, low experience, poor training, deleterious event factors, poor weather). Under these conditions the ANOVA results show that the PSFs are rated differently among the muster actions. That is, for more severe muster scenarios, the PSFs' ratings vary significantly among the various muster actions.

Table 5.10 Effect of muster severity on action 1 ratings.

Action 1 – detect alarm (H_o = muster severity has no effect on PSF ratings, α = 0.05)					
Test no.	**PSF**	**ANOVA**			
		F	**F_c**	**P-Value**	**Result**
1a	stress	12.28	3.13	$2.74*10^{-5}$	**reject**
1b	complexity	10.69	3.13	$9.02*10^{-5}$	**reject**
1c	training	13.54	3.13	$1.09*10^{-5}$	**reject**
1d	experience	26.49	3.13	$2.90*10^{-9}$	**reject**
1e	event factors	44.48	3.13	$3.9*10^{-13}$	**reject**
1f	atmospheric factors	53.88	3.13	$8.05*10^{-15}$	**reject**

Table 5.11 Comparison of ANOVA and KW results for effect of muster severity on action 1 ratings.

ANOVA (H_o = muster severity has no effect on PSF ratings, α =-0.05)					
Action	**PSF**	**F**	**F_c**	**P-Value**	**Result**
1	training	13.54	3.13	$1.09*10^{-5}$	**reject**
Kruskal-Wallis (H_o = muster severity has no effect on PSF ratings, α = 0.05)					
Action	**PSF**	**H**	**H_c**	**p-Value**	**Result**
1	training	39.33	5.99	$2.87*10^{-9}$	**reject**

Table 5.12 Effect of muster actions on PSF ratings (MO).

ANOVA (H_o = muster actions have no effect on PSF ratings, α = 0.05)				
PSF	**F**	**F_c**	**P-Value**	**Result**
stress	0.97	1.65	0.50	accept
complexity	2.16	1.65	0.0047	*reject*
training	1.07	1.65	0.37	accept
experience	0.85	1.65	0.63	accept
event factors	1.73	1.65	0.036	*reject*
atmospheric factors	0.63	1.65	0.86	accept

5.14 Success Likelihood Index Results

This section summarizes the Success Likelihood Index (SLI) results for all three muster scenarios. As a reminder, the SLI value is the product of a normalized PSF weight (n-weight) and its corresponding rating as given by equation [4-6]. The greater the SLI value the greater the probability of success in completing a muster action. Appendix H contains summary tables for the SLI values for each muster scenario (Table H.1), ERT subgroup (Tables H.2 to H.4) and PSFs (Table H.5). The total SLI for each action is the sum of the PSFs SLI values as shown for example in Table 5.13. The PSFs n-weights for all scenarios are summarized in Appendix I.

Figure 5.42 is a trend of the mean SLI (SLI) for each action. It can be seen from this figure that the F&E scenario actions are predicted to have the least likelihood of success among the three muster sequences. The likelihood of success is lower through the high risk phases (i.e. awareness, evaluation and egress) for both the GR and F&E series, while the MO sequence maintains a similar SLI through all four muster phases. The MO scenario has the highest SLI values for all actions among the three muster scenarios. Further, there is little variation in SLI values among the MO actions with a maximum SLI spread (maximum SLI value – minimum SLI value) of 13 (Table H.1). This is reasonable as the MO muster sequence provides the lowest level of severity which is translated into each action having a similar chance of being performed successfully. There is a slight drop in SLI at action 14 (assist others if needed or as directed) but as there is no immediate risk during the muster, the likelihood of success of this action (76) is not significantly lower than the mean SLI (81).

Under the more severe muster scenarios of GR and F&E the likelihood of completing each muster action varies. For example, in the GR scenario the SLI for action 15 (register at TSR) is 71 (Table H.1). This is a much higher likelihood of success than action 9 (evaluate potential egress paths and choose route), which has a SLI of 51 (Table H.1). SLI predictions for the GR scenario fall between the MO and F&E SLI values for all muster actions (Figure 5.42). The likelihood of success drops significantly after action 2 (identify alarm) and remains low through to action 12 (choose alternate route if egress path is not tenable), before rising sharply in the recovery phase actions that take place in the TSR.

Table 5.13 SLI predictions for Judges A to E and actions 1 to 5 (MO).

Action	PSF	Judge A	Judge B	Judge C	Judge D	Judge E
1	stress	1.14	20.00	2.78	7.74	10.00
	complexity	8.57	0.00	8.89	0.00	2.29
	training	28.57	25.71	22.22	29.03	23.14
	experience	25.71	25.71	10.00	29.03	17.14
	event factors	0.00	0.00	3.33	5.81	5.71
	atmospheric factors	25.71	28.57	27.78	5.81	28.57
	SLI	**89.71**	**100.00**	**75.00**	**77.42**	**86.86**
2	stress	7.27	11.76	0.00	4.00	12.00
	complexity	10.91	2.94	11.61	0.00	4.57
	training	30.30	29.41	15.48	36.00	28.57
	experience	27.27	26.47	14.52	32.40	18.00
	event factors	3.03	0.00	3.23	7.20	1.43
	atmospheric factors	18.18	29.41	32.26	7.20	25.71
	SLI	**96.97**	**100.00**	**77.10**	**86.80**	**90.29**
3	stress	11.03	11.11	2.50	4.44	11.76
	complexity	9.31	3.70	5.83	0.00	3.53
	training	27.93	37.04	37.50	30.00	29.41
	experience	34.48	33.33	25.00	33.33	18.53
	event factors	6.21	0.00	5.00	13.33	2.35
	atmospheric factors	3.45	3.70	8.33	6.67	12.35
	SLI	**92.41**	**88.89**	**84.17**	**87.78**	**77.94**
4	stress	9.60	8.33	4.29	2.50	12.25
	complexity	9.60	3.33	10.00	3.33	8.00
	training	10.80	23.33	28.57	26.25	22.50
	experience	36.00	27.00	19.29	37.50	22.50
	event factors	7.20	0.00	3.57	0.00	3.00
	atmospheric factors	20.00	16.67	7.14	18.75	14.00
	SLI	**93.20**	**78.67**	**72.86**	**88.33**	**82.25**
5	stress	10.71	2.38	1.11	1.92	11.95
	complexity	9.64	4.76	8.89	3.08	9.76
	training	28.93	47.62	33.33	38.46	24.39
	experience	28.57	42.86	29.63	31.15	19.76
	event factors	3.57	0.00	3.70	0.00	2.93
	atmospheric factors	14.29	0.00	7.41	19.23	9.76
	SLI	**95.71**	**97.62**	**84.07**	**93.85**	**78.54**

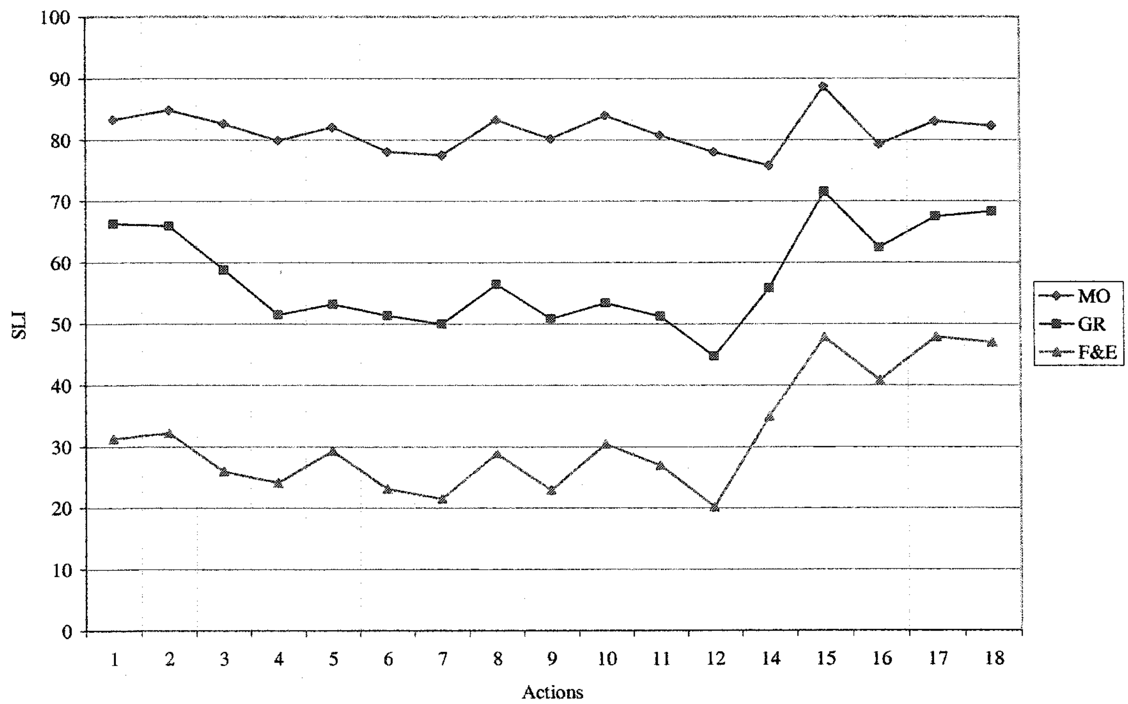

Figure 5.42 SLI for each action and muster scenario.

The SLI values for the F&E scenario are the lowest of the three muster scenarios; this is expected because this scenario is the most severe of the musters considered in the current work. There is no significant drop in SLI from the point of muster initiation to the recovery phase actions. It is only in the TSR where F&E SLI values increase significantly from approximately 20 to 48 (Table H.1). The gravity of the muster scenario has made actions in the first three stages of muster less likely to be completed successfully.

Hypothesis testing was conducted to determine if the muster scenarios and muster actions affected the SLI values in Table H.1. ANOVA results (Table 5.14) show that the three muster scenarios (severity) significantly influence the success likelihood index for each action (i.e. H_o is strongly rejected for all actions). In addition, ANOVA testing for the effect of muster actions on SLI values was conducted (Table 5.15). The results indicate that the muster actions in the GR and F&E scenarios considerably influence the SLI values. The success likelihood index is not influenced by the MO muster tasks. This is consistent with the ANOVA results for the MO PSFs' weights and ratings. In both cases the ANOVA results showed that the MO sequence did not influence these values. All actions within the MO scenario have a similar likelihood of success.

Table 5.14 Effect of muster severity on SLI values.

ANOVA (H_o = muster severity has no effect on muster action's SLI, $\alpha = 0.05$)				
Action	**F**	**F_c**	**P-Value**	**Result**
1	53..86	1.67	$8.09*10^{-15}$	**reject**
2	68.87	1.67	$3.62*10^{-17}$	**reject**
3	114.11	1.67	$1.32*10^{-22}$	**reject**
4	122.11	1.67	$2.15*10^{-23}$	**reject**
5	96.54	1.67	$1.01*10^{-20}$	**reject**
6	12.49	1.67	$4.40*10^{-24}$	**reject**
7	123.25	1.67	$1.68*10^{-23}$	**reject**
8	94.58	1.67	$1.70*10^{-20}$	**reject**
9	113.05	1.67	$1.68*10^{-22}$	**reject**
10	105.35	1.67	$1.07*10^{-21}$	**reject**
11	109.91	1.67	$3.54*10^{-22}$	**reject**
12	128.27	1.67	$5.69*10^{-24}$	**reject**
14	50.19	1.67	$3.50*10^{-14}$	**reject**
15	40.33	1.67	$2.51*10^{-12}$	**reject**
16	41.28	1.67	$1.64*10^{-12}$	**reject**
17	21.70	1.67	$4.89*10^{-8}$	**reject**
18	27.07	1.67	$2.10*10^{-9}$	**reject**

Table 5.15 Effect of muster actions on SLI values.

ANOVA (H_o = muster actions have no effect on SLI values, $\alpha = 0.05$)				
Scenario	**F**	**F_c**	**P-Value**	**Result**
MO	1.39	1.67	0.14	accept
GR	8.70	1.67	$3.22*10^{-18}$	**reject**
F&E	7.76	1.67	$5.11*10^{-16}$	**reject**

To get a better sense of the difference between the SLI values for each muster scenario, a relative comparison of the MO SLI values was obtained by dividing the MO SLIs by the corresponding GR SLI values (this was also done for the F&E scenario as described shortly). This ratio is referred to as RGR (MO/GR) as illustrated in Figure 5.43. The RGR increases from 1.25 during the initial actions of alarm detection and identification to approximately 1.5 for the remainder of the awareness, evaluation and egress phases. There is a notable increase in RGR at action 12 (choose alternate route if egress path is not tenable) in the egress phase. The SLI values decrease (i.e. become more like those for the MO scenario) for actions in the TSR as the RGR approaches a value of unity.

The F&E SLIs are compared with the MO values through a similar ratio termed RFE (MO/F&E). RFE values are determined by dividing the MO SLIs by their respective F&E counterparts, and are shown as the red line in Figure 5.43. The high level of severity for the F&E scenario is reflected by the higher RFE values as compared to RGR. The high risk phases (awareness, evaluation, and egress) show the MO SLIs to be 2.5 to 3.5 times more likely to succeed than in the F&E scenario. Of note again is action 12 (choose alternate route if egress path is not tenable), where the likelihood of success in the MO sequence is nearly 4 times that of the F&E scenario. There is a high level of confidence reflected in action 14 (assist others if needed or as directed) as the ratio falls to 2.2 and remains below 2 for the remainder of awareness phase activities in the TSR.

Though all MO actions are more likely to succeed than F&E actions, several actions (3, 4, 6, 7, 9 and 12) show a much stronger tendency for success (Figure 5.43). Actions 4 (ascertain if danger is imminent), 9 (evaluate potential egress paths and choose route) and 12 (choose alternate route while moving to TSR) are decision-based tasks that are more difficult to complete successfully in more severe muster scenarios. Actions 6 (return process equipment to safe state) and 7 (make workplace safe as possible in limited time) are also much more likely to succeed in an MO scenario as these tasks may be more difficult to complete because of the event factors and the inexperience of the individual in the more severe muster. Action 3 (act accordingly) was also seen to be much more likely to succeed in the MO scenario than in the F&E scenario (RFE = 3.2). As the MO muster is the most benign of the three sequences, the ability to maintain composure is understandably more likely.

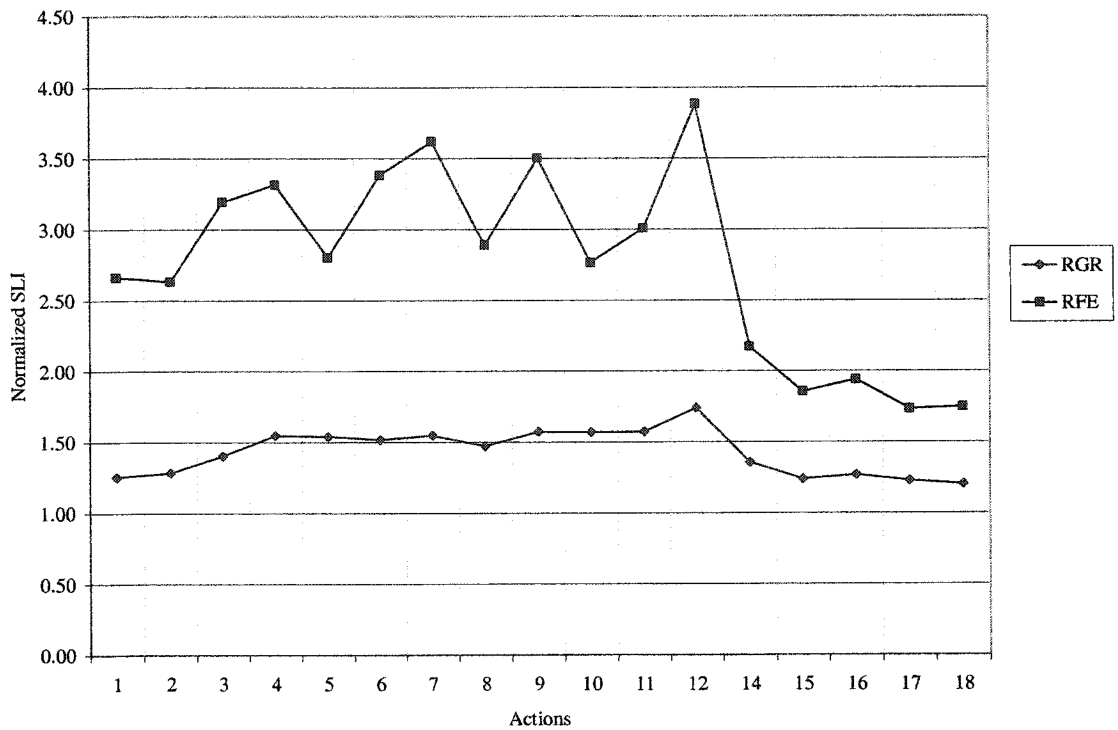

Figure 5.43 Relative SLI values.

A comparison of SLI predictions by ERT subgroup can be found in Appendix H. The SLIs do not vary significantly among the subgroups, although the operators subgroup was less optimistic (i.e. lower SLIs) for actions in the awareness, evaluation and egress phases. As this subgroup has more muster experience than the other subgroups, they may tend to be more pessimistic because of their familiarity with the errors that are made during muster drills. The SLI predictions for the recovery phase actions are more uniform among all the groups.

A graphical comparison of SLI values based on the ERT subgroups (Figures 5.44, to 5.46) was performed by comparing the subgroups' SLI values with those of the ERT

SLI values. This was done by dividing the SLI value of the subgroups by the SLI value of the ERT. A ratio of 1 would indicate that the subgroup SLI was the same as the ERT SLI value. A value less than one indicates that the subgroup SLI value was less than the ERT value, and conversely a ratio greater than one would indicate that the subgroup SLI was greater than the ERT value.

In general, for all three scenarios the > 35 group and the operators were more pessimistic than the ERT as a whole, with SLI ratios less than unity for all actions in each scenario (except F&E where the operators were more optimistic than the ERT). In general, the mix of the ERT appears to have balanced out any strong biases that may have existed in any one subgroup. The larger and more diverse the ERT is, the more balanced the results are likely to be (with small standard deviations). The standard deviation for any action in all three scenarios is approximately 10 on a scale 0 to 100.

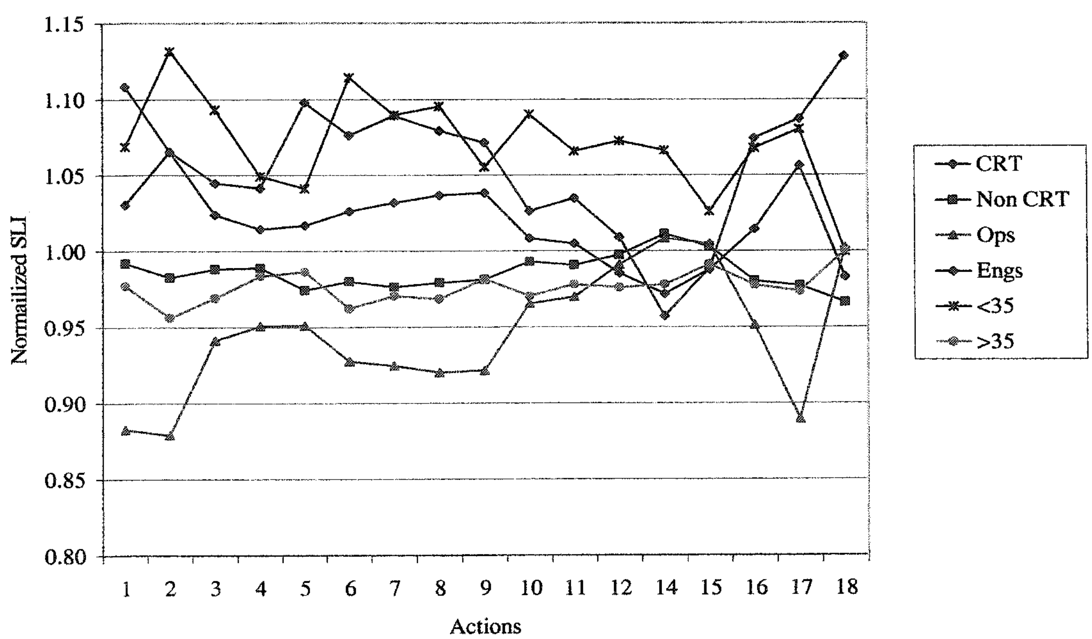

Figure 5.44 Normalized MO SLI values by ERT subgroup.

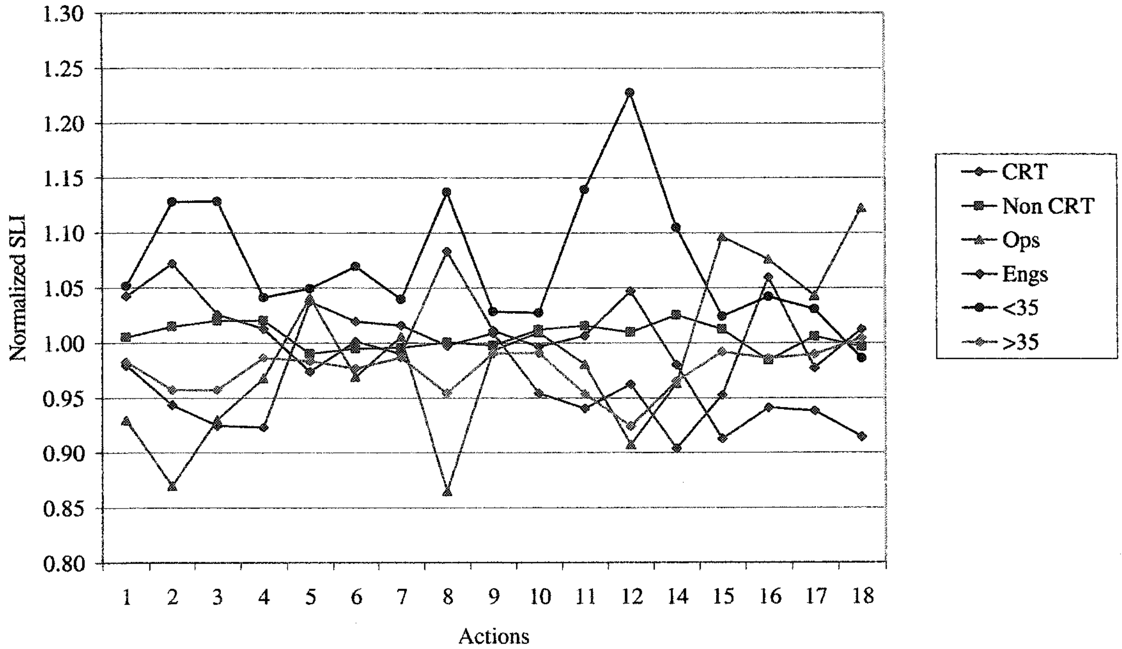

Figure 5.45 Normalized GR SLI values by ERT subgroup.

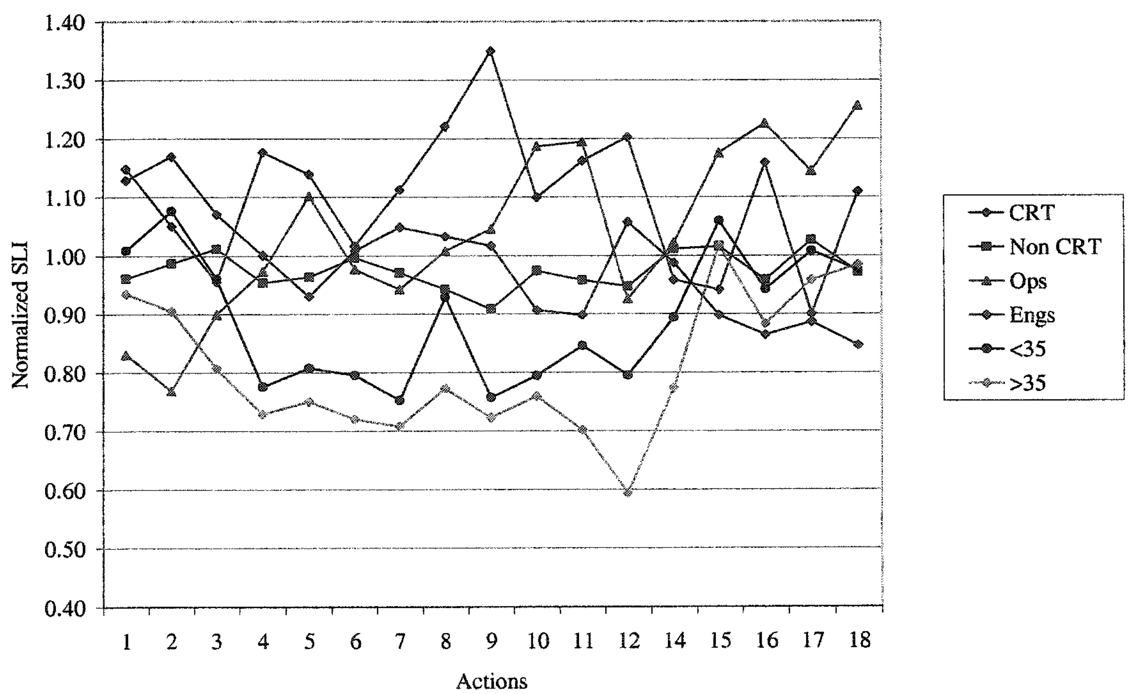

Figure 5.46 Normalized F&E SLI values by ERT subgroup.

5.15 Prediction of Human Error Probabilities

This section presents the predicted Human Error Probabilities (HEPs) for all three muster series. An important component of the SLIM process is the calculation of the constants a and b for equation [4-7] from either two known or two estimated HEPs. These base human error probabilities (BHEPS) were predicted for the actions associated with the maximum and minimum SLI (MaxSLI and MinSLI, respectively) for a given muster scenario. The constants a and b were then determined by the solution of two simultaneous equations. This process was repeated for each muster scenario. The HEPs of the remaining actions were then determined using their respective SLI values (equation [4-7]).

A review of the literature did not provide two HEPs that could be directly applied to a muster scenario. However, Swain and Guttmann (1983) generated several tables in their presentation of the THERP technique that were targeted at control room applications and are quoted extensively by other researchers (Visser and Wieringa, 2001, Gertman and Blackman, 1993, Vaurio, 2001, Bersini et al., 1988, Kirwan et al., 1997).

The HEPs for the MO scenario were estimated first among the three muster scenarios, followed by the GR and F&E musters. The MO scenario provides the least amount of stress in completing the actions of the formal muster procedure and forms a basis from which other HEPs can be scaled. Tables 5.16 to 5.18 provide the references from which the BHEPs were estimated. In the MO scenario, action 15 (register at the TSR) (MaxSLI for all scenarios) is a routine simple task under a low stress environment and was estimated to have a HEP of 0.001. The MaxSLI action (14) in this muster sequence (assist others if needed or as directed) is more dynamic and non-routine and is factored by 10 for a HEP of 0.01.

The estimated HEP for the MaxSLI action in the GR scenario is 0.01 (Table 5.17). This is obtained by factoring the MO HEP for the same action (15) by 10 based on an increased level of stress. The HEP references for decisions are based on ranges of HEPs for example, a failure to complete action 12 (choose alternate route if egress path is not tenable) could be due to any one of the reasons listed in Table 5.17. The lowest HEP (0.1) was used as an estimate for action 12.

Table 5.16 MO BHEP estimates.

Source	Source Description	Multiplier* or HEP	Muster Action	Estimated HEP
Swain and Guttmann (1983)	Omitting a step or important instruction from a formal procedure	0.003	15. Register at TSR (MO)	0.001
Swain and Guttmann (1983)	Error of omission for procedures with check off provisions	0.001		
Swain and Guttmann (1983)	Probability of errors in recalling oral instructions	0.001		
Kirwan (1994)	Error in simple routine operation	0.001		
Swain and Guttmann (1983)	Task consists of relatively dynamic interplay between operator and system indications	10 (multiplier)	14. Assist others if needed or as directed (MO)	0.01
Kirwan (1994)	Error in simple routine operation where care is required	0.01		

* A multiplier is used to generate a new HEP by multiplying a known HEP by the multiplier value.

The MaxSLI and MinSLI actions (15 and 12, respectively) for the F&E scenario, are the same as the GR MaxSLI and MinSLI actions. The HEP references for these actions are supplied in Table 5.18. Applying a scaling factor of 10 to the HEP for action 15 (register at TSR) in the GR scenario results in a HEP of 0.1. The HEP estimate from Kirwan (1994) is 0.3 for actions performed under high stress levels. As stress levels are relieved while in the recovery phase (actions that takes place in the TSR) an average of these two reference HEPs was utilized (0.2). The MinSLI action takes place in the egress phase of the sequence and is associated with high stress levels. The THERP tables

Table 5.17 GR BHEP estimates.

Source	Source Description	Multiplier* or HEP	Muster Action	Estimated HEP
Swain and Guttmann (1983)	Dynamic extremely high threat stress	10 (multiplier)	15. Register at TSR	0.01
Swain and Guttmann (1983)	Symptoms noticed but incorrect interpretation	0.1 - 0.0042	12. Choose alternate route if egress path is not tenable	0.1
	Right diagnosis, wrong response	0.22 – 0.0039		
	Competing goal states lead to wrong conclusion	0.17 - 0.0089		
	Task consists of relatively dynamic interplay between operator and system indications	10 (multiplier)		

* A multiplier is used to generate a new HEP by multiplying a known HEP by the multiplier value.

Table 5.18 F&E BHEP estimates.

Source	Source Description	Multiplier* or HEP	Muster Action	Estimated HEP
Swain and Guttmann (1983)	Dynamic extremely high threat stress (novice)	10 (multiplier)	15. Register at TSR	0.2
Swain and Guttmann (1983)	Step by step extremely high threat stress (novice)	10 (multiplier)		
Kirwan (1994)	General rate for errors involving high stress levels	0.3		
Swain and Guttmann (1983)	Dynamic diagnosis; extremely high threat stress (novice)	0.5	12. Choose alternate route if egress path is not tenable	0.5
Strutt et al., (1998)	Totally unfamiliar task; performed at speed with no idea of likely consequences	0.55		

* A multiplier is used to generate a new HEP by multiplying a known HEP by the multiplier value.

recommend a HEP of 0.5 for a novice. As the operator in question for the F&E scenario has limited experience (6 months), it was decided to adopt this HEP directly.

Embrey et al. (1984) suggested a method to elicit two HEPs for the actions with the MaxSLI and MinSLI if there were no empirical data available. Based on this previous work, a random selection of ERT judges was polled to estimate the BHEPs (Tables 5.19 to 5.21) for the MinSLI and MaxSLI for each muster scenario. The forms for this elicitation are in Appendix J. Each judge was met with individually and direction provided on how to fill out the forms. The judges were permitted to select a single value or range of values for each action. In the event a range was chosen, then the mean of that range was used for their HEP prediction.

Once two BHEPs were formulated, the constants a and b were determined through equation [4-7]. The result is two sets (Table 5.22) of constants (a, b) from which HEPs were determined (Appendix K). The elicited BHEPs (Table 5.19 and Table 5.20) are similar to the estimated BHEPs (Table 5.16 and Table 5.17) for the MO and GR muster scenarios. The F&E scenario produced a wider range of elicited BHEP responses and is not as similar to the estimated BHEPs. This is not surprising as the F&E muster presents a scenario that is the most unfamiliar to judges and therefore the most difficult to predict consistently.

Table 5.19 MO HEP predictions for MaxSLI and MinSLI actions.

Judge	**HEP**		**POS (1-HEP)**	
	Action 14	**Action 15**	**Action 14**	**Action 15**
G	0.050	0.001	0.950	0.999
L	0.050	0.001	0.950	0.999
S	0.010	0.010	0.990	0.990
R	0.010	0.001	0.990	0.999
Q	0.010	0.001	0.990	0.999
I	0.010	0.001	0.990	0.999
J	0.010	0.001	0.990	0.999
P	0.001	0.001	0.999	0.999
A	0.010	0.001	0.990	0.999
Mean	**0.018**	**0.002**	**0.982**	**0.998**

Table 5.20 GR HEP predictions for MaxSLI and MinSLI actions.

Judge	HEP		POS (1-HEP)	
	Action 12	Action 15	Action 12	Action 15
G	0.055	0.001	0.945	0.999
L	0.055	0.0055	0.945	0.995
S	0.100	0.010	0.900	0.990
R	0.100	0.100	0.900	0.900
Q	0.055	0.010	0.945	0.990
I	0.100	0.010	0.900	0.990
J	0.100	0.010	0.900	0.990
P	0.100	0.001	0.900	0.999
A	0.100	0.010	0.900	0.990
Mean	**0.085**	**0.0175**	**0.915**	**0.982**

Table 5.21 F&E HEP predictions for MaxSLI and MinSLI actions.

Judge	HEP		POS (1-HEP)	
	Action 12	Action 15	Action 12	Action 15
G	0.300	0.001	0.700	0.999
L	0.300	0.010	0.700	0.990
S	0.500	0.100	0.500	0.900
R	0.500	0.500	0.500	0.500
Q	0.300	0.055	0.700	0.945
I	0.500	0.100	0.500	0.900
J	0.500	0.100	0.500	0.900
P	0.010	0.001	0.990	0.999
A	0.500	0.200	0.500	0.800
Mean	**0.379**	**0.119**	**0.621**	**0.881**

Table 5.22 Estimated and elicited BHEPs to determine constants a and b.

Muster scenario	Action	Description	Estimated BHEP	a	b	Elicited BHEP	a	b
MO	14	Assist others if needed or as directed	0.01	0.000302	-0.0273	0.018	0.000504	-0.0489
	15	Register at TSR	0.001			0.002		
GR	12	Choose alternate route if egress path is not tenable	0.1	0.00154	-0.115	0.085	0.00091	-0.0723
	15	Register at TSR	0.01			0.017		
F&E	12	Choose alternate route if egress path is not tenable	0.5	0.00736	-0.448	0.38	0.00493	-0.290
	15	Register at TSR	0.2			0.12		

In order to calculate the HEP for each action, the previously determined success likelihood index (SLI) value for each muster action is substituted into equation [4-7]. As the estimated and elicited constants (a, b) are not identical, the resulting HEPs from equation [4-7] will not be identical. The HEPs from this approach are now referred to as estimated HEPs and elicited HEPs based on how the constants a and b were determined.

A comparison of the estimated log HEP and the elicited log HEP is illustrated in Figure 5.47. The elicited and estimated HEPs are similar for all three muster scenarios. The elicited and estimated HEPs show some continuity as the SLI increases from the F&E scenario to the MO scenario.

A third method of determining BHEPs is through empirical muster data. A review of three years of proprietary muster reports from two different operations (the groups are referred to as Set #1 and Set #2) was conducted in an effort to determine two empirically based BHEPs (EBHEPs). The EBHEPs are tabulated in Table 5.23.

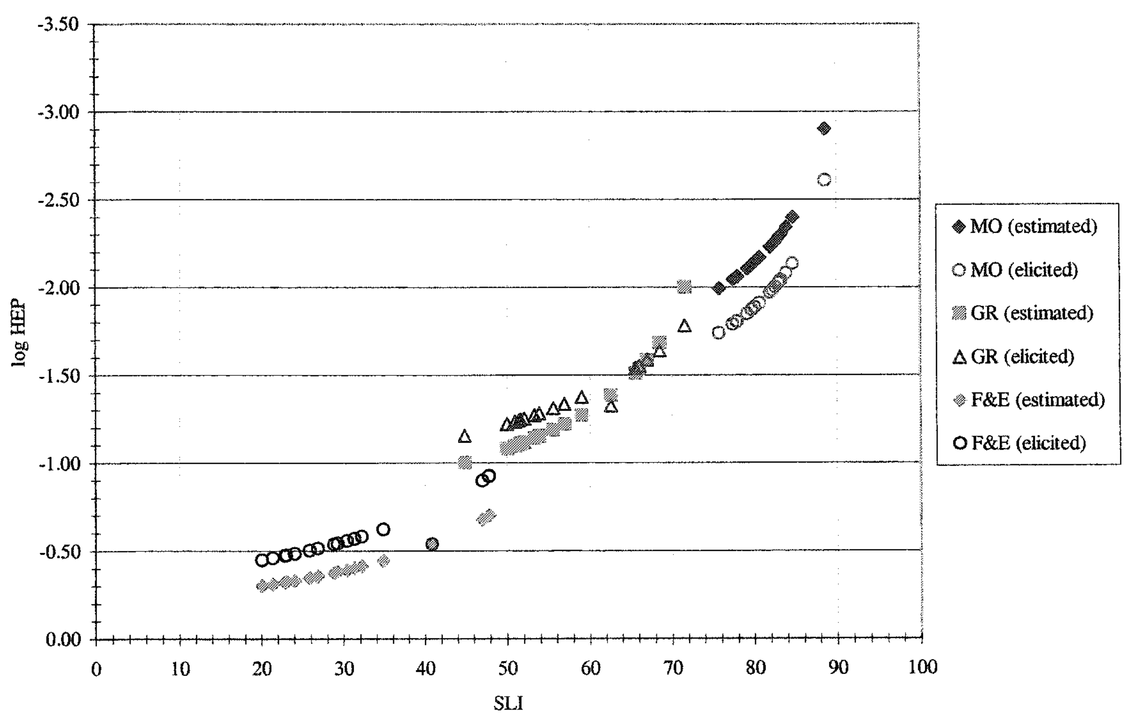

Figure 5.47 Comparison of log HEP values based on estimated and elicited BHEPs.

Table 5.23 Empirical data for BHEP and constants a and b.

Drill Data	No. of Musters	No. of Personnel	Action	SLI	No. of Reported Occurrences	EBHEP*	a	b
Set #1	110	3850	7	77	10	0.0026	0.0000388	-0.00413
			15	89	6	0.0016		
Set #2	30	600	9	80	2	0.0033	0.000174	-0.0153
			10	84	1	0.0017		

*Determined by equation [2-1].

Unfortunately, the reports did not provide enough data to ascertain the HEP for each muster action. The focus of the muster reports was primarily on control room and emergency response actions but deviations were reported from the muster procedure when observed. The BHEP estimates derived from the empirical data were used to predict the HEPs for the remaining muster actions and are referred to as empirical HEPs (Table K.1). The data derived from the muster reports are predominantly for muster drills and low severity musters. To assess the predicted HEP data, the empirical HEPs are compared with the least severe muster scenario's (MO) estimated and elicited HEPs (Figure 5.48). The SLI values for the MO scenario were applied to determine the HEPs for the empirically based data. The empirically based data provide the highest probabilities of success while the data based on elicitation of BHEPs provided the lowest probabilities of success for all muster actions. The HEP data based on estimated BHEPs fall nearly centrally between these two sets of data.

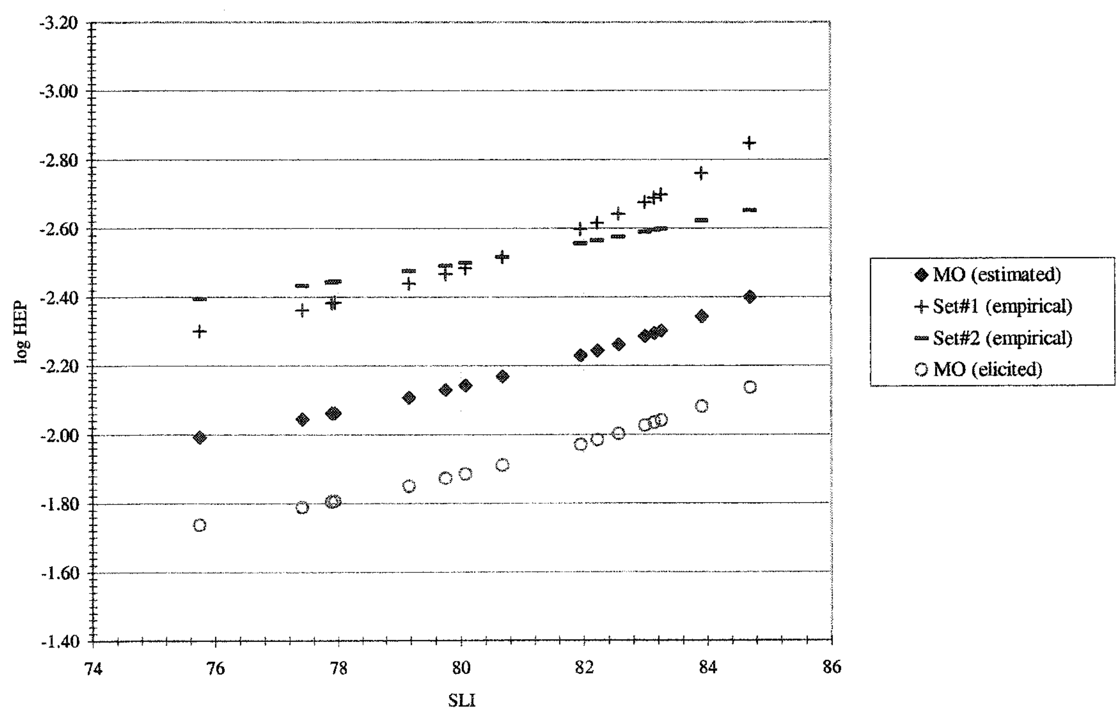

Figure 5.48 Comparison of log HEP values based on estimated, elicited and empirical BHEPs for low severity musters.

The estimated BHEPs were used to develop the probability of success (POS) reference graphs used in HEPI (as will be shown in Chapter 6). The empirical BHEP data are sparse and do not cover severe musters and hence were not utilized further. The elicited BHEPs utilized feedback from a portion of the ERT to estimate HEPs based on the MaxSLI and MinSLI actions for all three muster scenarios. A summary of HEPs based on elicited BHEPs is found in Table K.5. The relatively similar HEPs generated from both estimated and elicited BHEPS in Figure 5.48 provide encouragement to pursue this approach further with the full ERT. Until more reliable empirical data can be generated, the estimated BHEPS are used throughout the remainder of the current work.

The validity of the empirical data could be significantly improved with muster drills that allow for appointed individuals to act as observers throughout the platform for the purpose of recording errors. In industry, job observation techniques are well established in the critique of employees. The application of a similar strategy to muster drills would provide a tool to capture data that can be used to develop a human error database. The database would provide a means of measuring the success or failures of modifications to muster training, procedures, management systems and equipment.

In previous studies (Embrey, 1983, Embrey et al., 1984) the validity of the logarithmic POS correlation (equation [4-7]) was checked through graphical means. A linear regression of their plotted log empirical POS and corresponding SLI values was conducted. The level of agreement was defined by the approach of the coefficient of determination (R^2) to unity. As the empirical data in the current work are minimal, this check could not be conducted. The two empirical data points from Set #1 (hollow green squares) and Set #2 (solid green squares) used to calculate the EBHEPS are shown with the estimated MO log POS data (Figure 5.49) with accompanying upper and lower bounds (red data). Similar plots for GR and F&E scenarios are provided in Figures 5.50 and 5.51. The upper and lower bounds for each action are predicted from equation [4-12].

The HEP predictions with the upper and lower bounds for each action are tabulated in Appendix K. A summary of all estimate based HEPs, as defined by action and muster phase, is found in Table 5.24. As a reminder, HEP is defined as the probability of not completing a task successfully. There still exists the opportunity to recover from the failure. Of course, as muster severity increases, the ability to recover and the time available to recover become more limited. Table 5.24 also provides a list of

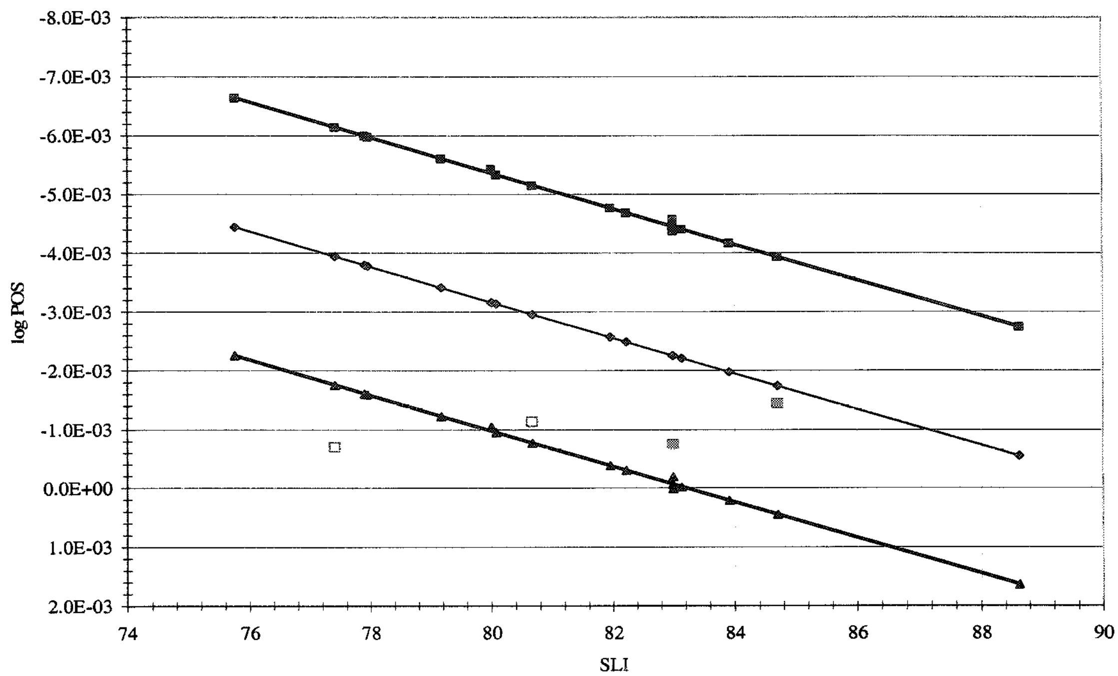

Figure 5.49 MO log POS with upper and lower bounds (red) including empirical data. Solid and hollow squares represent empirical data from Set #1 and Set #2, respectively (EBHEPs).

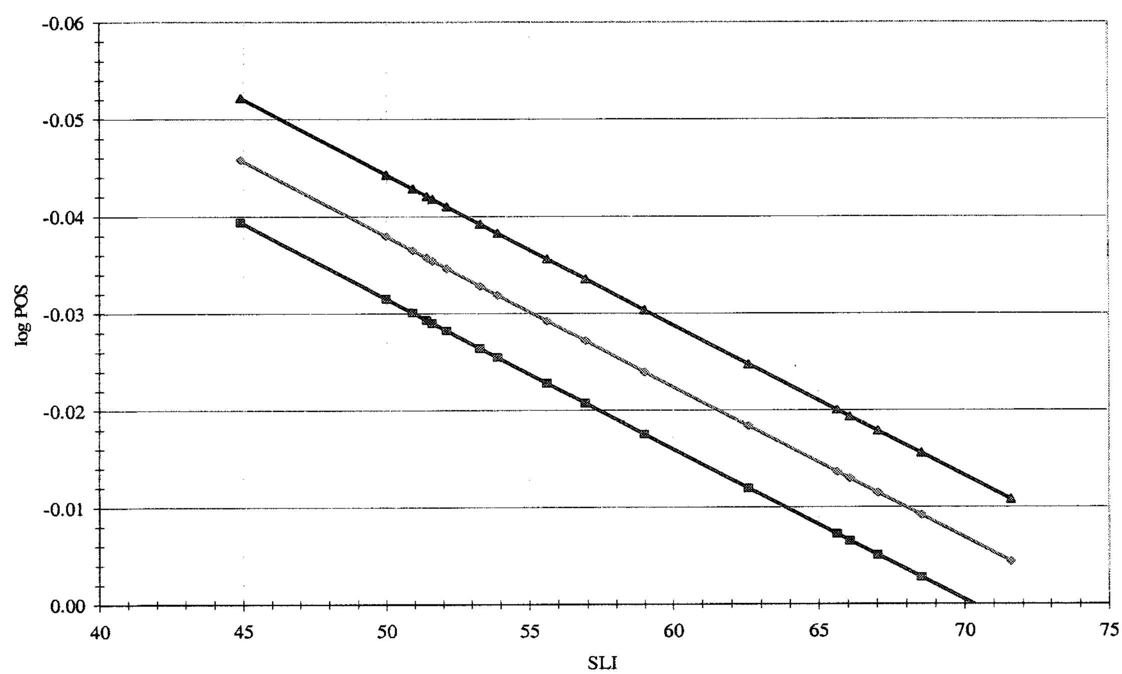

Figure 5.50 GR log POS with upper and lower bounds (red).

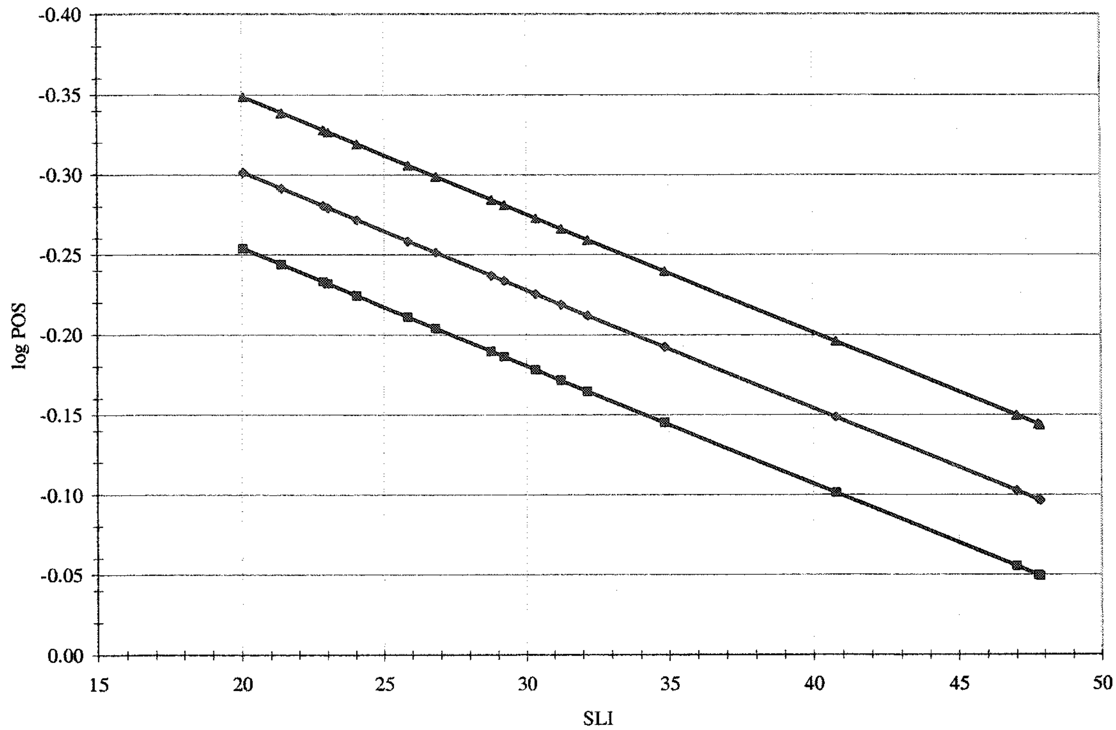

Figure 5.51 F&E log POS with upper and lower bounds (red).

failure mechanisms (loss of defences) for the actions within each of the four muster phases.

In Table 5.1 the muster actions were defined by SRK behaviour for each muster scenario. The actions that fall within each mode were grouped together and the estimated HEPs averaged. Table 5.25 provides a summary of these values. In each muster scenario, the knowledge-based actions are the most likely to fail, although in the F&E scenario the difference between each mode is small as the event factors become overwhelmingly significant and reduce the effectiveness of correct human actions and decisions. The rule-based actions in the GR and F&E sequences are the most likely to succeed (having the lowest average HEPs).

The skill-based actions in the three reference musters (MO, GR and F&E) are actions 1 (detect alarm) and 3 (act accordingly). The initiating events in these sequences may directly impact action 1 by significantly reducing the operator's ability to hear the alarm or see the flashing muster lights. The increased likelihood of not being able to act

Table 5.24 Summary of predicted HEPs based on estimated BHEPs.

No.	Actions	HEP			Phases	Loss of Defences
		MO	GR	F&E		
1	Detect alarm	0.00499	0.0308	0.396	Awareness	Do not hear alarm. Do not properly identify alarm. Do not maintain composure (panic).
2	Identify alarm	0.00398	0.0293	0.386		
3	Act accordingly	0.00547	0.0535	0.448		
4	Ascertain if danger is imminent	0.00741	0.0765	0.465	Evaluation	Misinterpret muster initiator seriousness and fail to muster in a timely fashion. Do not return process to safe state. Leave workplace in a condition that escalates initiator or impedes others egress.
5	Muster if in imminent danger	0.00589	0.0706	0.416		
6	Return process equipment to safe state	0.00866	0.0782	0.474		
7	Make workplace as safe as possible in limited time	0.00903	0.0835	0.489		
8	Listen and follow PA announcements	0.00507	0.0605	0.420	Egress	Misinterpret or do not hear PA announcements. Misinterpret tenability of egress path. Fail to follow a path which leads to TSR; decide to follow a different egress path with lower tenability. Fail to assist others. Provide incorrect assistance which delays or prevents egress.
9	Evaluate potential egress paths and choose route	0.00718	0.0805	0.476		
10	Move along egress route	0.00453	0.0726	0.405		
11	Assess quality of egress route while moving to TSR	0.00677	0.0788	0.439		
12	Choose alternate route if egress path is not tenable	0.00869	0.1000	0.500		
14	Assist others if needed or as directed	0.0101	0.0649	0.358		
15	Register at TSR	0.00126	0.0100	0.200	Recovery	Fail to register while in the TSR. Fail to provide pertinent feedback. Provide incorrect feedback. Do not don personal survival suit in an adequate time for evacuation. Misinterpret OIM's instructions or do not follow OIM's instructions.
16	Provide pertinent feedback attained while enroute to TSR	0.00781	0.0413	0.289		
17	Don personal survival suit or TSR survival suit is instructed to abandon	0.00517	0.0260	0.199		
18	Follow OIM's instructions	0.00570	0.0208	0.210		

Table 5.25 Average HEPs defined by SRK behaviour.

Human Error Probabilities (HEPs)			
SRK	**MO**	**GR**	**F&E**
Skill	0.0052	0.042	0.73
Rule	0.0055	0.038	0.61
Knowledge	0.0080	0.074	0.74

accordingly, in action 3, is related strongly to the lower levels of experience associated with the operator in the GR and F&E muster set-up.

The MO skill- and rule-based HEPs (and also those for the GR scenarios) are similar and cannot be accurately discriminated. It is clear that the knowledge-based actions in the MO and GR scenario are more likely to fail with a significantly higher HEP. The F&E HEPs are similar for all three modes of behaviour and essentially have the same likelihood of failure. As previously commented, the event factors in the F&E scenario are so strong that simple actions have no better chance of success than complicated actions.

The next chapter outlines the HEPI methodology of applying quantitative human error predictions to determine risk levels with the additional use of a consequence table. Mitigating measures are offered through a tabular HTA process and a re-rating conducted to determine the new level of risk for the muster setup. Subsequent to this discussion is a case study of the Ocean Odyssey.

Chapter 6

HUMAN ERROR PROBABILITY INDEX

The Human Error Probability Index (HEPI) proposed in this work provides a means by which a credible muster scenario can be evaluated for its risk potential on a human factors basis. Potential human errors are identified and quantified, and through the application of risk mitigation measures, the probability and consequences associated with human failure are reduced. This chapter details the HEPI process and how the HEPs predicted through the SLIM procedure are applied. A worked example is provided in the final section of this chapter.

6.1 HEPI Overview

The HEPI process as introduced in Chapter 1 is summarized in Table 6.1. The HEPI methodology is intended to be flexible and allows PSFs, ranking questions and risk mitigation measures to be changed by the user to suit their application needs. If required, the HEPI methodology permits additional reference musters and HEPs to be employed.

The three muster scenarios (MO, GR and F&E) considered in Chapter 5 are the basis for HEPI. These musters are now referred to as reference musters. In order to frame the muster scenario, an approach somewhat similar to the Dow Fire and Explosion Index was taken. The Dow Fire and Explosion Index (Dow Chemical Company, 1994) sets the scenario to be evaluated by asking key questions which permit the evaluation of the system based on its risk for fire and explosion. This is accomplished in HEPI by determining the PSF weights and ratings for the muster through a ranking process. This ranking process starts by setting up the muster scenario through a list of relevant questions (Table 6.2).

Included in Table 6.2 are the applicable PSFs for each question. The response to each question influences the weight and rating of these PSFs. For example, the relevant PSFs for question 4 (What is the time of day when the muster is initiated?) are

Table 6.1 The main steps of HEPI.

Step	Description	Result
1	Complete muster questionnaire.	Sets up muster scenario so that PSF rankings can be calculated.
2	Rank each PSF.	The ranking value for each PSF permits the determination of PSF weights and ratings through reference graphs for each action.
3	Determine PSF weights and ratings through reference graphs.	The weights and ratings are used to determine each muster action's SLI.
4	Calculate SLI for each action.	The SLIs are converted to HEPs for each action by another set of reference graphs.
5	Determine HEPs and assign consequences for each action.	The HEP and consequence allow the determination of risk through a risk matrix.
6	Estimate risk level and decide if acceptable.	If risk is acceptable, then no re-rating is required.
7	Apply risk mitigation measures to reduce risk.	Actions are re-rated based on mitigating measures and new HEPs and consequences are determined.
8	Determine revised risk level.	Apply further mitigation if risk is not acceptable and re-rate.

stress and complexity. If the muster occurs at night, stress levels will be higher than a muster during daylight hours. Similarly, the complexity of the muster actions will be affected by the time of day. For example, egress phase actions are more complex at night due to a lower visibility or due to an individual's level of alertness if woken from sleep. These twelve questions frame the muster scenario by identifying key aspects of the muster such as the muster initiator, the mustering individual and the conditions at the time of the muster.

Each question has a multiple choice answer that has a corresponding value (rank) as shown in Table 6.3. The values in Table 6.3 that formulate the rankings for the three muster scenarios (MO, GR and F&E) can be identified through a legend (Table 6.4). These muster setup questions in Table 6.3 are linked to PSFs (i.e. each question has related PSFs in parentheses after the question). The PSFs are ranked by summing the

Table 6.2 HEPI muster ranking questions.

No.	Major Questions	Relevant PSFs
1	What is the muster initiator?	Event Factors, Stress, Complexity
2	What is the immediate risk from the muster initiator?	Event Factors, Stress, Complexity
3	What is the weather at the time of muster?	Atmospheric Factors, Stress, Complexity
4	What is the time of day when the muster is initiated?	Stress, Complexity
5	What is the individual's description (job type)?	Training
6	What is the level of the individual's offshore experience?	Experience, Training
7	How familiar is the individual with respect to their job at the time of muster?	Stress, Experience, Complexity
8	How complex is the individual's job at the time of muster?	Complexity
9	What is the level of criticality of the job at the time of muster?	Stress
10	What is the location of the individual in relation to the muster initiator?	Stress, Complexity, Event Factors
11	How many personnel are onboard (POB) at the time of muster?	Stress, Complexity
12	Does the individual have any specialized level of training?	Training, Complexity, Stress

Table 6.3 HEPI muster ranking questionnaire.

Muster Ranking					
1) What is the muster initiator? (Event Factors, Stress, Complexity)					
i) Drill	0	iv) Fire	30	vii) Spill	20
ii) Man overboard	10	v) Fire & explosion	30	viii) Helicopter crash	20
iii) Gas release	20	vi) Ship collision	20	ix) Man down	20
Total					
2) What is the immediate risk from the muster initiator? (Event Factors, Stress, Complexity)					
i) No effect on platform integrity; does not impede muster progress; no threat to personnel					0
ii) Can impede muster progress with potential injury to personnel					10
iii) Threatens integrity of platform; impedes muster progress; potential for loss of life					30
Total					
3) What is the weather at the time of muster? (Atmospheric Factors, Stress, Complexity)					
ia) Sun/cloud	0	ib) No wind	0	ic) < -30 deg C	30
iia) Rain	10	iib) Windy	10	iic) -21 to -30 deg C	20
iiia) Snow/sleet	20	iiib) Significant wind	20	iiic) -20 to 0 deg C	10
iva) Snow storm	30	ivb) Hurricane	30	ivc) 1 to 30 deg C	0
va) Heavy fog	20	vb) Tornado	30	vc) > 30 deg C	10
Total					
4) What is the time of day when the muster is initiated? (Stress, Complexity)					
i) Daytime	0	0	iii) Crew change		20
ii) Night time	20		iv) Night time after 12 am and before 6 am		30
Total					

Table 6.3 Cont'd.

5) What is the individual's description (job type)? (Training)					
i) Operator	**10** **10** **10**	iii) Maintenance	20	v) Kitchen staff	30
ii) Engineer	20	iv) Administration	30	vi) Cleaning staff	30
Total					

6) What is the level of the individual's offshore experience? (Experience, Training)					
ia) < 6 months	40	ib) Regular hitches	**10** **10** **10**	ic) No musters	**20**
iia) 6 months to 3 years	**30**	iib) Irregular hitches	20	iic) 1 to 5 musters	**10**
iiia) 4 to 10 years	**20**	iiib) Rare hitch	40	iiic) > 5 musters	**0**
iva) > 10 years	**10**				
Total					

7) How familiar is the individual with respect to their job at the time of muster? (Stress, Experience, Complexity)			
i) Routine task that is familiar	**10** **10**	iii) New task; never done before	40
ii) Task that is infrequently performed	**20**		
Total			

8) How complex is the individual's job at the time of muster? (Complexity)			
i) Not complex	**10**	iii) Very complex and highly procedural	30
ii) Somewhat complex and procedural	**20** **20**	iv) Very complex; highly procedural; team required	40
Total			

Table 6.3 Con't.

9) What is the level of criticality of the job at the time of muster? (Stress)					
i) Job will not result in escalation of muster initiator	**0**	**0**	**0**	iii) Job will escalate muster initiator	20
ii) Job has potential to escalate muster initiator	10				
Total					

10) What is the location of the individual in relation to the muster initiator? (Stress, Complexity, Event Factors)				
ia) Event initiated on different deck or platform	**10**	ib) Event does not affect egress route	**0**	
iia) Event initiated on same deck	**20**	iib) Event may affect egress route	**10**	**10**
iiia) Event initiated in close proximity to individual	**30**	iiib) Event affects egress route	20	
Total				

11) How many personnel are onboard (POB) at the time of muster? (Stress, Complexity)							
i) < 25% POB	10	ii) 25 to 75% POB	20	iii) 76 to 100% POB	**30**	**30**	**30**
Total							

12) Does the individual have any specialized level of training? (Training, Complexity, Stress)			
i) Not trained - First Aid	10	iii) Not trained - rescue	**10**
ii) Not trained - gas detection	10	iv) Not trained - fire fighting	**10**
Total			

Table 6.4 HEPI ranking table color legend.

Color	Muster Scenario
yellow	Man Overboard
green	Gas Release
purple	Fire and Explosion

values associated with each question that is relevant to that PSF. For example, the ranking for the PSF, training, would be the sum of the values from questions 5, 6, and 12.

The determination of the muster actions' HEP follows the SLIM methodology presented in Chapter 4. Reference graphs (presented in section 6.2) have been developed for each action to determine the normalized PSF weights (n-weights) and PSF ratings. The SLI values for each muster action are determined next (equation [4-6]). Subsequent to determining the SLI values, the HEP for each muster action is predicted from one of three reference graphs (shown in section 6.2). The HEP in conjunction with an assigned consequence provides a means of estimating the risk from failure to complete an action. Mitigating measures are suggested for each action in order to reduce risk, if deemed necessary.

6.2 HEPI Reference Graphs

To determine the PSF n-weights and ratings for a muster scenario, it was necessary to find a means to relate the PSF rankings from Table 6.3 to the reference musters. This was accomplished through a series of reference graphs based on the three reference muster scenarios as summarized in Table 6.5. The first step was to complete the ranking process for each of the three reference musters and sum the ranks for each PSF. The color coded answers in Table 6.3 provide the ranks chosen for each of the six PSFs in each reference muster.

As an example, PSF ranking for complexity is performed in Table 6.6 (MO scenario). The questions that are relevant to complexity are 1, 2, 3, 4, 7, 8, 10, 11 and 12 (Table 6.2). The values associated with these questions from Table 6.3 are summed to achieve a PSF rank of 100. The remaining reference muster PSFs were similarly ranked and are summarized in Table 6.7.

Table 6.5 Reference muster descriptions.

Component	Muster Scenario		
	MO	**GR**	**F&E**
Situation	A person falls overboard resulting in the activation of the muster alarm	A hydrocarbon gas release in the process units	A fire and explosion in the process units
Muster person in question	A very experienced (15 years) operator who at the time of muster alarm is in the process units draining a process vessel	An experienced (3 years) operator who at the time of muster alarm is changing filters in a solids removal unit	An inexperienced (6 months) operator who at the time of muster alarm is in the process units working valves to isolate a vessel
Weather	The incident occurs in good weather and calm seas	The incident occurs in cold, wet weather	The incident occurs during a winter storm
Time of day	The muster is conducted during daylight hours	The muster is conducted during daylight hours	The muster is conducted during night time hours
Location of muster initiator	The operator is on a different deck than the person who has fallen overboard. The operator does not see or hear the muster initiator	The operator is on the same deck as the gas release	The operator is on the same deck as the fire and explosion

Table 6.6 Example of how to determine the MO complexity ranking.

No.	Ranking Question	Value
1	What is the muster initiator?	10
2	What is the immediate risk from the muster initiator?	0
3	What is the weather at the time of muster?	0
4	What is the time of day when the muster is initiated?	0
5	What is the individual's description (job type)?	n/a
6	What is the level of the individual's offshore experience?	n/a
7	How familiar is the individual with respect to their job at the time of muster?	10
8	How complex is the individual's job at the time of muster?	10
9	What is the level of criticality of the job at the time of muster?	n/a
10	What is the location of the individual in relation to the muster initiator?	10
11	How many personnel are onboard (POB) at the time of muster?	30
12	Does the individual have any specialized level of training?	0
Total		**70**

Table 6.7 HEPI reference musters - PSFs' ranking.

Stress			**Complexity**			**Training**		
MO	**GR**	**F&E**	**MO**	**GR**	**F&E**	**MO**	**GR**	**F&E**
Low	Medium	High	Low	Medium	High	Very Good	Medium	Poor
60	130	260	70	150	280	30	50	90
Experience			**Event Factors**			**Atmospheric Factors**		
MO	**GR**	**F&E**	**MO**	**GR**	**F&E**	**MO**	**GR**	**F&E**
Very Good	Medium	Poor	Mild	Medium	Strong	Very Good	Medium	Poor
30	50	80	20	60	100	0	30	70

The next step is to pair the PSF n-weights (Table I.1) and ratings (Tables E.1 to E.3) with the PSF rankings (Table 6.7) for the three reference muster scenarios. An example of set of n-weights and ratings is provided in Table 6.8. As a reminder, the n-weight is defined as a PSF weight divided by the sum of the all the PSF weights for a given action as described by equation [4-4]. The result is three pairs of data consisting of PSF ranks and PSF n-weights for each muster action. Similarly, 3 pairs of data are formed from the PSF ranks and PSF ratings for each muster action. These data sets

Table 6.8 MO stress ranking (90) with n-weights and ratings.

Action	Description	n-Weight*	Rating^
1	Detect alarm	0.1149	65
2	Identify alarm	0.1244	66
3	Act Accordingly	0.1620	68
4	Ascertain if danger is imminent	0.1466	67
5	Muster if in imminent danger	0.1607	64
6	Return process equipment to safe state	0.1588	65
7	Make workplace as safe as possible in limited time	0.1674	62
8	Listen and follow PA announcements	0.1562	69
9	Evaluate potential egress paths and choose route	0.1554	69
10	Move along egress route	0.1557	73
11	Assess quality of egress route while moving to TSR	0.1747	70
12	Choose alternate route if egress path is not tenable	0.1616	71
14	Assist others if needed or as directed	0.1930	65
15	Register at TSR	0.1611	80
16	Provide pertinent feedback attained while enroute to TSR	0.1981	73
17	Don personal survival suit or TSR survival suit if instructed to abandon	0.2068	70
18	Follow OIM's instructions	0.2299	76

*Table I.1
^Table E.1

form the reference curves for each muster action. To determine the PSF n-weight or rating for a given action, the value is interpolated based on the PSF ranking. Figure 6.1 provides a generic example; if the PSF ranking for the action was 40, the interpolated rating is 60. The n-weight is determined in a similar fashion.

Each muster action has six reference curves (one for each PSF) to determine the n-weights and ratings. These curves have been placed on a single graph resulting in 17 n-weight reference graphs (one for each muster action) and 17 rating reference graphs. There are 18 muster actions, but action 13 (collect personal survival suit if in accommodations at time of alarm) is not part of the three reference musters and therefore not included. A best-fit curve was utilized so that interpolation of PSF n-weights and ratings would be consistently determined.

Figures 6.2 and 6.3 are examples of reference graphs for action 1 (detect muster alarm). The PSF n-weights and ratings for action 1 are determined from these two

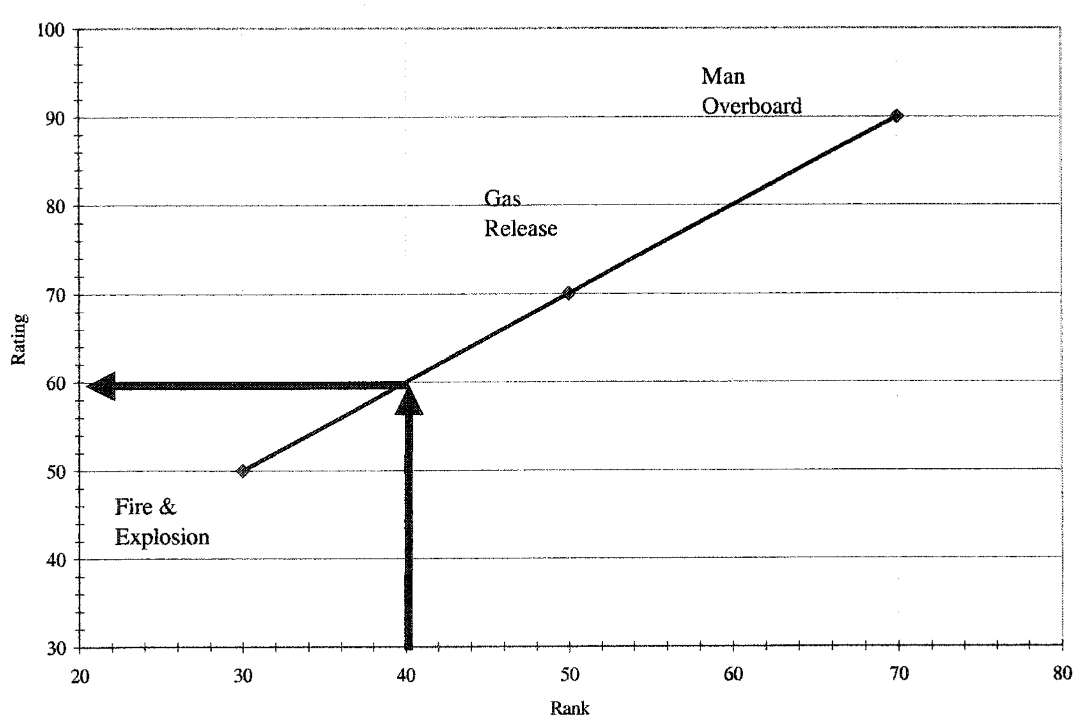

Figure 6.1 General form of a PSF rating reference curve for a given action.

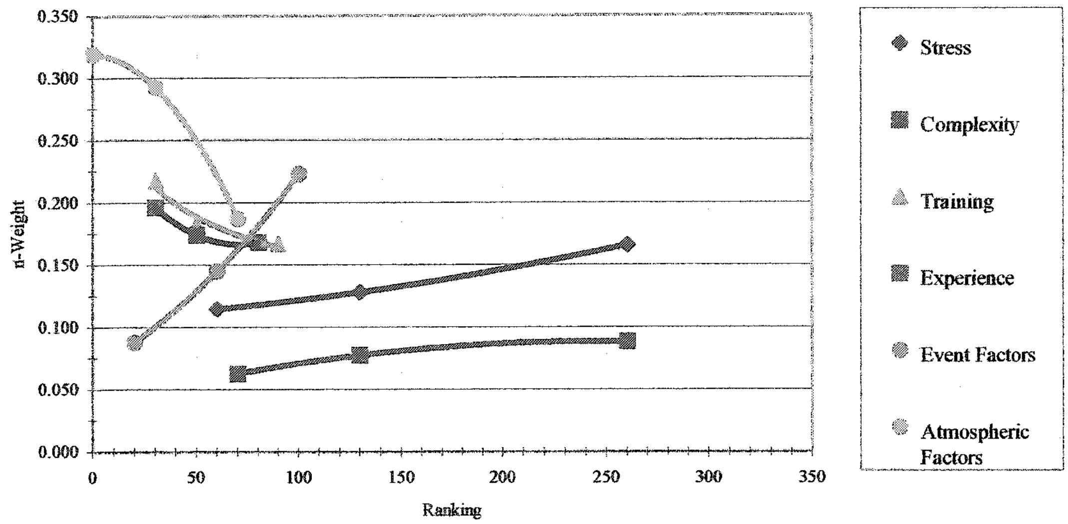

Figure 6.2 Action 1 n-weight reference graph.

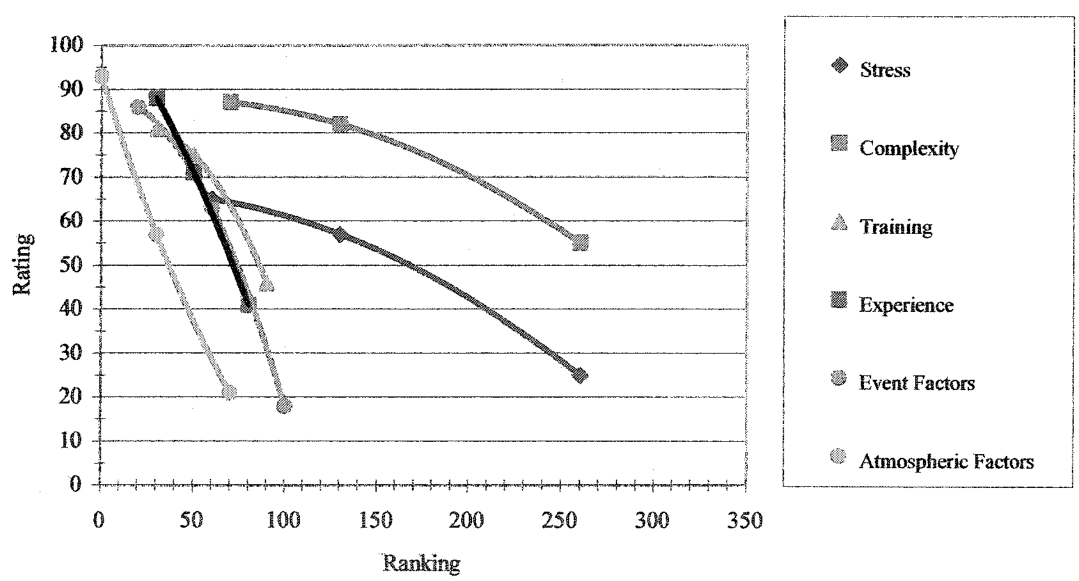

Figure 6.3 Action 1 rating reference graph.

graphs. Appendix L contains the remaining reference graphs for PSF n-weights and Appendix M contains the remaining reference graphs for PSF ratings.

6.3 Description of the HEPI Process

The main steps in the HEPI process were introduced in Chapter 1. This section provides a description of how HEPI is applied. This is followed by a worked example in Section 6.4. The first step in the HEPI process is to develop a muster scenario and rank the PSFs by means of Table 6.3. Once complete, the rankings for each PSF are tabulated (Table 6.9). The shaded boxes in Table 6.9 indicate which questions pertain to a particular PSF. The PSF rankings are summed and are used to determine the individual PSF n-weights and ratings from the reference graphs located in Appendices L and M, as previously mentioned.

Table 6.9 HEPI PSF ranking summary table.

Question	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
Total						

Note: PSF rankings are the sum of the values in the shaded blocks for each PSF.

Any PSF ranking which falls beyond the range of the reference muster rankings (Table 6.7) retains the boundary value to prevent extrapolation of the curves. The values for the PSF n-weights ($\sigma_{i,j}$) and ratings ($\delta_{i,j}$) beyond these boundaries are considered unknown and cannot be predicted. The n-weights and ratings are then recorded in Tables 6.10 and 6.11, respectively. The SLI values ($\psi_{i,j}$) are subsequently calculated and

Table 6.10 HEPI PSF n-weight table.

Action	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	$\sigma_{1,1}$	$\sigma_{1,2}$	$\sigma_{1,3}$	$\sigma_{1,4}$	$\sigma_{1,5}$	$\sigma_{1,6}$
2	$\sigma_{2,1}$	$\sigma_{2,2}$	$\sigma_{2,3}$	$\sigma_{2,4}$	$\sigma_{2,5}$	$\sigma_{2,6}$
3	$\sigma_{3,1}$	$\sigma_{3,2}$	$\sigma_{3,3}$	$\sigma_{3,4}$	$\sigma_{3,5}$	$\sigma_{3,6}$
4	$\sigma_{4,1}$	$\sigma_{4,2}$	$\sigma_{4,3}$	$\sigma_{4,4}$	$\sigma_{4,5}$	$\sigma_{4,6}$
5	$\sigma_{5,1}$	$\sigma_{5,2}$	$\sigma_{5,3}$	$\sigma_{5,4}$	$\sigma_{5,5}$	$\sigma_{5,6}$
6	$\sigma_{6,1}$	$\sigma_{6,2}$	$\sigma_{6,3}$	$\sigma_{6,4}$	$\sigma_{6,5}$	$\sigma_{6,6}$
7	$\sigma_{7,1}$	$\sigma_{7,2}$	$\sigma_{7,3}$	$\sigma_{7,4}$	$\sigma_{7,5}$	$\sigma_{7,6}$
8	$\sigma_{8,1}$	$\sigma_{8,2}$	$\sigma_{8,3}$	$\sigma_{8,4}$	$\sigma_{8,5}$	$\sigma_{8,6}$
9	$\sigma_{9,1}$	$\sigma_{9,2}$	$\sigma_{9,3}$	$\sigma_{9,4}$	$\sigma_{9,5}$	$\sigma_{9,6}$
10	$\sigma_{10,1}$	$\sigma_{10,2}$	$\sigma_{10,3}$	$\sigma_{10,4}$	$\sigma_{10,5}$	$\sigma_{10,6}$
11	$\sigma_{11,1}$	$\sigma_{11,2}$	$\sigma_{11,3}$	$\sigma_{11,4}$	$\sigma_{11,5}$	$\sigma_{11,6}$
12	$\sigma_{12,1}$	$\sigma_{12,2}$	$\sigma_{12,3}$	$\sigma_{12,4}$	$\sigma_{12,5}$	$\sigma_{12,6}$
13	$\sigma_{13,1}$	$\sigma_{13,2}$	$\sigma_{13,3}$	$\sigma_{13,4}$	$\sigma_{13,5}$	$\sigma_{13,6}$
14	$\sigma_{14,1}$	$\sigma_{14,2}$	$\sigma_{14,3}$	$\sigma_{14,4}$	$\sigma_{14,5}$	$\sigma_{14,6}$
15	$\sigma_{15,1}$	$\sigma_{15,2}$	$\sigma_{15,3}$	$\sigma_{15,4}$	$\sigma_{15,5}$	$\sigma_{15,6}$
16	$\sigma_{16,1}$	$\sigma_{16,2}$	$\sigma_{16,3}$	$\sigma_{16,4}$	$\sigma_{16,5}$	$\sigma_{16,6}$
17	$\sigma_{17,1}$	$\sigma_{17,2}$	$\sigma_{17,3}$	$\sigma_{17,4}$	$\sigma_{17,5}$	$\sigma_{17,6}$
18	$\sigma_{18,1}$	$\sigma_{18,2}$	$\sigma_{18,3}$	$\sigma_{18,4}$	$\sigma_{18,5}$	$\sigma_{18,6}$

Table 6.11 HEPI PSF rating table.

Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	$\delta_{1,1}$	$\delta_{1,2}$	$\delta_{1,3}$	$\delta_{1,4}$	$\delta_{1,5}$	$\delta_{1,6}$
2	$\delta_{2,1}$	$\delta_{2,2}$	$\delta_{2,3}$	$\delta_{2,4}$	$\delta_{2,5}$	$\delta_{2,6}$
3	$\delta_{3,1}$	$\delta_{3,2}$	$\delta_{3,3}$	$\delta_{3,4}$	$\delta_{3,5}$	$\delta_{3,6}$
4	$\delta_{4,1}$	$\delta_{4,2}$	$\delta_{4,3}$	$\delta_{4,4}$	$\delta_{4,5}$	$\delta_{4,6}$
5	$\delta_{5,1}$	$\delta_{5,2}$	$\delta_{5,3}$	$\delta_{5,4}$	$\delta_{5,5}$	$\delta_{5,6}$
6	$\delta_{6,1}$	$\delta_{6,2}$	$\delta_{6,3}$	$\delta_{6,4}$	$\delta_{6,5}$	$\delta_{6,6}$
7	$\delta_{7,1}$	$\delta_{7,2}$	$\delta_{7,3}$	$\delta_{7,4}$	$\delta_{7,5}$	$\delta_{7,6}$
8	$\delta_{8,1}$	$\delta_{8,2}$	$\delta_{8,3}$	$\delta_{8,4}$	$\delta_{8,5}$	$\delta_{8,6}$
9	$\delta_{9,1}$	$\delta_{9,2}$	$\delta_{9,3}$	$\delta_{9,4}$	$\delta_{9,5}$	$\delta_{9,6}$
10	$\delta_{10,1}$	$\delta_{10,2}$	$\delta_{10,3}$	$\delta_{10,4}$	$\delta_{10,5}$	$\delta_{10,6}$
11	$\delta_{11,1}$	$\delta_{11,2}$	$\delta_{11,3}$	$\delta_{11,4}$	$\delta_{11,5}$	$\delta_{11,6}$
12	$\delta_{12,1}$	$\delta_{12,2}$	$\delta_{12,3}$	$\delta_{12,4}$	$\delta_{12,5}$	$\delta_{12,6}$
13	$\delta_{13,1}$	$\delta_{13,2}$	$\delta_{13,3}$	$\delta_{13,4}$	$\delta_{13,5}$	$\delta_{13,6}$
14	$\delta_{14,1}$	$\delta_{14,2}$	$\delta_{14,3}$	$\delta_{14,4}$	$\delta_{14,5}$	$\delta_{14,6}$
15	$\delta_{15,1}$	$\delta_{15,2}$	$\delta_{15,3}$	$\delta_{15,4}$	$\delta_{15,5}$	$\delta_{15,6}$
16	$\delta_{16,1}$	$\delta_{16,2}$	$\delta_{16,3}$	$\delta_{16,4}$	$\delta_{16,5}$	$\delta_{16,6}$
17	$\delta_{17,1}$	$\delta_{17,2}$	$\delta_{17,3}$	$\delta_{17,4}$	$\delta_{17,5}$	$\delta_{17,6}$
18	$\delta_{18,1}$	$\delta_{18,2}$	$\delta_{18,3}$	$\delta_{18,4}$	$\delta_{18,5}$	$\delta_{18,6}$

recorded in Table 6.12 for each PSF. The SLI (ψ_{ij}) for a muster action is the sum of the PSF SLIs ($\sum \psi_{i,j}$). Next, the log POS values are determined from Figures 6.4 to 6.6, which are identical to Figures 5.49 to 5.51 without the upper and lower boundary lines. The SLI ranges for these curves contain gaps and some overlap. For example, the upper bound of the SLI range for Figure 6.5 is 72 while the lower bound of Figure 6.4 is 76. If a determined SLI value falls between these bounds it is recommended to determine the log POS based on the more conservative (lower) SLI range. The SLI ranges overlap for Figures 6.5 (lower bound is 45) and 6.6 (upper bound is 47). Again, if the determined SLI value falls within both ranges the more conservative SLI range should be used. The inverse (anti-log) of the log POS is performed to determine the probability of success (POS). The POS and HEP (1-POS) and assigned consequence for each action are recorded in Table 6.13. Risk ranking is also recorded in Table 6.13 and is described later in this section.

The next step is to relate the failure to complete an action with its consequence. A common industry practice is to relate the severity of an incident or failure to relevant

Table 6.12 HEPI PSF SLI table.

Action	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors	SLI Total
1	$\psi_{1,1}$	$\psi_{1,2}$	$\psi_{1,3}$	$\psi_{1,4}$	$\psi_{1,5}$	$\psi_{1,6}$	$\sum \psi_{i,1}$
2	$\psi_{2,1}$	$\psi_{2,2}$	$\psi_{2,3}$	$\psi_{2,4}$	$\psi_{2,5}$	$\psi_{2,6}$	$\sum \psi_{i,2}$
3	$\psi_{3,1}$	$\psi_{3,2}$	$\psi_{3,3}$	$\psi_{3,4}$	$\psi_{3,5}$	$\psi_{3,6}$	$\sum \psi_{i,3}$
4	$\psi_{4,1}$	$\psi_{4,2}$	$\psi_{4,3}$	$\psi_{4,4}$	$\psi_{4,5}$	$\psi_{4,6}$	$\sum \psi_{i,4}$
5	$\psi_{5,1}$	$\psi_{5,2}$	$\psi_{5,3}$	$\psi_{5,4}$	$\psi_{5,5}$	$\psi_{5,6}$	$\sum \psi_{i,5}$
6	$\psi_{6,1}$	$\psi_{6,2}$	$\psi_{6,3}$	$\psi_{6,4}$	$\psi_{6,5}$	$\psi_{6,6}$	$\sum \psi_{i,6}$
7	$\psi_{7,1}$	$\psi_{7,2}$	$\psi_{7,3}$	$\psi_{7,4}$	$\psi_{7,5}$	$\psi_{7,6}$	$\sum \psi_{i,7}$
8	$\psi_{8,1}$	$\psi_{8,2}$	$\psi_{8,3}$	$\psi_{8,4}$	$\psi_{8,5}$	$\psi_{8,6}$	$\sum \psi_{i,8}$
9	$\psi_{9,1}$	$\psi_{9,2}$	$\psi_{9,3}$	$\psi_{9,4}$	$\psi_{9,5}$	$\psi_{9,6}$	$\sum \psi_{i,9}$
10	$\psi_{10,1}$	$\psi_{10,2}$	$\psi_{10,3}$	$\psi_{10,4}$	$\psi_{10,5}$	$\psi_{10,6}$	$\sum \psi_{i,10}$
11	$\psi_{11,1}$	$\psi_{11,2}$	$\psi_{11,3}$	$\psi_{11,4}$	$\psi_{11,5}$	$\psi_{11,6}$	$\sum \psi_{i,11}$
12	$\psi_{12,1}$	$\psi_{12,2}$	$\psi_{12,3}$	$\psi_{12,4}$	$\psi_{12,5}$	$\psi_{12,6}$	$\sum \psi_{i,12}$
13	$\psi_{13,1}$	$\psi_{13,2}$	$\psi_{13,3}$	$\psi_{13,4}$	$\psi_{13,5}$	$\psi_{13,6}$	$\sum \psi_{i,13}$
14	$\psi_{14,1}$	$\psi_{14,2}$	$\psi_{14,3}$	$\psi_{14,4}$	$\psi_{14,5}$	$\psi_{14,6}$	$\sum \psi_{i,14}$
15	$\psi_{15,1}$	$\psi_{15,2}$	$\psi_{15,3}$	$\psi_{15,4}$	$\psi_{15,5}$	$\psi_{15,6}$	$\sum \psi_{i,15}$
16	$\psi_{16,1}$	$\psi_{16,2}$	$\psi_{16,3}$	$\psi_{16,4}$	$\psi_{16,5}$	$\psi_{16,6}$	$\sum \psi_{i,16}$
17	$\psi_{17,1}$	$\psi_{17,2}$	$\psi_{17,3}$	$\psi_{17,4}$	$\psi_{17,5}$	$\psi_{17,6}$	$\sum \psi_{i,17}$
18	$\psi_{18,1}$	$\psi_{18,2}$	$\psi_{18,3}$	$\psi_{18,4}$	$\psi_{18,5}$	$\psi_{18,6}$	$\sum \psi_{i,18}$

Success Likelihood Index (SLI) = rating x n-weight (e.g. $\psi_{1,1} = \delta_{1,1} \times \sigma_{1,1}$)

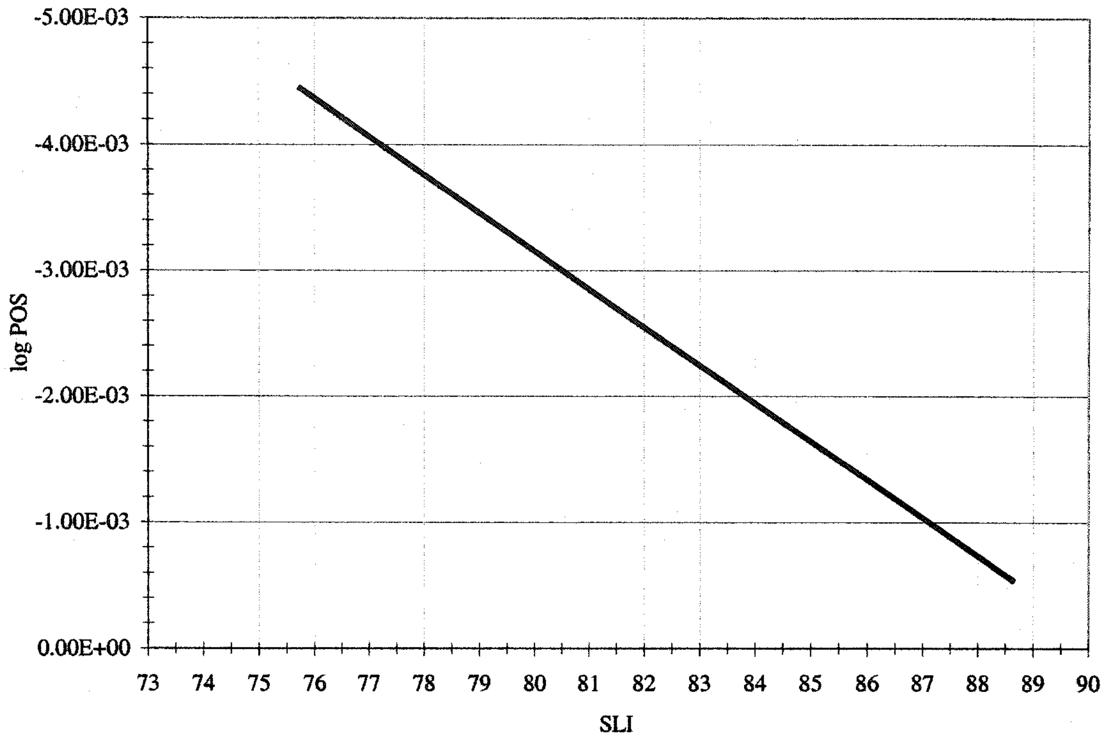

Figure 6.4 POS reference graph (SLI Range 76 to 88).

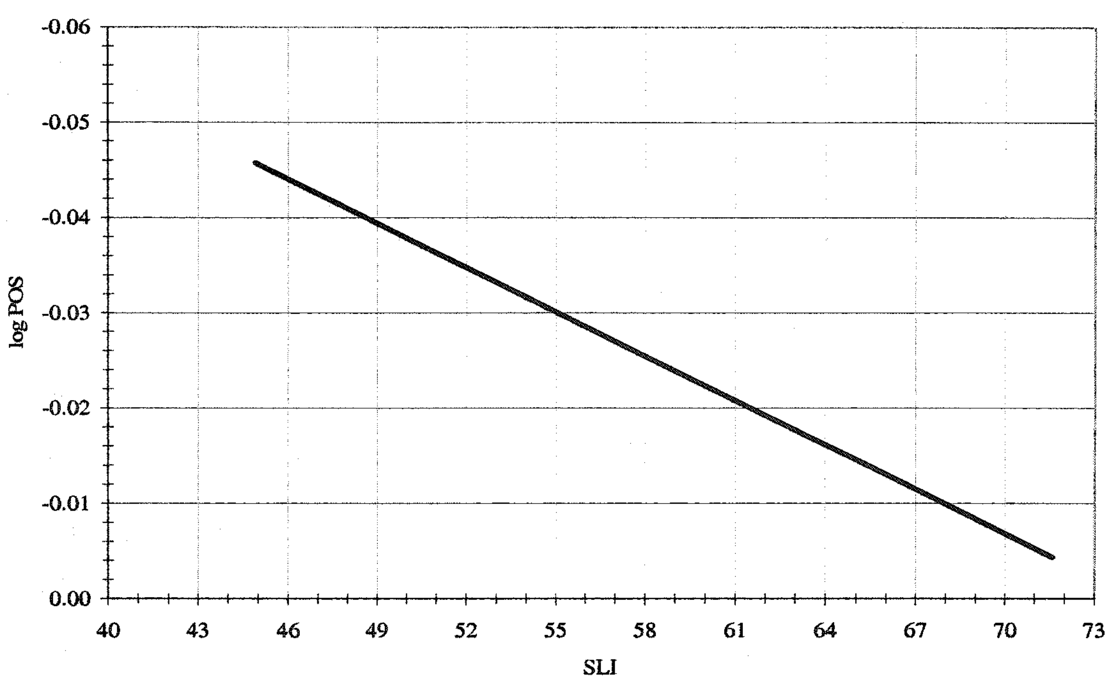

Figure 6.5 POS reference graph (SLI Range 45 to 72).

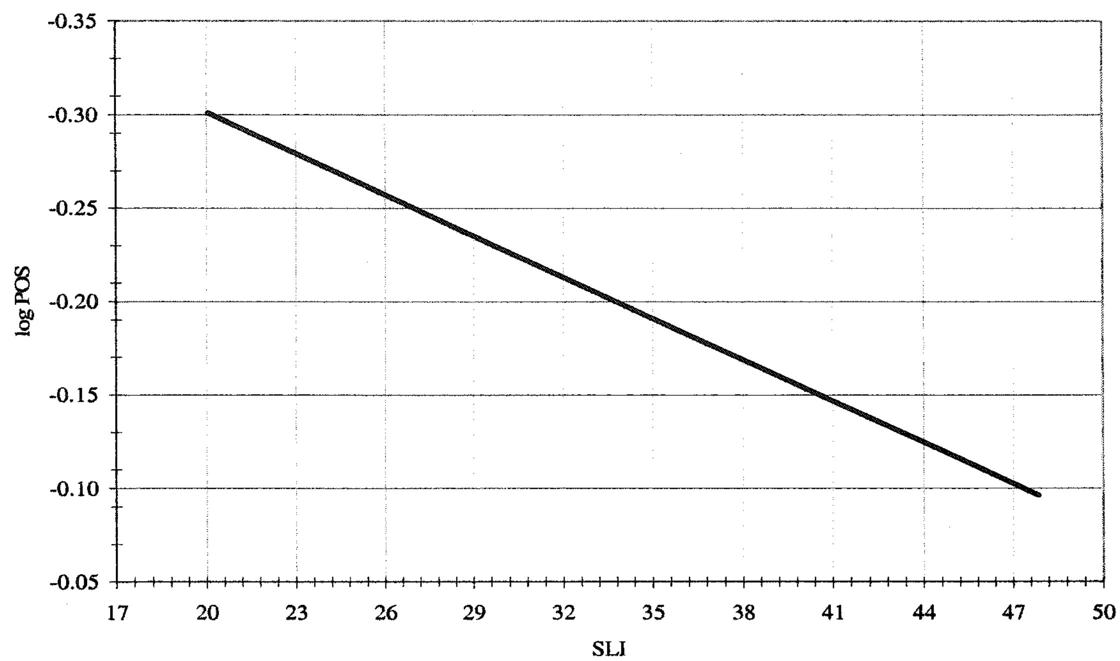

Figure 6.6 POS reference graph (SLI Range 20 to 47).

Table 6.13 HEPI risk record table.

Action	SLI	log POS	POS	HEP	Consequence	Risk Ranking	Risk Re-Rank
1	$\sum \psi_{i,1}$	$\log(\kappa_1)$	κ_1	$1-\kappa_1$	χ_1	Θ_1	Θ'_1
2	$\sum \psi_{i,2}$	$\log(\kappa_2)$	κ_2	$1-\kappa_2$	χ_2	Θ_2	Θ'_2
3	$\sum \psi_{i,3}$	$\log(\kappa_3)$	κ_3	$1-\kappa_3$	χ_3	Θ_3	Θ'_3
4	$\sum \psi_{i,4}$	$\log(\kappa_4)$	κ_4	$1-\kappa_4$	χ_4	Θ_4	Θ'_4
5	$\sum \psi_{i,5}$	$\log(\kappa_5)$	κ_5	$1-\kappa_5$	χ_5	Θ_5	Θ'_5
6	$\sum \psi_{i,6}$	$\log(\kappa_6)$	κ_6	$1-\kappa_6$	χ_6	Θ_6	Θ'_6
7	$\sum \psi_{i,7}$	$\log(\kappa_7)$	κ_7	$1-\kappa_7$	χ_7	Θ_7	Θ'_7
8	$\sum \psi_{i,8}$	$\log(\kappa_8)$	κ_8	$1-\kappa_8$	χ_8	Θ_8	Θ'_8
9	$\sum \psi_{i,9}$	$\log(\kappa_9)$	κ_9	$1-\kappa_9$	χ_9	Θ_9	Θ'_9
10	$\sum \psi_{i,10}$	$\log(\kappa_{10})$	κ_{10}	$1-\kappa_{10}$	χ_{10}	Θ_{10}	Θ'_{10}
11	$\sum \psi_{i,11}$	$\log(\kappa_{11})$	κ_{11}	$1-\kappa_{11}$	χ_{11}	Θ_{11}	Θ'_{11}
12	$\sum \psi_{i,12}$	$\log(\kappa_{12})$	κ_{12}	$1-\kappa_{12}$	χ_{12}	Θ_{12}	Θ'_{12}
13	$\sum \psi_{i,13}$	$\log(\kappa_{13})$	κ_{13}	$1-\kappa_{13}$	χ_{13}	Θ_{13}	Θ'_{13}
14	$\sum \psi_{i,14}$	$\log(\kappa_{14})$	κ_{14}	$1-\kappa_{14}$	χ_{14}	Θ_{14}	Θ'_{14}
15	$\sum \psi_{i,15}$	$\log(\kappa_{15})$	κ_{15}	$1-\kappa_{15}$	χ_{15}	Θ_{15}	Θ'_{15}
16	$\sum \psi_{i,16}$	$\log(\kappa_{16})$	κ_{16}	$1-\kappa_{16}$	χ_{16}	Θ_{16}	Θ'_{16}
17	$\sum \psi_{i,17}$	$\log(\kappa_{17})$	κ_{17}	$1-\kappa_{17}$	χ_{17}	Θ_{17}	Θ'_{17}
18	$\sum \psi_{i,18}$	$\log(\kappa_{18})$	κ_{18}	$1-\kappa_{18}$	χ_{18}	Θ_{18}	Θ'_{18}

categories through a consequence table. The advantage of a consequence table is its flexibility to suit any relevant consequence category with a wide range of severity.

The categories that can make up a consequence table include public safety, individual safety, occupational safety, environment, and economic (CSA, 1991). Table 6.14 is a consequence table developed by the International Organization for Standardization (ISO). This table applies to offshore natural gas production installations and is found in ISO standard 17776 (DNV, 2001). The relevant categories in Table 6.14 are people, assets, environment and company reputation (reputation). Severity ranges from no impact (0) to extremely serious (5).

Table 6.14 ISO 17776 consequence table (DNV, 2001).

Severity	People	Assets	Environment	Reputation
0	Zero injury	Zero damage	Zero effect	Zero impact
1	Slight injury	Slight damage	Slight effect	Slight impact
2	Minor injury	Minor damage	Major effect	Limited impact
3	Major injury	Local damage	Local effect	Considerable impact
4	Single fatality	Major damage	Major effect	Major national impact
5	Multiple fatalities	Extensive damage	Massive damage	Major international impact

The consequence categories for the current work are based on four key muster categories (ability to egress, effect on others, effect on muster initiator, and effect on personal health). The potential consequences range from simple time delays to loss of life (Table 6.15). As a guide, Table 6.16 assigns a consequence category for each reference muster action. Empirical data are required to more accurately assign consequences to human error. Observations taken from muster drills can help facilitate this need. Alternatively, consequences can be assigned through elicited feedback as was performed for PSF weights and ratings.

The next step is to translate the assigned consequences and predicted human error probabilities to risk through the use of a risk matrix. Table 6.17 is a risk matrix from ISO 17776 showing how probability and severity (Table 6.14) are qualitatively risk ranked. The white areas require no mitigating measures, the light gray areas require risk reduction measures and the dark gray area are not acceptable (DNV, 2001). If the risk lies in the

Table 6.15 HEPI consequence table.

Severity	Egressability	Other POB	Muster Initiator	Health
Critical (C)	Can no longer reach TSR or any other safe refuge. Can no longer have a dry evacuation.	Prevents one or more persons from reaching TSR or any safe refuge. Prevents others from having a dry evacuation.	Raises muster initiator severity to a level where muster is no longer possible.	Results in loss of life.
High (H)	Can no longer reach TSR or complete actions in TSR.	Prevents one or more persons from reaching TSR or prevents others from completing actions in TSR.	Raises muster initiator severity to a level where muster is in jeopardy.	Results in significant physical injury.
Medium (M)	Moderate to significant delay in arriving at TSR. Moderate to significant delay in completing TSR actions.	Moderately to significantly delays others from reaching TSR or their actions in TSR.	Raises muster initiator severity to a level which produces moderate to long delays in reaching TSR.	Potential for minor to moderate injuries.
Low (L)	Minor delay in reaching TSR or in performing actions in TSR.	Minor delay for others reaching TSR, or on others completing actions in TSR.	Is not likely to raise muster initiator severity and does not affect time to muster to any significant level.	No injuries likely.

Table 6.16 Assigned consequence category for reference muster actions.

Action	Description	MO*	GR*	F&E*
1	Detect alarm	L	M	H
2	Identify alarm	L	M	H
3	Act Accordingly	L	M	H
4	Ascertain if danger is imminent	M	H	C
5	Muster if in imminent danger	M	H	C
6	Return process equipment to safe state	M	H	C
7	Make workplace as safe as possible in limited time	M	H	C
8	Listen and follow PA announcements	M	H	C
9	Evaluate potential egress paths and choose route	M	H	C
10	Move along egress route	M	H	C
11	Assess quality of egress route while moving to TSR	M	H	C
12	Choose alternate route if egress path is not tenable	M	H	C
14	Assist others if needed or as directed	M	H	C
15	Register at TSR	L	M	H
16	Provide pertinent feedback attained while enroute to TSR	L	M	H
17	Don personal survival suit or TSR survival suit if instructed to abandon	L	M	H
18	Follow OIM's instructions	L	M	H

*For each action one or more consequences are possible within each category (Table 6.15).

Table 6.17 ISO 17776 risk table (DNV, 2001).

Severity	Probability				
	Rarely occurred in industry	Several times per year in industry	Has occurred in the operating company	Happened several times a year in the operating company	Happened several times per year in location
0					
1	Manage for continued improvement				
2					
3	Incorporate risk reducing measures				
4					
5			Intolerable		

dark gray areas, actions should be taken to reduce the risk to the light gray or preferably to the white areas. In industry, if mitigating measures are implemented and the risk remains in a light gray area, management approval is typically required to continue operations.

Table 6.18 is the risk matrix that is used in HEPI, relating HEP (determined through SLIM) and assigned consequences (Table 6.15) to risk. Risk is divided into three categories (indicated by shaded blocks). The dark gray blocks indicate a high risk, followed by lower risk signified by light gray shading, and the lowest risk associated with the non-shaded (white) blocks. Risks that fall in dark and light gray areas should be mitigated to the white areas, if possible.

Table 6.18 HEPI risk table.

Category	Human Error Probability	Consequence Severity			
		Critical (C)	High (H)	Medium (M)	Low (L)
A	0.10 to 1.0	1A	2A	3A	4A
B	0.01 to 0.10	1B	2B	3B	4B
C	0.001 to 0.01	1C	2C	3C	4C

It is useful to consider the mechanisms through which human error may manifest itself when choosing risk mitigation measures (RMMs). As a guide, Table 6.19 provides a list of error mechanisms as previously presented in Chapter 2 (Table 2.5). Risk mitigation measures (RMMs) for each action were developed based on the format provided by Kennedy (1993). Table 6.20 is an example for action 1. Risk mitigation measure tables for the remaining muster actions can be found in Appendix N. The RMM

Table 6.19 Human error mechanisms (adapted from Kennedy, 1993).

Error Mechanism	Error Form	Muster Example
Short cut invoked	A wrong intention is formed based on familiar cues which activate a short cut or inappropriate rule	Not bothering to make workplace safe before starting egress to TSR
Failure to consider special circumstances	A task is similar to others but special circumstances prevail which are ignored and the task is carried out inappropriately	An egress path is picked without considering its proximity to a gas release
Need for information not prompted	Failure of internal or external cues to prompt need to search for information	A malfunction of the muster alarm system prevents important messages from reaching personnel
Stereotype overrule	Due to a strong habit, actions are diverted along a familiar but incorrect pathway	An egress route taken during muster drills is chosen during a gas release despite the path's close proximity to the muster initiator
Assumption	Response is based, inappropriately, on data supplied through recall or guesses which do not correlate with available external information	Prior to opening a door, no checks are performed on surface temperature despite a known fire in the local area
Misinterpretation	Response is based on incorrect interpretation of data or the misunderstanding of verbal message command or request	A PA announcement is misinterpreted and taking an egress path of low tenability is taken
Mistake among alternatives	Several options available of which the incorrect one is chosen	Muster process offers alternative modes of egress and incorrect path is picked
Losing one's place	The correct position in the sequence of actions is misidentified as being later than actual	Once in the TSR, individual does not register, generating a missing person scenario
Motor variability	Lack of manual precision or incorrect force applied	Does not effectively close a valve while making workplace safe
Panic	Lack of composure; result is disorientation, incoherence and possibly static movement	Upon hearing muster alarm or witnessing muster initiator, person becomes incapacitated and unable to cope
Memory slip	Forgets to perform an action or some component of the action	Forgetting which direction the TSR is from current location
Spatial orientation inadequate	Despite individual's correct intention and recall of identification markings, performs an action in the wrong place or on the incorrect object	Closing similar but incorrect valve while in haste to make workplace safe before starting egress to TSR

Table 6.20 Risk mitigation table for action 1.

Action	Training	Procedure and Management Systems	Equipment
Detect alarm	1. Familiarize personnel with alarms 2. Muster training at infrequent intervals 3. Enlist feedback after training exercises on alarm effectiveness 4. Behavioural testing to determine panic potential 5. CCR operators trained to limit and remove inhibits as soon as possible 6. Experienced personnel trained to assist others as identified	1. Regular preventative maintenance of alarm system 2. Regular testing of alarm system 3. Survey of alarm effectiveness in severe weather conditions 4. Limit number of alarm types that can be annunciated to lower potential confusion 5. Identify new personnel with different coloured clothing 6. Buddy system for new personnel 7. Location board in CCR identifying work locations and personnel 8. All personnel in the process units equipped with two-way radios 9. Push buttons in strategic process locations	1. Alarm systems strategically placed to ensure coverage in all areas 2. Alarm redundancy through both audio and visual enunciation 3. Review of alarm system; compare with advances in technology 4. Review of applicable regulations and standards

tables provide suggestions to lower risk through improvements in training, procedures, management systems and equipment. HEPI does not restrict RMMs solely to these categories. The user may apply additional categories and risk mitigation measures, as required. Based on an action's risk mitigation measures, new PSF ratings are established. The revised HEP and consequence severity lead to the determination of a new risk level. An example of the application of RMMs is provided in Section 6.4.

The PSF n-weights are not recalculated if RMMs are applied. The n-weights signify the importance of each PSF based on each muster action. Recalling the elicitation of PSF weights from Chapter 4, each PSF is considered in their worst state during the weighting process. The PSF weights are a measure of the importance of each PSF relative to the most important PSF (PSF_{100}). The RMMs do, however, enhance the quality of the PSFs and their rating. An example of how RMMs influence PSF ratings is provided in Section 6.4. The re-ranked risks are recorded in Table 6.13. It would be useful to provide reference tables that relate improvements in PSF ratings through RMMs. An example of such a table is provided in Section 6.4. A recommendation is presented in Chapter 8 to consider the effect of RMMs on PSF ratings through a process similar to the elicitation of PSF weights and ratings.

The next section provides an example of the HEPI method for the Ocean Odyssey incident.

6.4 HEPI Example

To illustrate the use of HEPI, an example is performed applying the tables and graphs in the previous sections of this chapter. The case is that of the semi-submersible drilling rig, Ocean Odyssey (Odyssey), which suffered an explosion and caught fire following a well blowout in September of 1988. Most of the survivors evacuated via lifeboat, with several individuals jumping directly into the sea. One person on board, the radio operator, remained on the rig and perished (Robertson and Wright, 1997).

The Odyssey event occurred in the North Sea at mid-day. The muster initiator was a serious fire and explosion on the drilling rig. The weather was moderate at the time with wind speeds of 12 to 18 knots and visibility of over one mile. The personnel on board (POB) was a complement of 67 people, of which 58 evacuated by the totally enclosed motor propelled survival craft (TEMPSC) and eight jumped directly into the sea. As previously mentioned, one individual stayed on the Odyssey and perished.

The event was not a complete surprise, as well instability was recognized and had occurred over a prolonged period of time. This permitted individuals to prepare for muster and potential evacuations. When the event occurred, the noise from the escaping gas made PA announcements very difficult to hear, with only four of the 22 individuals who were interviewed stating that they heard any PA announcements. Fifteen of the interviewees also stated that they heard no muster alarm at the time of the event, and that the signal to muster was through word of mouth from other POB.

Several interviewees indicated that there was no great haste during the egress phase of the muster. Fifteen of the POB went directly to the muster station by a route practiced during their muster exercises, while five survivors were prevented from taking their first choice of egress route by gas, smoke or fire. Three of these five eventually jumped directly to the sea. These personnel did not muster immediately with "non-essential" personnel and as such received greater exposure to event factors that delayed their arrival at the TSR. This delay caused several individuals to actually miss the launch of the lifeboats.

The registration at the TSR was chaotic and may have actually occurred on the TEMPSC and not at the muster point. The muster lists were out of date and the confusion of the event resulted in some POB being accounted for twice. The Odyssey was equipped with single sized survival suits and many of the survivors indicated that the suits were difficult to put on. Three of the POB had no experience in donning these suits and this was further complicated by the loss of dexterity because of the integrated mitts.

Six of the survivors indicated the necessity of helping others don their survival suit. The suits further reduced the survivors' ability to walk and impaired their field of vision once their hoods were in place. Two-thirds of the survivors in each of the TEMPSC recalled that no-one instructed them to board the life boats after the muster check. They simply followed other POB into the boats as no boat marshals were in evidence.

The Odyssey's muster was inefficient and personnel relied heavily on one another in all phases of the muster. If the muster initiator had escalated more quickly, the loss of life may have been much greater. The report (Robertson and Wright, 1997) provides little information on the single fatality, although it appears that he was on-duty at the time of the muster. Further, there is no information concerning the Odyssey's POB capacity and little information is given in the report of any work activities at the time of muster that may have affected the initiating event or impeded egress routes.

For the purposes of this example, a likely scenario for the Odyssey is an operator who has a reasonable amount of experience (3 to 10 years) and is conducting a routine task that has no effect on the initiating event. The first step was to answer the questions in the muster setup table (Table 6.21, shaded blocks). These ranking values were used to populate the PSF ranking summary table (Table 6.22). This fire and explosion scenario on the Odyssey was severe and the event factors PSF ranking reflects this with a value of 100 (which indicates the event factors are strong as shown in Table 6.7). The reference graphs (Figures 6.2 and 6.3) were reproduced as Figures 6.7 and 6.8 to illustrate how the PSF n-weights and ratings were determined. These values are found in Tables 6.23 and 6.24, respectively.

The PSFs' SLI values were calculated as the product of the n-weights and ratings by equation [4-6]. These SLI values are found in Table 6.25. The sum of these PSF SLI values (equation [4-7]) is the SLI for action 1, which is 53.9. Figure 6.5 was reproduced as Figure 6.9 to graphically illustrate how the log POS value was determined from the SLI value. The HEP estimate (0.07) was recorded in Table 6.26 with the log POS and POS values. The consequence associated with a failure to perform this action was assigned through the HEPI consequence table (Table 6.27). The consequence is high, as failure to detect the alarm may result in an inability to reach the TSR (highlighted in yellow in Table 6.27).

The risk associated with this HEP (0.07) and consequence (H) is "2B", as seen in Table 6.28 (highlighted in yellow). In an effort to reduce the risk associated with this action, risk mitigation measures were considered (Table 6.20). Table 6.29 provides new PSF ratings based on a percent improvement of the original ratings for this action. The percent improvement was based on the difference between the PSFs' rating determined through the HEPI ranking process (Step 4, Figure 6.8) and the optimal PSFs' rating. The optimal PSF values are based on the MO scenario (Table E.1).

Table 6.21 Step 1 - HEPI muster ranking questionnaire (Odyssey example).

Muster Ranking					
1) What is the muster initiator? (Event Factors, Stress, Complexity)					
i) Drill	0	iv) Fire	30	vii) Spill	20
ii) Man overboard	10	v) Fire & explosion	**30**	viii) Helicopter crash	20
iii) Gas release	20	vi) Ship collision	20	ix) Man down	20
Total 30					
2) What is the immediate risk from the muster initiator? (Event Factor, Stress, Complexity)					
i) No effect on platform integrity; does not impede muster progress; no threat to personnel					0
ii) Can impede muster progress with potential injury to personnel					10
iii) Threatens integrity of platform; impedes muster progress; potential for loss of life					**30**
Total 30					
3) What is the weather at the time of muster? (Atmospheric Factors, Stress, Complexity)					
ia) Sun/cloud	0	ib) No wind	0	ic) < -30 deg C	30
iia) Rain	**10**	iib) Windy	**10**	iic) -21 to -30 deg C	20
iiia) Snow/sleet	20	iiib) Significant wind	20	iiic) -20 to 0 deg C	**10**
iva) Snow storm	30	ivb) Hurricane	30	ivc) 1 to 30 deg C	0
va) Heavy fog	20	vb) Tornado	30	vc) > 30 deg C	10
Total 30					
4) What is the time of day when the muster is initiated? (Stress, Complexity)					
i) Daytime	**0**	iii) Crew change			20
ii) Night time	20	iv) Night time after 12 am and before 6 am			30
Total 0					

Table 6.21 Con't.

5) What is the individual's description (job type)? (Training)					
i) Operator	**10**	iii) Maintenance	20	v) Kitchen staff	30
ii) Engineer	20	iv) Administration	30	vi) Cleaning staff	30
Total 10					

6) What is the level of the individual's offshore experience? (Experience, Training)					
ia) < 6 months	40	ib) Regular hitches	**10**	ic) No musters	20
iia) 6 months to 3 years	30	iib) Irregular hitches	20	iic) 1 to 5 musters	10
iiia) 4 to 10 years	**20**	iiib) Rare hitch	40	iiic) > 5 musters	**0**
iva) > 10 years	10				
Total 30					

7) How familiar is the individual with respect to their job at the time of muster? (Stress, Experience, Complexity)			
i) Routine task that is familiar	**10**	iii) New task; never done before	40
ii) Task that is infrequently performed	20		
Total 10			

8) How complex is the individual's job at the time of muster? (Complexity)			
i) Not complex	10	iii) Very complex and highly procedural	30
ii) Somewhat complex and procedural	**20**	iv) Very complex; highly procedural; team required	40
Total 20			

Table 6.21 Con't.

9) What is the level of criticality of the job at the time of muster? (Stress)			
i) Job will not result in escalation of muster initiator	**0**	iii) Job will escalate muster initiator	20
ii) Job has potential to escalate muster initiator	10		
Total 0			
10) What is the location of the individual in relation to the muster initiator? (Stress, Complexity, Event Factor)			
ia) Event initiated on different deck or platform	10	ib) Event does not affect egress route	0
iia) Event initiated on same deck	**20**	iib) Event may affect egress route	10
iiia) Event initiated in close proximity to individual	30	iiib) Event affects egress route	**20**
Total 40			

11) How many personnel are onboard (POB) at the time of muster? (Stress, Complexity)					
i) < 25% POB	10	ii) 25 to 75% POB	20	iii) 76 to 100% POB	**30**
Total 30					

12) Does the individual have any specialized level of training? (Training, Complexity, Stress)			
i) Not trained - First Aid	10	iii) Not trained - rescue	10
ii) Not trained - gas detection	10	iv) Not trained - fire fighting	10
Total 0			

Table 6.22 Step 2 – Determine PSF rankings (Odyssey example).

PSF Rankings						
Question	**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
1	30	30			30	
2	30	30			30	
3	30	30				30
4	0	0				
5			10			
6			30	30		
7	10	10		10		
8		20				
9	0					
10	40	40			40	
11	30	30				
12	0	0	0			
Total*	**170**	**190**	**40**	**40**	**100**	**30**

* PSF rankings are used in Figures 6.7 and 6.8 to determine PSFs' n-weight and rating, respectively.

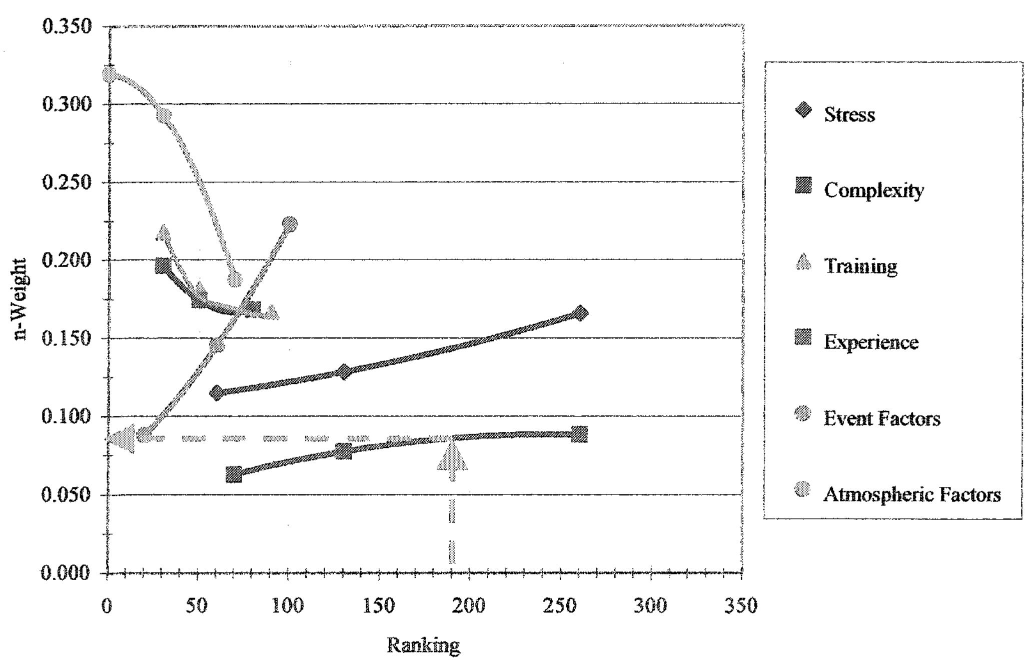

Figure 6.7 Step 3 - Determine PSF n-weights for action 1 (Odyssey example).

Table 6.23 Record of PSF n-weights (Odyssey example).

PSF n-Weights*						
Action	**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
1 (detect alarm)	0.14	0.08	0.19	0.18	0.22	0.29

* determined from Figure 6.7

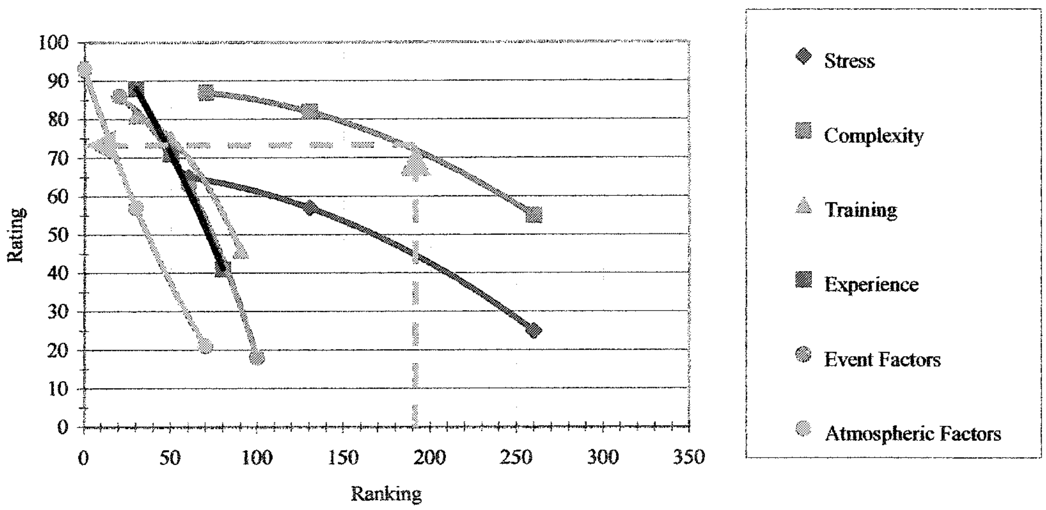

Figure 6.8 Step 4 – Determine PSF ratings for action 1 (Odyssey example).

Table 6.24 Record of PSF ratings (Odyssey example).

PSF Ratings*						
Action	**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
1 (detect alarm)	50	74	79	79	19	55

*determined from Figure 6.8

Table 6.25 Step 5 – Calculate and record PSF SLIs (Odyssey example).

SLI Values*							
Action	**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**	**SLI Total**
1 (detect alarm)	7.0	5.9	15.0	14.2	4.2	16.0	62.3

* equation [4-6]

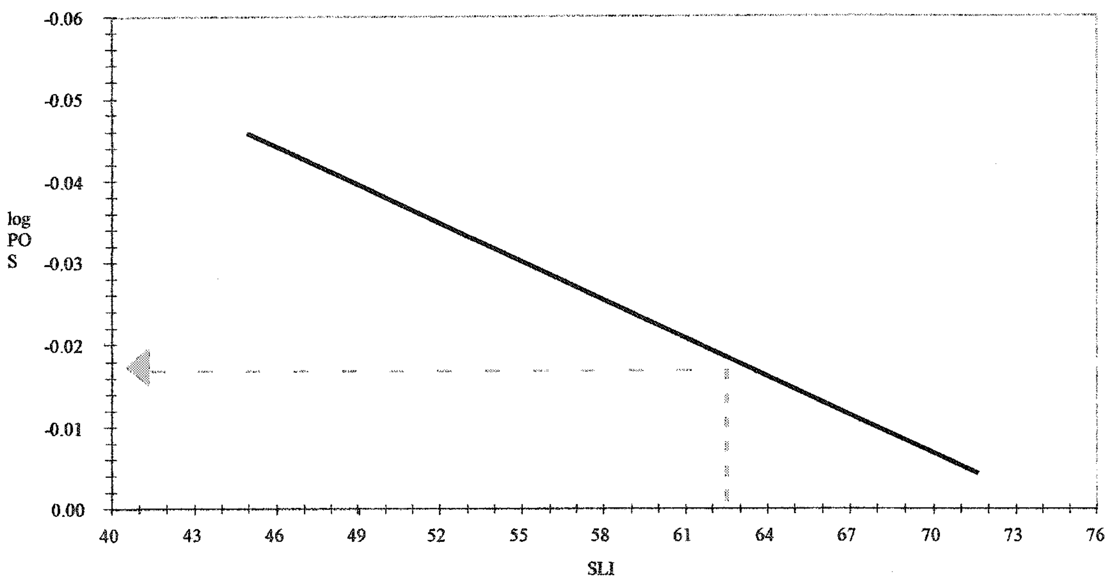

Figure 6.9 Step 6 – Determine log POS for action 1 (Odyssey example).

Table 6.26 Record of HEP, assigned consequence and risk (Odyssey example).

Risk						
Action	**SLI**	**log POS***	**POS**	**HEP (1-POS)**	**Consequence^**	**Risk Ranking~**
1 (detect alarm)	62.3	-0.018	0.96	0.04	H	2B

* determined from Figure 6.9
^ yellow shaded area, Table 6.27
~ yellow shaded area, Table 6.28

Table 6.27 HEPI consequence table (Odyssey example).

Severity	Egressability	Other POB	Muster Initiator	Health
Critical (C)	Can no longer reach TSR or any other safe refuge. Can no longer have a dry evacuation.	Prevents one or more persons from reaching TSR or any safe refuge. Prevents others from having a dry evacuation.	Raises muster initiator severity to a level where muster is no longer possible.	Results in loss of life.
High (H)	Can no longer reach TSR or complete actions in TSR.	Prevents one or more persons from reaching TSR or prevents others from completing actions in TSR.	Raises muster initiator severity to a level where muster is in jeopardy.	Results in significant physical injury.
Medium (M)	Moderate to significant delay in arriving at TSR. Moderate to significant delay in completing TSR actions.	Moderately to significantly delays others from reaching TSR or their actions in TSR.	Raises muster initiator severity to a level which produces moderate to long delays in reaching TSR.	Potential for minor to moderate injuries.
Low (L)	Minor delay in reaching TSR or in performing actions in TSR.	Minor delay for others reaching TSR, or on others completing actions in TSR.	Is not likely to raise muster initiator severity and does not affect time to muster to any significant level.	No injuries likely.

Table 6.28 HEPI risk table (Odyssey example).

Human Error Probability	Consequence Severity			
	Critical (C)	High (H)	Medium (M)	Low (L)
0.10 to 1.0	1A	2A	**3A**	**4A**
0.01 to 0.10	1B	**2B**	**3B**	**4B**
0.001 to 0.01	1C	**2C**	**3C**	**4C**

Table 6.29 Reference table for re-rating of PSFs – action 1 (Odyssey example).

Detect Alarm	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
Optimal Rating~	65	87	81	88	86	93
Original Rating^	50	74	79	79	19	55
Improved Ratings*						
10%	52	75	79	80	26	59
20%	53	77	79	81	32	63
30%	55	78	80	82	39	66
40%	56	79	80	83	46	70
50%	58	81	80	84	53	74
60%	59	82	80	84	59	78
70%	61	83	80	85	66	82
80%	62	84	81	86	73	85
90%	64	86	81	87	80	89
100%	65	87	81	88	86	93

* Percent improvement in PSF rating is the difference between the original PSF rating (^) found in Table 6.24 and the action's optimal PSF rating (~), based on the MO scenario (Table E.1). Example: 30 % improvement in stress = 55 + ((65-55) x 0.3) = 58.

As the MO sequence represents the best conditions of the three reference musters, the ratings associated with this scenario were considered optimal. Performance shaping factor ratings greater than those in the MO scenario were not studied in this work and are therefore not considered. Re-rating of PSFs for the remaining muster actions can be performed in a similar manner utilizing the RMM tables in Appendix N. Graphically, Figure 6.10 demonstrates a 30% improvement in stress rating (dotted line) as well as illustrating the optimal stress rating of 65 (dashed line), for action 1. Analogously, "improvement factors" based on task monitoring and feedback have been applied in the THERP methodology to improve failure probabilities (Kirwan et al., 1988).

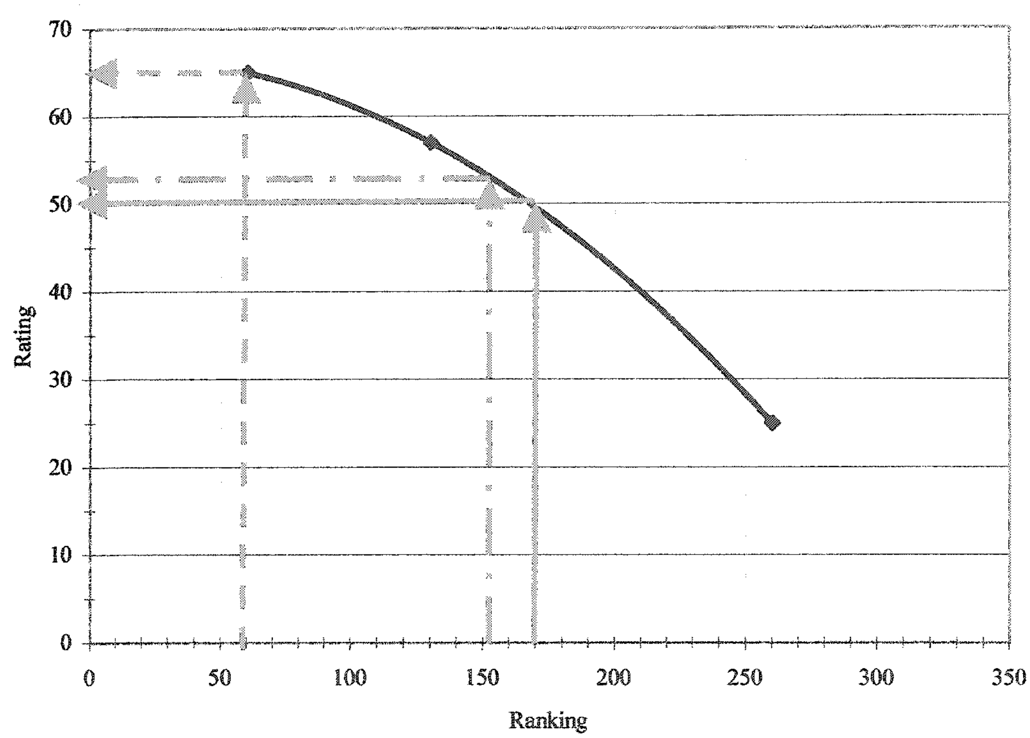

Figure 6.10 Re-rating of stress based on a 30% improvement through RMMs (solid line is the original PSF rating (50), dotted line is the re-rated PSF (52) and the dashed line is the optimal PSF rating (65) based on Table E.1, action 1, Odyssey example).

Based on the adoption of RMMs in Table 6.20 the percent improvement assigned to the PSFs' rating for action 1 were: stress (30%), complexity (30%), training (60%), experience (20%), event factors (20%), and atmospheric factors (30%). Stress was improved (lowered) through better training methods and the assistance of more experienced personnel. Complexity was improved (reduced) through improved training and alarm redundancy in the form of lights and audio signals. Training was improved by scheduling drills at infrequent intervals and enlisting feedback after training exercises. Experience was somewhat improved through more realistic drills and a higher frequency of testing. Event factors were mitigated through superior equipment and maintenance, improving reliability and availability of safety systems. Atmospheric factors were lessened through a reduction in the effect of severe weather by ensuring the ability of the safety systems to effectively annunciate the muster alarm to all personnel onboard in any location.

It is recognized that this approach to risk re-rating is subjective in nature and can lead to differences in interpretation. Empirical data are required for a more rigorous treatment of RMMs. Until these data are available, RMMs can be assessed through further elicitation of PSF ratings, qualified by the adoption of these measures. As previously mentioned in Section 6.3, this is a recommendation for further work found in Chapter 8.

The re-rated PSFs were recorded in Table 6.30 and the new PSF SLI values calculated (Table 6.31). Based on the re-rated PSFs, the SLI for action 1 was improved from 62.3 to 69.8. Figure 6.11 illustrates how the new log POS value was determined. The probability of success (POS) was increased from 0.96 to 0.98, and consequently, the HEP was reduced by 50% to 0.02 from 0.04. The HEP remained within the same probability range (0.10 to 0.01, Table 6.28) but the consequence deemed to have been lowered from a 2 (high) to a 3 (medium), resulting in a 3B risk level (Table 6.28, green shading). The new risk level was recorded in Table 6.32. The assigning of a reduced consequence because of the implementation of risk mitigation measures follows industry practice and requires experienced judgment. As with PSF re-ratings, new consequences

Table 6.30 Step 7 – Determine new PSF ratings based on RMMs (Odyssey example).

New Ratings*						
Action	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1 (detect alarm)	55	78	80	81	32	66
Percent improvement over original PSF ratings in Table 6.24	30	30	60	20	20	30

* determined from Table 6.29

Table 6.31 Step 8 – Calculate new SLI values based on new PSF ratings (Odyssey example).

New SLI Values*							
Action	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors	SLI Total
1 (detect alarm)	7.7	6.2	15.2	14.6	7.0	19.1	69.8

* equation [4-6] (n-weights from Table 6.23, ratings from Table 6.30)

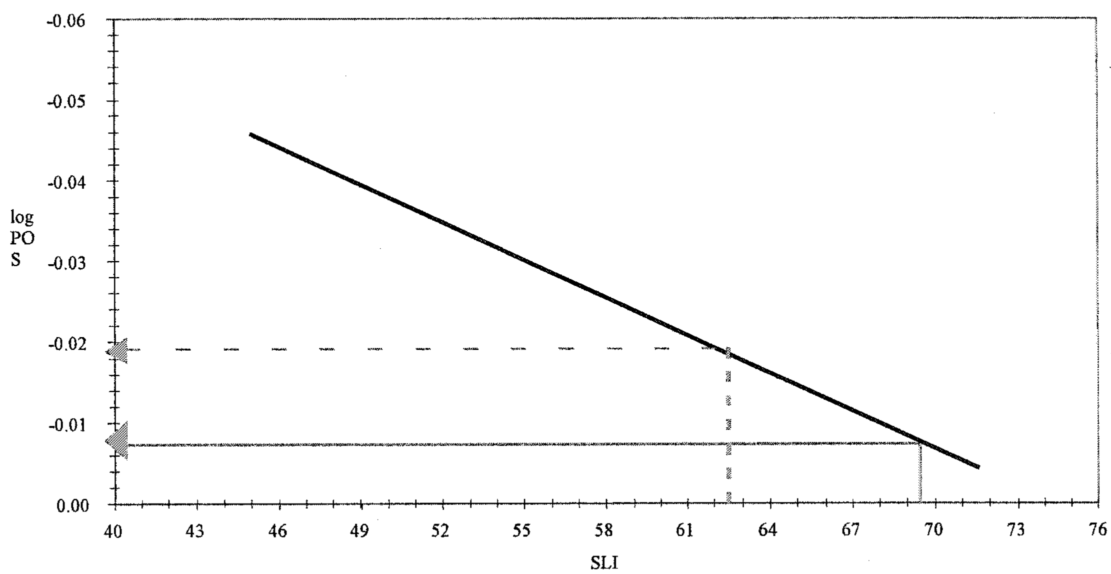

Figure 6.11 Step 9 - Determine log POS based on PSFs re-rating for action 1 (dashed line represents the original log POS (-0.018); the solid line is the revised log POS (-0.008) based on PSF re-rating, Odyssey example).

Table 6.32 Step 9 – Calculate new HEP and consequence (Odyssey example).

New Risk						
Action	SLI	log POS*	POS	HEP (1-POS)	Consequence^	Risk Re-Rank~
1	64.7	-0.08	0.98	0.02	M	3B

* determined from Figure 6.11
^ green shaded area, Table 6.27
~ green shaded area, Table 6.28

may also be obtained through the elicitation of judges. In order to lower the probability component of the estimated risk level for action 1, the SLI value needs to be sufficiently increased to move to a lower HEP range (0.01 to 0.001). For example, if the SLI for this example was increased to a value of 80 (log POS = -0.003, from Figure 6.4) the resultant POS would be 0.993. The HEP (0.007) would result in a 3C risk level (Table 6.28). This white area represents the optimal (lowest) risk level. This process can be repeated for the remaining muster actions that apply to this muster scenario. Further, the risk ranking can be extended to other individuals on the platform at the time of muster.

The next chapter provides conclusions drawn from this work followed by a section of recommendations for future work.

Chapter 7
CONCLUSIONS and RECOMMENDATIONS

7.1 Conclusions

The study of human factors in offshore platform musters has been presented in this work. This chapter provides a summary of this effort and the main conclusions derived from the analysis of data. Several recommendations are made in section 8.2 to further this area of study.

In summary, a core review team (CRT) of five individuals conducted a hierarchical task analysis of a muster sequence. A list of eighteen muster actions was developed that began at the sounding of the muster alarm and ended with the OIM's instructions in the temporary safe refuge (TSR). The actions were broken into four phases: awareness, evaluation, egress and recovery.

This team identified the most relevant performance shaping factors (i.e. stress, complexity, training, experience, event factors and atmospheric factors) that influence human error potential and developed three credible muster scenarios (i.e. man overboard (MO), gas release (GR) and fire and explosion (F&E)). An expert judgment technique, the success likelihood index methodology (SLIM) was applied with the assistance of a 24-person elicitation review team (ERT), to predict the probability of success (POS) of the muster tasks in each scenario. Questionnaires were developed to elicit the weight (i.e. importance) and rating (i.e. quality) of the six performance shaping factors (PSFs) for each muster action.

A human error probability index was proposed that applies the estimated probability of failure (1-POS) for each action through a series of reference graphs. The index methodology helps promote a consistent approach to the assessment of human factors in offshore platform musters. The index employs consequence and risk matrices to assess the ramifications of human failure for a range of muster severities. Risk mitigation measures are provided for each muster action, permitting a reevaluation of risk.

The logarithmic correlation developed by Pontecorvo (1965) and applied by Embrey et al. (1984) was utilized to provide a relationship between the success likelihood index (SLI) and the probability of success (equation [4-7]). Three of the four empirical data points derived from a review of three years of proprietary muster reports fell within the upper and lower bounds of the predicted log POS values for the MO scenario. Statistical tests of elicited data were performed through an analysis of variance technique (ANOVA) and a non-parametric ranking method (Kruskal-Wallis test). Analysis of PSF weight data showed that muster actions significantly influenced the weighting of PSFs for the GR and F&E scenarios; the muster scenarios strongly affected only the event factors PSF. Training and experience were weighted the highest of the PSFs, remaining essentially constant for all muster scenarios. Stress, complexity and event factors increased in weight as muster severity increased. Atmospheric factors became less important as the muster scenario became more severe.

ANOVA results for the PSF ratings were very clear with regard to muster scenarios. The severity of the muster significantly affected the ratings of all PSFs. The effect of the muster actions in the GR and F&E scenarios was equally as clear. In these musters, the tasks significantly affected the PSF ratings. In the MO scenario, complexity and event factor ratings were influenced by the muster actions, but the rejections of the null hypothesis (muster actions have no effect on PSF ratings) were weak. In the case of the MO scenario, the judges' responses indicated that they viewed the actions as not influencing the PSF ratings. This is consistent with the benign nature of the incident, the individual's high level of experience and the excellent weather. PSFs were rated highly throughout the muster sequence for MO.

The PSF ratings were highest in the awareness phase for all cases except for atmospheric factors in the fire and explosion scenario. In this scenario, the winter storm was seen to have an effect on the ability to detect the muster alarm. The lowest PSF ratings were found for actions in the evaluation and egress phases. The ratings improved once the individual entered the recovery phase, as these actions take place in the protective environment of the TSR. The ratings relative to skill, rule and knowledge modes of behaviour showed the PSF ratings were poorest for knowledge based actions which dominate the tasks in the evaluation and egress phases for the gas release and fire and explosion scenarios.

The ANOVA experiments for the calculated SLI values showed a strong indication that the muster scenarios affect the likelihood of success. When the muster actions were tested, the GR and F&E scenarios showed a significant impact on the likelihood of success. The MO scenario actions did not affect the likelihood of success. A check of the ERT subgroups showed good correlation in results between the subgroups with no excessive variations. The mix of operators, engineers, and health and safety professionals showed good consistency and provided balance in aspects of the SLIM process. The SLI values for each action in the MO scenario were highest among all the muster scenarios. The SLI values decreased with increasing muster severity and were lowest for knowledge-based action in the evaluation and egress phases for the gas release and fire and explosion scenarios.

The constants (*a* and *b*) for the log POS correlation (equation [4-7]) were determined by predicting HEPs for the MaxSLI and MinSLI actions by referencing literature, eliciting predictions from a group of ERT judges and through empirical data. The results were similar in the calculation of the HEPs by all three methods for the MO scenarios. The constants determined from the review of literature (estimated BHEPs) were used in the development of the HEPI reference graphs.

The probability of failure increased as muster severity and the individual's level of inexperience increased. HEPs ranged from 0.001 to 0.01 for low severity musters to a maximum of 0.5 for high severity musters. The application of these HEP predictions in the form of an index (HEPI) brings forward a human reliability assessment (HRA) tool that is accessible and practical. HEPI helps to bring human error out of the post-accident blame context into a proactive risk reduction process.

This research has identified areas where traditional muster training does not adequately prepare individuals to deal with high stress, difficult environments. The ability to prepare adequately for severe muster scenarios is achievable through advancements in training, procedures, management systems and equipment. As no system can ever be free of human error, preparing to deal with this eventuality by making systems more error tolerant will help to lower risk.

Muster training must seek out and identify human error in drills and challenge personnel to deal with unusual circumstances. The collection of human error data through drills and actual events can lead to the formation of a human error database that is specific to this application. The elicitation of more PSF data can be used to complement the current set of data or can generate new scenarios and provide greater detail to the index. HEPI can be enhanced as more data are gathered, improving the quality of HEP predictions and risk mitigation measures. Tools such as HEPI can help bring a common understanding of human error, the mechanisms that cause error, and the modes under which human failure occurs.

7.2 Recommendations

Recommendations to further this line of study are as follows:

1. Develop more muster scenarios to better define the weight and rating reference graphs.

2. Establish a muster program that includes job observations to permit the recording of errors made through all four phases of the muster sequence. Empirical data can be used to update HEP predictions, confirm consequences from human error and determine the effects of RMMs in reducing error probability.

3. Apply a second expert judgment technique to compare to HEP estimates derived from the success likelihood index method.

4. Apply a probabilistic approach to determine success likelihood index values based on the product of the normalized weight (n-weight) and rating distributions. Monte Carlo simulation may be used to determine the SLI values. The success likelihood index becomes the most probable value as opposed to a mean value.

5. Consider the use of fuzzy logic to better describe the weight and rating PSF boundaries and the SLI regions for reference muster scenarios.

6. Develop a spreadsheet application of HEPI based on Excel to permit faster HEP determinations.

7. Elicit data to develop consequence tables based on human error for each muster action.

8. Elicit data to develop RMM tables that relate an improvement in PSF rating to the incorporation of risk mitigating measures.

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Appendix A

Example Table for ERT Judge Ranking

Table A.1 Example ranking of ERT judges.

Criteria	Ranking	Judge A	Judge B
Years of Industry Experience			
< 2	2		
3 to 5	5		
6 to 10	10		10
11 to 20	15	15	
> 20	20		
Safety Training			
Basic risk assessment	5	5	5
Advanced risk assessment	10		
Basic Survival Training (BST)	2	2	2
Workplace Hazardous Materials Information System (WHMIS)	2	2	2
Incident investigation	2		
Confined space	2	2	
Rescue	5		
Safety Experience			
Hazard and Operability Study (HAZOP)	5	5	5
Tap Root ©	2	2	
Concept/design risk assessment	5	5	5
Years of Offshore Experience			
< 1	5		
1 to 3	10	10	10
3 to 10	15		
10 to 20	20		
> 20	25		
Muster Experience			
Participated in drills	5	5	
Participated in actual musters	10	10	
Variety of Experience			
Single platform	3		
Multiple platforms, same project	6	6	6
Multiple platforms, various projects	10		
Multiple platforms, different geographical location	15		
Job Type			
Engineer	2	2	
Offshore operator	5		
Regulatory authority	3		3
Health and Safety	10		
Offshore supervisor	12		
Administrative	1		
Maintenance	5		
Total		71	48

Appendix B
PSF Weighting Questionnaires

Table B.1 PSF weighting questionnaire for gas release scenario.

Weighting of Performance Shaping Factors PSFs are weighted in increments of 10 from 0 to 100, 100 having the greatest influence and 0 having least influence							
Scenario		**Performance Shaping Factors**					
Gas Release							
No.	**Actions**	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm						
2	Identify alarm						
3	Act accordingly						
4	Ascertain if danger is imminent						
5	Muster if in imminent danger						
6	Return process equipment to safe state						
7	Make workplace safe as possible in limited time						
8	Listen and follow PA announcements						
9	Evaluate potential egress paths and choose route						
10	Move along egress route						
11	Assess quality of egress route while moving to TSR						
12	Choose alternate route if egress path is not tenable						
13	Collect personal survival suit if in accommodations at time of muster						
14	Assist others if needed or as directed						
15	Register at TSR						
16	Provide pertinent feedback attained while enroute to TSR						
17	Don personal or TSR survival suit if instructed to abandon						
18	Follow OIM's instructions						

Directions: Assume all PSFs are as severe as possible in their own right. Take the PSF that if improved would afford the greatest possibility of completing the task successfully. Give that PSF a value of 100. Next weight each of the remaining PSFs against the one valued at 100, from 0 to 90. The 5 remaining PSFs may be of duplicate value. Consider the scenario when weighting PSFs for each task.

Table B.2 PSF weighting questionnaire for fire and explosion scenario.

Weighting of Performance Shaping Factors PSFs are weighted in increments of 10 from 0 to 100, 100 having the greatest influence and 0 having least influence							
Scenario		**Performance Shaping Factors**					
Fire and Explosion							
No.	**Actions**	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm						
2	Identify alarm						
3	Act accordingly						
4	Ascertain if danger is imminent						
5	Muster if in imminent danger						
6	Return process equipment to safe state						
7	Make workplace safe as possible in limited time						
8	Listen and follow PA announcements						
9	Evaluate potential egress paths and choose route						
10	Move along egress route						
11	Assess quality of egress route while moving to TSR						
12	Choose alternate route if egress path is not tenable						
13	Collect personal survival suit if in accommodations at time of muster						
14	Assist others if needed or as directed						
15	Register at TSR						
16	Provide pertinent feedback attained while enroute to TSR						
17	Don personal or TSR survival suit if instructed to abandon						
18	Follow OIM's instructions						

Directions: Assume all PSFs are as severe as possible in their own right. Take the PSF that if improved would afford the greatest possibility of completing the task successfully. Give that PSF a value of 100. Next weight each of the remaining PSFs against the one valued at 100, from 0 to 90. The 5 remaining PSFs may be of duplicate value. Consider the scenario when weighting PSFs for each task.

Appendix C

Performance Shaping Factor Weights

Table C.1 Mean PSF weights (MO).

No.	Action	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm	39	22	70	70	30	80
2	Identify alarm	45	34	85	85	36	64
3	Act accordingly	57	36	88	88	35	41
4	Ascertain if danger is imminent	54	36	75	75	40	54
5	Muster if in imminent danger	59	39	89	89	39	52
6	Return process equipment to safe state	60	65	88	88	30	38
7	Make workplace safe in limited time	63	62	77	77	33	47
8	Listen and follow PA announcements	58	47	70	70	38	76
9	Evaluate potential egress paths and choose route	59	43	76	76	40	64
10	Move along egress route	55	39	64	64	38	71
11	Assess quality of egress route while moving to TSR	60	46	60	60	34	63
12	Choose alternate route if egress path is not tenable	60	52	73	73	38	53
13	Collect personal survival suit if in accommodations at time of alarm	60	28	82	82	32	16
14	Assist others if needed or as directed	67	51	78	78	33	29
15	Register at TSR	50	26	93	93	29	14
16	Provide pertinent feedback attained while enroute to TSR	63	40	79	79	34	26
17	Don personal survival suit or TSR survival suit if instructed to abandon	65	46	88	88	24	10
18	Follow OIM's instructions	73	57	76	76	28	24

Table C.2 Mean PSF weights (GR).

No.	Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm	46	30	63	59	50	77
2	Identify alarm	52	33	90	75	51	63
3	Act accordingly	64	36	85	83	56	42
4	Ascertain if danger is imminent	65	43	72	87	66	50
5	Muster if in imminent danger	68	40	87	81	69	46
6	Return process equipment to safe state	69	76	83	87	70	41
7	Make workplace safe in limited time	71	62	80	81	68	43
8	Listen and follow PA announcements	73	47	70	73	66	76
9	Evaluate potential egress paths and choose route	73	56	80	85	76	56
10	Move along egress route	62	50	74	78	77	63
11	Assess quality of egress route while moving to TSR	72	53	71	83	69	60
12	Choose alternate route if egress path is not tenable	77	61	76	85	72	57
13	Collect personal survival suit if in accommodations at time of alarm	73	34	83	80	36	15
14	Assist others if needed or as directed	69	49	83	87	46	27
15	Register at TSR	57	34	93	81	39	16
16	Provide pertinent feedback attained while enroute to TSR	71	49	73	81	43	20
17	Don personal survival suit or TSR survival suit if instructed to abandon	70	50	84	79	35	15
18	Follow OIM's instructions	78	55	80	81	34	17

Table C.3 Mean PSF weights (F&E).

No.	Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm	59	35	63	62	79	67
2	Identify alarm	66	37	90	77	75	51
3	Act accordingly	75	44	85	82	71	40
4	Ascertain if danger is imminent	72	47	72	83	77	46
5	Muster if in imminent danger	72	45	87	77	80	43
6	Return process equipment to safe state	77	75	83	84	81	40
7	Make workplace safe in limited time	78	66	80	84	82	40
8	Listen and follow PA announcements	75	53	70	72	84	62
9	Evaluate potential egress paths and choose route	75	55	80	83	87	57
10	Move along egress route	70	53	74	77	83	53
11	Assess quality of egress route while moving to TSR	74	54	71	80	80	51
12	Choose alternate route if egress path is not tenable	77	59	76	87	83	49
13	Collect personal survival suit if in accommodations at time of alarm	70	33	83	80	51	18
14	Assist others if needed or as directed	80	54	83	87	67	34
15	Register at TSR	65	33	93	81	49	20
16	Provide pertinent feedback attained while enroute to TSR	73	48	73	82	52	18
17	Don personal survival suit or TSR survival suit if instructed to abandon	73	50	84	75	42	16
18	Follow OIM's instructions	78	60	80	78	49	21

Appendix D

Questionnaires for Rating Performance Shaping Factors

Table D.1 Questionnaire for rating of performance shaping factors (GR).

Rating of Performance Shaping Factors							
Scenario		**Performance Shaping Factors***					
Gas Release (3 yrs experience as an operator, daylight, winter, some wind, raining, gas release on other side of same deck)		**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
No.	Job at time of muster Gas Release is noticeable from operator's location, from high pressure source. Operator was changing filters on a solids filter.	100 = no stress associated with action 50 = some stress 0 = highly stressed	100 = not a complex action 50 = somewhat complex 0 = very complex	100 = highly trained in action 50 = some training 0 = no training	100 = very experienced in action 50 = somewhat experienced 0 = no experience	100 = no effect on action 50 = some effect 0 = large effect	100 = no effect on action 50 = some effect 0 = large effect
1	Detect alarm						
2	Identify alarm						
3	Act accordingly						
4	Ascertain if danger is imminent						
5	Muster if in imminent danger						
6	Return process equipment to safe state						
7	Make workplace as safe as possible in limited time						
8	Listen and follow PA announcements						
9	Evaluate potential egress paths and choose route						
10	Move along egress route						
11	Assess quality of egress route while moving to TSR						
12	Choose alternate route if egress path is not tenable						
13	Collect personal survival suit if in accommodations at time of muster						
14	Assist others if needed or as directed						
15	Register at TSR						
16	Provide pertinent feedback attained while enroute to TSR						
17	Don personal survival suit or TSR survival suit if instructed to abandon						
18	Follow OIM's instructions						

* Scales are provided as a guide. Ratings are in increments of 10 from 0 to 100.

Table D.2 Questionnaire for rating of performance shaping factors (F&E).

Rating of Performance Shaping Factors							
Scenario		**Performance Shaping Factors***					
Fire & Explosion (6 months experience as an operator, night time, winter storm, fire and explosion on same deck)		**Stress**	**Complexity**	**Training**	**Experience**	**Event Factors**	**Atmospheric Factors**
No.	Job at time of muster: Operator isolating A filter coalescer and switching flow to B unit.	100 = no stress associated with action 50 = some stress 0 = highly stressed	100 = not a complex action 50 = somewhat complex 0 = very complex	100 = highly trained in action 50 = some training 0 = no training	100 = very experienced in action 50 = somewhat experienced 0 = no experience	100 = no effect on action 50 = some effect 0 = large effect	100 = no effect on action 50 = some effect 0 = large effect
1	Detect alarm						
2	Identify alarm						
3	Act accordingly						
4	Ascertain if danger is imminent						
5	Muster if in imminent danger						
6	Return process equipment to safe state						
7	Make workplace as safe as possible in limited time						
8	Listen and follow PA announcements						
9	Evaluate potential egress paths and choose route						
10	Move along egress route						
11	Assess quality of egress route while moving to TSR						
12	Choose alternate route if egress path is not tenable						
13	Collect personal survival suit if in accommodations at time of muster						
14	Assist others if needed or as directed						
15	Register at TSR						
16	Provide pertinent feedback attained while enroute to TSR						
17	Don personal survival suit or TSR survival suit if instructed to abandon						
18	Follow OIM's instructions						

* Scales are provided as a guide. Ratings are in increments of 10 from 0 to 100.

Appendix E

Performance Shaping Factor Ratings

Table E.1 Mean PSF ratings (MO).

No.	Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm	65	87	81	88	86	93
2	Identify alarm	66	81	89	88	83	95
3	Act accordingly	68	77	86	88	81	92
4	Ascertain if danger is imminent	67	75	83	82	82	89
5	Muster if in imminent danger	64	77	88	84	84	91
6	Return process equipment to safe state	65	65	84	84	78	91
7	Make workplace as safe as possible in limited time	62	64	86	85	78	90
8	Listen and follow PA announcements	69	77	85	86	86	89
9	Evaluate potential egress paths and choose route	69	71	79	85	80	90
10	Move along egress route	73	80	85	86	83	92
11	Assess quality of egress route while moving to TSR	70	75	80	82	81	90
12	Choose alternate route if egress path is not tenable	71	72	79	78	80	90
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters					
14	Assist others if needed or as directed	65	68	80	82	77	90
15	Register at TSR	80	86	91	92	96	98
16	Provide pertinent feedback attained while enroute to TSR	73	73	82	79	81	91
17	Don personal survival suit or TSR survival suit if instructed to abandon	70	75	88	87	89	95
18	Follow OIM's instructions	76	79	88	89	93	96

Table E.2 Mean PSF ratings (GR).

No.	Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm	57	82	75	71	63	57
2	Identify alarm	52	73	75	73	63	58
3	Act accordingly	43	64	71	68	44	62
4	Ascertain if danger is imminent	40	53	60	61	38	59
5	Muster if in imminent danger	41	55	64	60	38	60
6	Return process equipment to safe state	41	49	64	63	33	59
7	Make workplace as safe as possible in limited time	35	47	64	63	32	57
8	Listen and follow PA announcements	46	58	66	65	48	55
9	Evaluate potential egress paths and choose route	40	51	62	60	36	56
10	Move along egress route	50	63	63	62	34	50
11	Assess quality of egress route while moving to TSR	48	58	56	56	38	50
12	Choose alternate route if egress path is not tenable	34	45	54	51	34	49
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters					
14	Assist others if needed or as directed	47	58	58	57	57	73
15	Register at TSR	66	79	75	73	76	83
16	Provide pertinent feedback attained while enroute to TSR	57	64	61	62	66	73
17	Don personal survival suit or TSR survival suit if instructed to abandon	55	72	68	65	76	76
18	Follow OIM's instructions	63	72	63	68	80	80

Table E.3 Mean PSF ratings (F&E).

No.	Actions	Stress	Complexity	Training	Experience	Event Factors	Atmospheric Factors
1	Detect alarm	25	55	46	41	18	21
2	Identify alarm	20	56	50	39	13	20
3	Act accordingly	15	46	38	30	10	28
4	Ascertain if danger is imminent	13	41	35	28	10	26
5	Muster if in imminent danger	18	46	44	31	17	24
6	Return process equipment to safe state	12	28	40	29	10	26
7	Make workplace as safe as possible in limited time	10	28	39	26	8	25
8	Listen and follow PA announcements	22	43	45	37	11	23
9	Evaluate potential egress paths and choose route	15	31	35	31	9	21
10	Move along egress route	24	43	43	38	17	25
11	Assess quality of egress route while moving to TSR	22	38	39	31	16	23
12	Choose alternate route if egress path is not tenable	11	27	33	25	8	23
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters					
14	Assist others if needed or as directed	26	43	40	36	33	38
15	Register at TSR	42	58	54	49	51	48
16	Provide pertinent feedback attained while enroute to TSR	35	49	50	43	33	37
17	Don personal survival suit or TSR survival suit if instructed to abandon	34	53	56	51	50	52
18	Follow OIM's instructions	39	53	57	49	46	50

Appendix F

Statistical Analysis of PSF Weights

Table F.1 Effect of muster initiators on action 2 weights.

Action 2 – identify muster alarm (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test no.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
2a	stress	5.67	3.13	0.01	*reject*	6.70	5.99	0.03	*reject*
2b	complexity	0.34	3.13	0.71	accept	0.37	5.99	0.83	accept
2c	training	0.33	3.13	0.72	accept	1.61	5.99	0.48	accept
2d	experience	0.82	3.13	0.44	accept	4.13	5.99	0.13	accept
2e	event factors	15.65	3.13	$2.49*10^{-6}$	**reject**	12.04	5.99	.0024	**reject**
2f	atmospheri c factors	1.17	3.13	0.32	accept	2.83	5.99	0.24	accept

Table F.2 Effect of muster initiators on action 3 weights.

Action 3 – act accordingly (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
3a	stress	3.47	3.13	0.04	*reject*	4.28	5.99	0.11	accept
3b	complexity	0.91	3.13	0.40	accept	1.12	5.99	0.57	accept
3c	training	0.15	3.13	0.87	accept	2.97	5.99	0.23	accept
3d	experience	0.09	3.13	0.91	accept	1.85	5.99	0.40	accept
3e	event factors	11.35	3.13	$5.46*10^{-5}$	**reject**	12.18	5.99	0.0022	**reject**
3f	atmospheric factors	0.04	3.13	0.96	accept	0.14	5.99	0.93	accept

Table F.3 Effect of muster initiators on action 4 weights.

Action 4 – ascertain if danger is imminent (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
4a	stress	4.27	3.13	0.18	*reject*	3.70	5.99	0.16	accept
4b	complexity	1.59	3.13	0.21	accept	2.11	5.99	0.35	accept
4c	training	0.13	3.13	0.88	accept	0.41	5.99	0.82	accept
4d	experience	0.50	3.13	0.61	accept	6.08	5.99	0.05	*reject*
4e	event factors	12.03	3.13	$3.28*10^{-5}$	**reject**	12.13	5.99	0.0023	**reject**
4f	atmospheric factors	0.47	3.13	0.62	accept	1.41	5.99	0.49	accept

Table F.4 Effect of muster initiators on action 5 weights.

Action 5 – muster if in imminent danger (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
5a	stress	2.32	3.13	0.11	accept	2.14	5.99	0.34	accept
5b	complexity	0.46	3.13	0.63	accept	0.51	5.99	0.77	accept
5c	training	0.65	3.13	0.52	accept	3.10	5.99	0.23	accept
5d	experience	0.96	3.13	0.39	accept	3.80	5.99	0.15	accept
5e	event factors	14.71	3.13	$4.78*10^{-6}$	**reject**	11.90	5.99	0.0026	**reject**
5f	atmospheric factors	0.53	3.13	0.59	accept	1.14	5.99	0.57	accept

Table F.5 Effect of muster initiators on action 6 weights.

Action 6 – return process equipment to safe state (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
6a	stress	3.86	3.13	0.03	*reject*	3.73	5.99	0.15	accept
6b	complexity	2.03	3.13	0.14	accept	2.22	5.99	0.33	accept
6c	training	1.68	3.13	0.19	accept	4.51	5.99	0.10	accept
6d	experience	0.43	3.13	0.65	accept	2.54	5.99	0.28	accept
6e	event factors	30.36	3.13	$3.47*10^{-10}$	**reject**	22.64	5.99	$1.21*10^{-5}$	**reject**
6f	atmospheric factors	0.18	3.13	0.84	accept	0.20	5.99	.090	accept

Table F.6 Effect of muster initiators on action 7 weights.

Action 7 – make workplace as safe as possible in limited time (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
7a	stress	3.86	3.13	0.03	*reject*	2.41	5.99	0.30	accept
7b	complexity	0.22	3.13	0.80	accept	0.14	5.99	0.93	accept
7c	training	0.13	3.13	0.88	accept	0.60	5.99	0.74	accept
7d	experience	1.00	3.13	0.37	accept	4.99	5.99	0.08	accept
7e	event factors	27.23	3.13	$1.91*10^{-9}$	**reject**	20.17	5.99	$4.18*10^{-5}$	**reject**
7f	atmospheric factors	0.77	3.13	0.78	accept	0.79	5.99	0.68	accept

Table F.7 Effect of muster initiators on action 8 weights.

Action 8 – listen and follow PA announcements (H_0 = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
8a	stress	3.52	3.13	0.04	*reject*	2.27	5.99	0.32	accept
8b	complexity	0.59	3.13	0.56	accept	0.55	5.99	0.76	accept
8c	training	0.17	3.13	0.84	accept	1.37	5.99	0.50	accept
8d	experience	0.02	3.13	0.98	accept	0.18	5.99	0.91	accept
8e	event factors	25.83	3.13	$4.21*10^{-9}$	**reject**	20.41	5.99	$3.68*10^{-5}$	**reject**
8f	atmospheric factors	1.83	3.13	0.17	accept	4.78	5.99	0.09	accept

Table F.8 Effect of muster initiators on action 9 weights.

Action 9 – evaluate potential egress paths and choose route (H_0 = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
9a	stress	3.29	3.13	0.04	*reject*	1.73	5.99	0.42	accept
9b	complexity	2.62	3.13	0.08	accept	2.52	5.99	0.28	accept
9c	training	0.86	3.13	0.43	accept	2.26	5.99	0.32	accept
9d	experience	0.47	3.13	0.63	accept	2.03	5.99	0.36	accept
9e	event factors	21.18	3.13	$6.74*10^{-8}$	**reject**	15.78	5.99	0.0004	**reject**
9f	atmospheric factors	0.39	3.13	0.68	accept	0.88	5.99	0.64	accept

Table F.9 Effect of muster initiators on action 10 weights.

Action 10 – move along egress route (H_0 = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
10a	stress	2.82	3.13	0.07	accept	2.10	5.99	0.34	accept
10b	complexity	1.77	3.13	0.17	accept	1.85	5.99	0.40	accept
10c	training	1.39	3.13	0.26	accept	1.13	5.99	0.57	accept
10d	experience	0.32	3.13	0.72	accept	0.92	5.99	0.63	accept
10e	event factors	20.99	3.13	$7.55*10^{-8}$	**reject**	15.52	5.99	0.0004	**reject**
10f	atmospheric factors	1.88	3.13	0.16	accept	3.83	5.99	0.15	accept

Table F.10 Effect of muster initiators on action 11 weights.

Action 11 – assess quality of egress route while moving to TSR (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	**PSF**	**ANOVA**				**Kruskal-Wallis**			
		F	**F_c**	**P-Value**	**Result**	**H**	**H_c**	**p-Value**	**Result**
11a	stress	2.79	3.13	0.07	accept	1.68	5.99	0.43	accept
11b	complexity	0.95	3.13	0.39	accept	1.16	5.99	0.56	accept
11c	training	1.11	3.13	0.33	accept	2.56	5.99	0.28	accept
11d	experience	0.34	3.13	0.71	accept	0.41	5.99	0.81	accept
11e	event factors	22.37	3.13	$3.25*10^{-8}$	**reject**	19.62	5.99	$5.48*10^{-5}$	**reject**
11f	atmospheric factors	0.84	3.13	0.43	accept	1.79	5.99	0.41	accept

Table F.11 Effect of muster initiators on action 12 weights.

Action 12 – choose alternate route if egress path is not tenable (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	**PSF**	**ANOVA**				**Kruskal-Wallis**			
		F	**F_c**	**P-Value**	**Result**	**H**	**H_c**	**p-Value**	**Result**
12a	stress	3.37	3.13	0.04	*reject*	1.56	5.99	0.46	accept
12b	complexity	0.94	3.13	0.40	accept	1.28	5.99	0.53	accept
12c	training	0.12	3.13	0.88	accept	1.21	5.99	0.54	accept
12d	experience	0.11	3.13	0.89	accept	0.82	5.99	0.66	accept
12e	event factors	21.14	3.13	$6.87*10^{-8}$	**reject**	18.54	5.99	$9.39*10^{-5}$	**reject**
12f	atmospheric factors	0.42	3.13	0.66	accept	1.30	5.99	0.52	accept

Table F.12 Effect of muster initiators on action 13 weights.

Action 13 – collect personal survival suit if in accommodations at time of muster (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	**PSF**	**ANOVA**				**Kruskal-Wallis**			
		F	**F_c**	**P-Value**	**Result**	**H**	**H_c**	**p-Value**	**Result**
13a	stress	1.23	3.13	0.30	accept	0.73	5.99	0.70	accept
13b	complexity	0.35	3.13	0.71	accept	0.39	5.99	0.82	accept
13c	training	0.03	3.13	0.97	accept	0.48	5.99	0.79	accept
13d	experience	0.15	3.13	0.86	accept	0.86	5.99	0.65	accept
13e	event factors	2.76	3.13	0.07	accept	4.91	5.99	0.08	accept
13f	atmospheric factors	0.25	3.13	0.78	accept	0.31	5.99	0.85	accept

Table F.13 Effect of muster initiators on action 14 weights.

Action 14 – assist others if needed or as directed (H_0 = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	**PSF**	**ANOVA**				**Kruskal-Wallis**			
		F	**F_c**	**P-Value**	**Result**	**H**	**H_c**	**p-Value**	**Result**
14a	stress	1.96	3.13	0.15	accept	1.73	5.99	0.42	accept
14b	complexity	0.14	3.13	0.87	accept	0.32	5.99	0.85	accept
14c	training	0.28	3.13	0.76	accept	2.20	5.99	0.33	accept
14d	experience	0.34	3.13	0.72	accept	0.05	5.99	0.98	accept
14e	event factors	9.89	3.13	$1*10^{-4}$	**reject**	13.18	5.99	0.0013	**reject**
14f	atmospheric factors	0.57	3.13	0.57	accept	0.71	5.99	0.70	accept

Table F.14 Effect of muster initiators on action 15 weights.

Action 15 – register at TSR (H_0 = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	**PSF**	**ANOVA**				**Kruskal-Wallis**			
		F	**F_c**	**P-Value**	**Result**	**H**	**H_c**	**p-Value**	**Result**
15a	stress	1.94	3.13	0.15	accept	2.22	5.99	0.33	accept
15b	complexity	0.54	3.13	0.59	accept	0.35	5.99	0.84	accept
15c	training	1.12	3.13	0.33	accept	3.18	5.99	0.20	accept
15d	experience	0.14	3.13	0.87	accept	0.56	5.99	0.76	accept
15e	event factors	3.18	3.13	0.05	*reject*	4.28	5.99	0.12	accept
15f	atmospheric factors	0.40	3.13	0.67	accept	0.21	5.99	0.90	accept

Table F.15 Effect of muster initiators on action 16 weights.

Action 16 – provide pertinent feedback attained while enroute to TSR (H_0 = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	**PSF**	**ANOVA**				**Kruskal-Wallis**			
		F	**F_c**	**P-Value**	**Result**	**H**	**H_c**	**p-Value**	**Result**
16a	stress	0.95	3.13	0.39	accept	0.58	5.99	0.75	accept
16b	complexity	0.71	3.13	0.49	accept	1.04	5.99	0.59	accept
16c	training	0.64	3.13	0.53	accept	1.90	5.99	0.39	accept
16d	experience	0.39	3.13	0.68	accept	1.26	5.99	0.53	accept
16e	event factors	2.61	3.13	0.08	accept	4.10	5.99	0.13	accept
16f	atmospheric factors	0.38	3.13	0.68	accept	0.15	5.99	0.93	accept

Table F.16 Effect of muster initiators on action 17 weights.

Action 17 – don personal survival suit or TSR survival suit if instructed to abandon (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	Result
17a	stress	0.84	3.13	0.44	accept	0.57	5.99	0.75	accept
17b	complexity	0.18	3.13	0.83	accept	0.45	5.99	0.80	accept
17c	training	0.23	3.13	0.80	accept	1.09	5.99	0.58	accept
17d	experience	0.65	3.13	0.52	accept	1.22	5.99	0.54	accept
17e	event factors	3.53	3.13	0.03	*reject*	3.31	5.99	0.19	accept
17f	atmospheric factors	1.32	3.13	0.27	accept	0.36	5.99	0.83	accept

Table F.17 Effect of muster initiators on action 18 weights.

Action 18 – follow OIM's instructions (H_o = severity of muster initiator does not affect PSF weights, $\alpha = 0.05$)									
Test No.	PSF	ANOVA				Kruskal-Wallis			
		F	F_c	P-Value	Result	H	H_c	p-Value	KW Result
18a	stress	0.36	3.13	0.70	accept	0.12	5.99	0.94	accept
18b	complexity	0.14	3.13	0.87	accept	0.94	5.99	0.95	accept
18c	training	0.30	3.13	0.74	accept	0.64	5.99	0.73	accept
18d	experience	0.30	3.13	0.74	accept	0.84	5.99	0.66	accept
18e	event factors	3.82	3.13	0.03	*reject*	5.28	5.99	0.71	accept
18f	atmospheric factors	0.20	3.13	0.82	accept	0.05	5.99	0.97	accept

Table F.18 Effect of muster actions on PSF weights (GR).

(H$_o$ = muster actions do not affect PSF weights, α = 0.05)				
PSF	**ANOVA**			
	F	**F$_c$**	**P-Value**	**Result**
stress	3.21	1.65	$1.91*10^{-5}$	**reject**
complexity	5.11	1.65	$3.35*10^{-10}$	**reject**
training	2.43	1.65	0.0012	**reject**
experience	2.18	1.65	0.0043	**reject**
event factors	7.85	1.65	$3.98*10^{-17}$	**reject**
atmospheric factors	15.92	1.65	$1.14*10^{-35}$	**reject**

Table F.19 Effect of muster actions on PSF weights (F&E).

(H$_o$ = muster actions do not affect PSF weights, α = 0.05)				
PSF	**ANOVA**			
	F	**F$_c$**	**P-Value**	**Result**
stress	1.26	1.65	0.21	accept
complexity	4.99	1.65	$6.76*10^{-10}$	**reject**
training	2.33	1.65	0.0020	**reject**
experience	1.96	1.65	0.012	**reject**
event factors	7.8	1.65	$5.39*10^{-17}$	**reject**
atmospheric factors	9.12	1.65	$3.13*10^{--20}$	**reject**

Appendix G

Statistical Analysis of PSF Ratings

Table G.1 Effect of muster severity on action 2 ratings.

Action 2 – identify muster alarm (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
2a	stress	22.54	3.13	$3.50*10^{-8}$	**reject**
2b	complexity	7.21	3.13	0.0014	**reject**
2c	training	21.37	3.13	$5.98*10^{-8}$	**reject**
2d	experience	45.03	3.13	$3.05*10^{-13}$	**reject**
2e	event factors	58.19	3.13	$1.56*10^{-15}$	**reject**
2f	atmospheric factors	70.81	3.13	$1.9*10^{-17}$	**reject**

Table G.2 Effect of muster severity on action 3 ratings.

Action 3 – act accordingly (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$))					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
3a	stress	51.14	3.13	$2.38*10^{-14}$	**reject**
3b	complexity	10.88	3.13	$7.79*10^{-5}$	**reject**
3c	training	42.98	3.13	$7.53*10^{-13}$	**reject**
3d	experience	54.07	3.13	$7.45*10^{-15}$	**reject**
3e	event factors	75.89	3.13	$3.74*10^{-18}$	**reject**
3f	atmospheric factors	44.94	3.13	$3.18*10^{-13}$	**reject**

Table G.3 Effect of muster severity on action 4 ratings.

Action 4 – ascertain if danger is imminent (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
4a	stress	49.58	3.13	$4.5*10^{-14}$	**reject**
4b	complexity	15.26	3.13	$3.26*10^{-6}$	**reject**
4c	training	40.72	3.13	$2.10*10^{-12}$	**reject**
4d	experience	51.88	3.13	$1.77*10^{-14}$	**reject**
4e	event factors	97.58	3.13	$7.69*10^{-21}$	**reject**
4f	atmospheric factors	43.59	3.13	$5.75*10^{-13}$	**reject**

Table G.4 Effect of muster severity on action 5 ratings.

Action 5 – muster if in imminent danger (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
5a	stress	30.11	3.13	$3.97*10^{-10}$	**reject**
5b	complexity	13.42	3.13	$1.19*10^{-5}$	**reject**
5c	training	35.68	3.13	$2.29*10^{-11}$	**reject**
5d	experience	43.36	3.13	$6.35*10^{-13}$	**reject**
5e	event factors	68.8	3.13	$3.70*10^{-17}$	**reject**
5f	atmospheric factors	60.96	3.13	$5.64*10^{-16}$	**reject**

Table G.5 Effect of muster severity on action 6 ratings.

Action 6 – return process equipment to safe state (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
6a	stress	47.63	3.13	$1.01*10^{-13}$	**reject**
6b	complexity	19.10	3.13	$2.50*10^{-7}$	**reject**
6c	training	45.23	3.13	$2.81*10^{-13}$	**reject**
6d	experience	58.45	3.13	$1.41*10^{-15}$	**reject**
6e	event factors	79.07	3.13	$1.41*10^{-18}$	**reject**
6f	atmospheric factors	5.54	3.13	$3.03*10^{-14}$	**reject**

Table G.6 Effect of muster severity on action 7 ratings.

Action 7 – make workplace as safe as possible in limited time (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
7a	stress	41.51	3.13	$1.46*10^{-12}$	**reject**
7b	complexity	17.32	3.13	$7.99*10^{-7}$	**reject**
7c	training	47.23	3.13	$1.19*10^{-13}$	**reject**
7d	experience	57.71	3.13	$1.86*10^{-15}$	**reject**
7e	event factors	87.33	3.13	$1.25*10^{-19}$	**reject**
7f	atmospheric factors	51.82	3.13	$1.81*10^{-14}$	**reject**

Table G.7 Effect of muster severity on action 8 ratings.

Action 8 – listen and follow PA announcements (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
8a	stress	32.13	3.13	$1.37*10^{-10}$	**reject**
8b	complexity	13.91	3.13	$8.42*10^{-6}$	**reject**
8c	training	24.85	3.13	$7.45*10^{-9}$	**reject**
8d	experience	40.83	3.13	$1.99*10^{-12}$	**reject**
8e	event factors	84.40	3.13	$2.90*10^{-19}$	**reject**
8f	atmospheric factors	55.38	3.13	$4.51*10^{-15}$	**reject**

Table G.8 Effect of muster severity on action 9 ratings.

Action 9 – evaluate potential egress paths and choose route (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
9a	stress	57.04	3.13	$2.39*10^{-15}$	**reject**
9b	complexity	22.76	3.13	$2.56*10^{-8}$	**reject**
9c	training	31.45	3.13	$1.95*10^{-10}$	**reject**
9d	experience	45.45	3.13	$2.55*10^{-13}$	**reject**
9e	event factors	64.50	3.13	$1.60*10^{-16}$	**reject**
9f	atmospheric factors	61.83	3.13	$4.11*10^{-16}$	**reject**

Table G.9 Effect of muster severity on action 10 ratings.

Action 10 – move along egress route (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
10a	stress	34.47	3.13	$4.18*10^{-11}$	**reject**
10b	complexity	21.28	3.13	$6.32*10^{-8}$	**reject**
10c	training	33.40	3.13	$7.15*10^{-11}$	**reject**
10d	experience	34.26	3.13	$4.63*10^{-11}$	**reject**
10e	event factors	78.35	3.13	$1.75*10^{-18}$	**reject**
10f	atmospheric factors	58.24	3.13	$1.53*10^{-15}$	**reject**

Table G.10 Effect of muster severity on action 11 ratings.

Action 11 – assess quality of egress route while moving to TSR (H_o = muster severity does not affect PSF ratings, α = 0.05)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
11a	stress	40.22	3.13	$2.64*10^{-12}$	**reject**
11b	complexity	23.47	3.13	$1.67*10^{-8}$	**reject**
11c	training	34.75	3.13	$3.64*10^{-11}$	**reject**
11d	experience	40.80	3.13	$2.02*10^{-12}$	**reject**
11e	event factors	69.70	3.13	$2.75*10^{-17}$	**reject**
11f	atmospheric factors	63.81	3.13	$2.04*10^{-16}$	**reject**

Table G.11 Effect of muster severity on action 12 ratings.

Action 12 – choose alternate route if egress path is not tenable (H_o = muster severity does not affect PSF ratings, α = 0.05)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
12a	stress	64.95	3.13	$1.37*10^{-16}$	**reject**
12b	complexity	30.51	3.13	$3.20*10^{-10}$	**reject**
12c	training	41.29	3.13	$1.61*10^{-12}$	**reject**
12d	experience	39.02	3.13	$4.61*10^{-12}$	**reject**
12e	event factors	93.91	3.13	$2.03*10^{-20}$	**reject**
12f	atmospheric factors	52.69	3.13	$1.28*10^{-14}$	**reject**

Table G.12 Effect of muster severity on action 14 ratings.

Action 14 – assist others if needed or as directed (H_o = muster severity does not affect PSF ratings, α = 0.05)					
Test No.	PSF	ANOVA			
		F	F_c	P-Value	Result
14a	stress	18.95	3.13	$2.75*10^{-7}$	**reject**
14b	complexity	12.52	3.13	$2.29*10^{-5}$	**reject**
14c	training	32.76	3.13	$9.96*10^{-11}$	**reject**
14d	experience	39.17	3.13	$4.3*10^{-12}$	**reject**
14e	event factors	21.08	3.13	$7.15*10^{-8}$	**reject**
14f	atmospheric factors	31.58	3.13	$1.83*10^{-10}$	**reject**

Table G.13 Effect of muster severity on action 15 ratings.

Action 15 – register at TSR (H$_o$ = muster severity does not affect PSF ratings, α = 0.05)					
Test No.	**PSF**	**ANOVA**			
		F	**F$_c$**	**P-Value**	**Result**
15a	stress	15.16	3.13	$3.47*10^{-6}$	**reject**
15b	complexity	9.76	3.13	0.00019	**reject**
15c	training	17.42	3.13	$7.5*10^{-7}$	**reject**
15d	experience	23.63	3.13	$1.52*10^{-8}$	**reject**
15e	event factors	24.00	3.13	$1.23*10^{-8}$	**reject**
15f	atmospheric factors	33.64	3.13	$6.33*10^{-11}$	**reject**

Table G.14 Effect of muster severity on action 16 ratings.

Action 16 – provide pertinent feedback attained while enroute to TSR (H$_o$ = muster severity does not affect PSF ratings, α = 0.05)					
Test No.	**PSF**	**ANOVA**			
		F	**F$_c$**	**P-Value**	**Result**
16a	stress	17.95	3.13	$5.29*10^{-7}$	**reject**
16b	complexity	10.97	3.13	$7.25*10^{-5}$	**reject**
16c	training	17.52	3.13	$7.03*10^{-7}$	**reject**
16d	experience	17.32	3.13	$8.02*10^{-7}$	**reject**
16e	event factors	22.53	3.13	$2.95*10^{-8}$	**reject**
16f	atmospheric factors	31.03	3.13	$2.44*10^{-10}$	**reject**

Table G.15 Effect of muster severity on action 17 ratings.

Action 17 – don personal survival suit or TSR survival suit if instructed to abandon (H$_o$ = muster severity does not affect PSF ratings, α = 0.05)					
Test No.	**PSF**	**ANOVA**			
		F	**F$_c$**	**P-Value**	**Result**
17a	stress	9.25	3.13	0.00028	**reject**
17b	complexity	5.53	3.13	0.0060	**reject**
17c	training	13.41	3.13	$1.20*10^{-5}$	**reject**
17d	experience	14.33	3.13	$6.22*10^{-6}$	**reject**
17e	event factors	11.74	3.13	$3.98*10^{-5}$	**reject**
17f	atmospheric factors	14.87	3.13	$4.27*10^{-6}$	**reject**

Table G.16 Effect of muster severity on action 18 ratings.

Action 18 – follow OIM's instructions (H_o = muster severity does not affect PSF ratings, $\alpha = 0.05$)					
Test No.	**PSF**	**ANOVA**			
		F	**F_c**	**P-Value**	**Result**
18a	stress	11.98	3.13	$3.42*10^{-5}$	**reject**
18b	complexity	6.61	3.13	0.0024	**reject**
18c	training	15.35	3.13	$3.05*10^{-6}$	**reject**
18d	experience	14.24	3.13	$6.67*10^{-6}$	**reject**
18e	event factors	25.01	3.13	$6.75*10^{-9}$	**reject**
18f	atmospheric factors	21.72	3.13	$4.85*10^{-8}$	**reject**

Table G.17 Effect of muster actions on PSF ratings (GR).

(H$_o$ = muster actions do not affect PSF ratings, α = 0.05)				
PSF	**ANOVA**			
	F	**F$_c$**	**P-Value**	**Result**
stress	3.21	1.65	$1.91*10^{-5}$	**reject**
complexity	5.11	1.65	$3.34*10^{-10}$	**reject**
training	2.95	1.65	$8.12*10^{-5}$	**reject**
experience	2.09	1.65	0.0066	**reject**
event factors	13.30	1.65	$7.82*10^{-30}$	**reject**
atmospheric factors	4.72	1.65	$3.50*10^{-9}$	**reject**

Table G.18 Effect of muster actions on PSF ratings (F&E).

(H$_o$ = muster actions do not affect PSF ratings, α = 0.05)				
PSF	**ANOVA**			
	F	**F$_c$**	**P-Value**	**Result**
stress	6.06	1.65	$1.30*10^{-12}$	**reject**
complexity	3.71	1.65	$1.10*10^{-6}$	**reject**
training	2.88	1.65	0.00012	**reject**
experience	3.52	1.65	$3.45*10^{-6}$	**reject**
event factors	11.11	1.65	$5.55*10^{-25}$	**reject**
atmospheric factors	3.42	1.65	$5.96*10^{-6}$	**reject**

Appendix H

Success Likelihood Index Results

Table H.1 Mean SLI results for each muster scenario.

No.	Actions	Mean SLI		
		MO	GR	F&E
1	Detect alarm	83	66	31
2	Identify alarm	85	66	32
3	Act accordingly	83	59	26
4	Ascertain if danger is imminent	80	52	24
5	Muster if in imminent danger	82	53	29
6	Return process equipment to safe state	78	51	23
7	Make workplace as safe as possible in limited time	77	50	21
8	Listen and follow PA announcements	83	56	29
9	Evaluate potential egress paths and choose route	80	51	23
10	Move along egress route	84	53	30
11	Assess quality of egress route while moving to TSR	81	51	27
12	Choose alternate route if egress path is not tenable	78	45	20
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters		
14	Assist others if needed or as directed	76	56	35
15	Register at TSR	89	71	48
16	Provide pertinent feedback attained while enroute to TSR	79	62	41
17	Don personal survival suit or TSR survival suit if instructed to abandon	83	68	48
18	Follow OIM's instructions	83	68	47

Table H.2 Predicted SLI values by ERT and subgroups (MO).

No.	Description	Mean SLI						
		ERT	CRT	Non CRT	Operators	Engineers	<35	>35
1	Detect alarm	83	86	83	73	92	89	81
2	Identify alarm	85	90	83	74	90	96	81
3	Act accordingly	83	86	82	78	85	90	80
4	Ascertain if danger is imminent	80	83	79	76	81	84	78
5	Muster if in imminent danger	82	90	80	78	83	85	81
6	Return process equipment to safe state	78	84	76	72	80	87	75
7	Make workplace as safe as possible in limited time	77	84	76	72	80	84	75
8	Listen and follow PA announcements	83	90	81	76	86	91	81
9	Evaluate potential egress paths and choose route	80	86	79	74	83	85	79
10	Move along egress route	84	86	83	81	85	91	81
11	Assess quality of egress route while moving to TSR	81	83	80	78	81	86	79
12	Choose alternate route if egress path is not tenable	78	79	78	77	77	84	76
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters						
14	Assist others if needed or as directed	76	72	77	76	74	81	74
15	Register at TSR	89	88	89	89	88	91	88
16	Provide pertinent feedback attained while enroute to TSR	79	85	78	75	80	85	77
17	Don personal survival suit or TSR survival suit if instructed to abandon	83	90	81	74	88	90	81
18	Follow OIM's instructions	83	93	81	82	83	86	82

Table H.3 Predicted SLI values by ERT and subgroups (GR).

No.	Description	Mean SLI						
		ERT	CRT	Non CRT	Operators	Engineers	<35	>35
1	Detect alarm	66	65	67	62	69	70	65
2	Identify alarm	66	62	67	57	71	74	63
3	Act accordingly	59	54	60	55	60	66	56
4	Ascertain if danger is imminent	52	48	53	50	52	54	51
5	Muster if in imminent danger	53	55	53	55	52	56	52
6	Return process equipment to safe state	51	52	51	50	51	55	50
7	Make workplace as safe as possible in limited time	50	51	50	50	49	52	49
8	Listen and follow PA announcements	56	56	56	49	61	64	54
9	Evaluate potential egress paths and choose route	51	51	51	51	51	52	50
10	Move along egress route	53	51	54	54	53	55	53
11	Assess quality of egress route while moving to TSR	51	48	52	50	52	58	49
12	Choose alternate route if egress path is not tenable	45	43	45	41	47	55	41
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters						
14	Assist others if needed or as directed	56	50	57	54	55	62	54
15	Register at TSR	71	68	72	78	65	73	71
16	Provide pertinent feedback attained while enroute to TSR	62	66	61	67	59	65	62
17	Don personal survival suit or TSR survival suit if instructed to abandon	68	66	68	70	63	70	67
18	Follow OIM's instructions	68	69	68	77	62	67	69

Table H.4 Predicted SLI values by ERT and subgroups (F&E).

No.	Description	Mean SLI						
		ERT	CRT	Non CRT	Operators	Engineers	<35	>35
1	Detect alarm	31	36	30	26	35	29	32
2	Identify alarm	32	34	32	25	38	33	32
3	Act accordingly	26	25	26	23	28	23	27
4	Ascertain if danger is imminent	24	28	23	23	24	21	25
5	Muster if in imminent danger	29	33	28	32	27	22	32
6	Return process equipment to safe state	23	23	23	22	23	21	24
7	Make workplace as safe as possible in limited time	21	24	21	20	22	18	23
8	Listen and follow PA announcements	29	35	27	29	30	20	32
9	Evaluate potential egress paths and choose route	23	31	21	24	23	15	26
10	Move along egress route	30	33	30	36	27	22	33
11	Assess quality of egress route while moving to TSR	27	31	26	32	24	19	30
12	Choose alternate route if egress path is not tenable.	20	24	19	19	21	18	21
13	Collect personal survival suit if in accommodations at time of alarm	This action does not take place in the reference musters						
14	Assist others if needed or as directed	35	33	35	36	34	31	36
15	Register at TSR	48	45	49	56	43	40	50
16	Provide pertinent feedback attained while enroute to TSR	41	47	39	50	35	31	44
17	Don personal survival suit or TSR survival suit if instructed to abandon	48	43	49	55	42	46	49
18	Follow OIM's instructions	47	52	46	59	40	41	49

Table H.5 Summary of mean SLI values for each action based on PSFs.

	Mean SLI																	
No.	Stress			Complexity			Training			Experience			Event Factors			Atmospheric Factors		
	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E
1	69	64	21	88	90	60	78	70	45	80	69	40	91	64	21	94	55	25
2	68	57	25	82	77	65	85	78	55	84	74	38	87	66	13	97	55	26
3	67	41	18	77	67	56	81	75	47	86	65	36	78	35	11	93	69	39
4	62	45	20	74	55	42	74	58	40	76	60	32	76	28	14	87	61	27
5	58	43	25	75	60	49	83	65	51	76	57	31	83	30	23	91	66	27
6	63	41	13	62	47	35	83	67	48	81	65	36	74	27	13	93	66	35
7	61	36	12	62	45	35	83	65	50	78	62	36	74	25	13	92	65	32
8	70	50	29	76	65	55	78	69	49	79	65	44	79	45	18	86	58	31
9	67	45	19	71	56	40	73	60	38	78	55	41	77	35	15	88	63	28
10	69	49	33	78	65	46	78	62	41	78	61	40	77	35	23	89	62	30
11	67	49	27	73	59	43	71	53	40	72	55	35	75	38	20	88	59	25
12	64	39	18	68	48	35	70	49	40	68	46	31	73	34	15	88	60	31
14	57	52	32	62	59	48	70	55	49	72	56	43	69	55	34	88	71	40
15	78	63	43	88	78	55	86	73	51	88	68	44	97	71	52	98	81	44
16	68	51	40	72	63	45	75	56	54	73	60	45	78	59	31	88	76	34
17	67	53	42	69	71	50	86	63	53	83	63	49	84	76	53	94	72	38
18	73	58	42	81	75	55	86	54	56	87	65	48	88	75	47	96	77	41

Appendix I

Summary Table of PSF n-Weights

Table I.1 Summary of normalized PSF weights (n-weights).

No	PSF n-weights																	
	Stress			Complexity			Training			Experience			Event Factors			Atmospheric Factors		
	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E	MO	GR	F&E
1	0.1149	0.1284	0.1659	0.0630	0.0776	0.0884	0.2181	0.1815	0.1670	0.1964	0.1744	0.1683	0.0882	0.1455	0.2230	0.3193	0.2926	0.1874
2	0.1244	0.1374	0.1720	0.0924	0.0928	0.0972	0.2535	0.2483	0.2141	0.2353	0.2073	0.1960	0.0994	0.1350	0.1900	0.1950	0.1791	0.1308
3	0.1620	0.1704	0.1900	0.0977	0.0939	0.1090	0.2651	0.2405	0.2142	0.2598	0.2347	0.2059	0.0933	0.1440	0.1797	0.1220	0.1164	0.1011
4	0.1466	0.1686	0.1812	0.0956	0.1083	0.1169	0.2219	0.1903	0.1922	0.2675	0.2252	0.2045	0.1040	0.1700	0.1909	0.1645	0.1377	0.1145
5	0.1607	0.1721	0.1824	0.1019	0.1014	0.1114	0.2554	0.2217	0.2046	0.2423	0.2080	0.1910	0.0956	0.1774	0.2010	0.1441	0.1195	0.1095
6	0.1588	0.1608	0.1771	0.1731	0.1817	0.1729	0.2467	0.1938	0.1840	0.2432	0.2041	0.1892	0.0751	0.1638	0.1838	0.1031	0.0957	0.0929
7	0.1674	0.1765	0.1828	0.1623	0.1555	0.1541	0.2131	0.1953	0.1837	0.2472	0.1982	0.1932	0.0842	0.1685	0.1904	0.1258	0.1060	0.0957
8	0.1562	0.1790	0.1836	0.1244	0.1127	0.1314	0.2038	0.1739	0.1600	0.2026	0.1779	0.1722	0.0956	0.1655	0.2041	0.2174	0.1910	0.1487
9	0.1554	0.1689	0.1753	0.1125	0.1313	0.1285	0.2111	0.1904	0.1696	0.2454	0.1974	0.1913	0.0981	0.1801	0.2017	0.1775	0.1318	0.1337
10	0.1557	0.1492	0.1709	0.1035	0.1207	0.1269	0.1895	0.1842	0.1824	0.2187	0.1910	0.1850	0.0970	0.1904	0.2037	0.2356	0.1645	0.1311
11	0.1747	0.1748	0.1888	0.1321	0.1306	0.1305	0.1751	0.1719	0.1517	0.2286	0.1988	0.1928	0.0878	0.1720	0.2060	0.2017	0.1518	0.1302
12	0.1616	0.1794	0.1808	0.1368	0.1433	0.1355	0.2117	0.1777	0.1709	0.2484	0.1957	0.2027	0.0974	0.1703	0.1932	0.1441	0.1336	0.1169
14	0.1930	0.1903	0.2045	0.1367	0.1267	0.1299	0.2364	0.2253	0.1960	0.2701	0.2712	0.2196	0.0866	0.1158	0.1659	0.0773	0.0708	0.0841
15	0.1611	0.1790	0.1960	0.0801	0.0932	0.0908	0.3336	0.3036	0.2652	0.2988	0.2680	0.2492	0.0853	0.1116	0.1474	0.0411	0.0446	0.0515
16	0.1981	0.2129	0.2183	0.1179	0.1379	0.1341	0.2471	0.2175	0.2059	0.2725	0.2472	0.2381	0.0913	0.1235	0.1507	0.0731	0.0610	0.0528
17	0.2068	0.2160	0.2249	0.1427	0.1472	0.1383	0.2839	0.2488	0.2431	0.2653	0.2515	0.2235	0.0707	0.0963	0.1236	0.0305	0.0402	0.0466
18	0.2299	0.2318	0.2206	0.1620	0.1574	0.1630	0.2344	0.2342	0.2120	0.2385	0.2373	0.2174	0.0728	0.0883	0.1311	0.0623	0.0511	0.0559

Appendix J

Human Error Probability Questionnaires

Table J.1 HEP questionnaire for MO MaxSLI and MinSLI actions.

Man Overboard **Human Error Probability Predictions for MaxSLI and MinSLI Actions**								
Scenario		**Probabilities**						
Man Overboard (15 yrs experience as an operator, daylight, summer, no wind, calm seas, man falls O/B on different deck,) Job at time of muster Operator does not witness or hear the event. Operator draining/skimming a vessel.		1 in 1	1 in 2	1 in 10	1 in 100	1 in 1000	Other	
No.	Description							
14	Assist others if needed or as directed							
15	Register at TSR							
Predict the probability of failure to perform these actions during the muster sequence described. If you estimate that the probability of failure falls between two ranges check both boxes, otherwise check only one box for your estimate. The probability of failure relates to not performing the task in the prescribed manner of the muster procedure.								

Table J.2 HEP questionnaire for GR MaxSLI and MinSLI actions.

<table>
<tr><th colspan="8">Gas Release
Human Error Probability Predictions for MaxSLI and MinSLI Actions</th></tr>
<tr><th colspan="2">Scenario</th><th colspan="6">Probabilities</th></tr>
<tr><td colspan="2">Gas Release
(3 yrs experience as an operator, daylight, winter, some wind, raining, gas release on other side of same deck)</td><td rowspan="3">1 in 1</td><td rowspan="3">1 in 2</td><td rowspan="3">1 in 10</td><td rowspan="3">1 in 100</td><td rowspan="3">1 in 1000</td><td rowspan="3">Other</td></tr>
<tr><td colspan="2"><u>Job at time of muster</u>
Gas Release is noticeable from operator's location, from high pressure source. Operator changing filters on a solids filter.</td></tr>
<tr><td>No.</td><td>Description</td></tr>
<tr><td>12</td><td>Choose alternate route if egress path is not tenable</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td>Register at TSR</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Predict the probability of failure to perform these actions during the muster sequence described. If you estimate that the probability of failure falls between two ranges check both boxes, otherwise check only one box for your estimate. The probability of failure relates to not performing the task in the prescribed manner of the muster procedure.</td></tr>
</table>

Table J.3 HEP questionnaire for F&E MaxSLI and MinSLI actions.

Fire and Explosion Human Error Probability Predictions for MaxSLI and MinSLI Actions							
Scenario		**Probabilities**					
Fire & Explosion (6 months experience as an operator, night time, winter storm, fire & explosion on same deck) Job at time of muster Operator isolating A filter coalescer and switching flow to B.		1 in 1	1 in 2	1 in 10	1 in 100	1 in 1000	Other
No.	Description						
12	Choose alternate route if egress path is not tenable						
15	Register at TSR						
Predict the probability of failure to perform these actions during the muster sequence described. If you estimate that the probability of failure falls between two ranges check both boxes, otherwise check only one box for your estimate. The probability of failure relates to not performing the task in the prescribed manner of the muster procedure.							

Appendix K

Summary of Predicted Human Error Probabilities

Table K.1 Man overboard HEPs based on two empirical HEPs (EBHEPs).

No.	Action	HEP*	
		Set #1	**Set #2**
1	Detect alarm	0.00208	0.00200
2	Identify alarm	0.00195	0.00142
3	Act accordingly	0.00214	0.00228
4	Ascertain if danger is imminent	0.00239	0.00340
5	Muster if in imminent danger	0.00220	0.00252
6	Return process equipment to safe state	0.00255	0.00412
7	Make workplace as safe as possible in limited time	0.00260	0.00434
8	Listen and follow PA announcements	0.00209	0.00204
9	Evaluate potential egress paths and choose route	0.00236	0.00327
10	Move along egress route	0.00202	0.00173
11	Assess quality of egress route while moving to TSR	0.00231	0.00303
12	Choose alternate route if egress path is not tenable	0.00256	0.00414
14	Assist others if needed or as directed	0.00947	0.00500
15	Register at TSR	0.00275	0.00000
16	Provide pertinent feedback attained while enroute to TSR	0.00160	0.00363
17	Don personal survival suit or TSR survival suit if instructed to abandon	0.00244	0.00210
18	Follow OIM's instructions	0.00210	0.00241

Table K.2 Man overboard HEPs based on two estimated HEPs (BHEPs).

Action	Description	Lower Bound	HEP	Upper Bound
1	Detect alarm	0.00186	0.00499	0.0134
2	Identify alarm	0.00148	0.00398	0.0107
3	Act accordingly	0.00203	0.00547	0.0147
4	Ascertain if danger is imminent	0.00276	0.00741	0.0199
5	Muster if in imminent danger	0.00219	0.00589	0.0158
6	Return process equipment to safe state	0.00322	0.00866	0.0233
7	Make workplace as safe as possible in limited time	0.00336	0.00903	0.0243
8	Listen and follow PA announcements	0.00189	0.00507	0.0136
9	Evaluate potential egress paths and choose route	0.00267	0.00718	0.0193
10	Move along egress route	0.00169	0.00453	0.0122
11	Assess quality of egress route while moving to TSR	0.00252	0.00677	0.0182
12	Choose alternate route if egress path is not tenable	0.00324	0.00869	0.0234
14	Assist others if needed or as directed	0.00379	0.01	0.0273
15	Register at TSR	0.000470	0.001	0.00338
16	Provide pertinent feedback attained while enroute to TSR	0.00291	0.00781	0.0210
17	Don personal survival suit or TSR survival suit if instructed to abandon	0.00192	0.00517	0.0139
18	Follow OIM's instructions	0.00212	0.00570	0.0153

Table K.3 Gas release HEPs based on two estimated data HEPs (BHEPS).

Action	Description	Lower Bound	HEP	Upper Bound
1	Detect alarm	0.0168	0.0308	0.0566
2	Identify alarm	0.0160	0.0293	0.0538
3	Act accordingly	0.0291	0.0535	0.0983
4	Ascertain if danger is imminent	0.0417	0.0765	0.1404
5	Muster if in imminent danger	0.0385	0.0706	0.1297
6	Return process equipment to safe state	0.0426	0.0782	0.1435
7	Make workplace as safe as possible in limited time	0.0455	0.0835	0.1533
8	Listen and follow PA announcements	0.0329	0.0605	0.1111
9	Evaluate potential egress paths and choose route	0.0438	0.0805	0.1477
10	Move along egress route	0.0396	0.0726	0.1333
11	Assess quality of egress route while moving to TSR	0.0429	0.0788	0.1448
12	Choose alternate route if egress path is not tenable	0.0545	0.1000	0.1836
14	Assist others if needed or as directed	0.0353	0.0649	0.1192
15	Register at TSR	0.0054	0.0100	0.0184
16	Provide pertinent feedback attained while enroute to TSR	0.0225	0.0413	0.0758
17	Don personal survival suit or TSR survival suit if instructed to abandon	0.0141	0.0260	0.0477
18	Follow OIM's instructions	0.0113	0.0208	0.0382

Table K.4 Fire and explosion HEPs based on two estimated HEPs (BHEPs).

Action	Description	Lower Bound	HEP	Upper Bound
1	Detect alarm	0.318	0.396	0.491
2	Identify alarm	0.310	0.386	0.479
3	Act accordingly	0.361	0.448	0.556
4	Ascertain if danger is imminent	0.374	0.465	0.577
5	Muster if in imminent danger	0.334	0.416	0.516
6	Return process equipment to safe state	0.381	0.474	0.588
7	Make workplace as safe as possible in limited time	0.393	0.489	0.606
8	Listen and follow PA announcements	0.338	0.420	0.522
9	Evaluate potential egress paths and choose route	0.383	0.476	0.590
10	Move along egress route	0.325	0.405	0.502
11	Assess quality of egress route while moving to TSR	0.353	0.439	0.545
12	Choose alternate route if egress path is not tenable	0.402	0.500	0.620
14	Assist others if needed or as directed	0.287	0.358	0.444
15	Register at TSR	0.161	0.200	0.248
16	Provide pertinent feedback attained while enroute to TSR	0.232	0.289	0.359
17	Don personal survival suit or TSR survival suit if instructed to abandon	0.160	0.199	0.247
18	Follow OIM's instructions	0.169	0.210	0.261

Table K.5 Human error probabilities based on elicited HEPs (BHEPs).

No.	Actions	HEP		
		MO	GR	F&E
1	Detect alarm	0.0094	0.0287	0.2699
2	Identify alarm	0.0073	0.0278	0.2621
3	Act accordingly	0.0094	0.0421	0.3133
4	Ascertain if danger is imminent	0.0131	0.0558	0.3272
5	Muster if in imminent danger	0.0107	0.0523	0.2864
6	Return process equipment to safe state	0.0156	0.0568	0.3349
7	Make workplace as safe as possible in limited time	0.0163	0.0600	0.3472
8	Listen and follow PA announcements	0.0092	0.0463	0.2900
9	Evaluate potential egress paths and choose route	0.0130	0.0582	0.3362
10	Move along egress route	0.0083	0.0535	0.2773
11	Assess quality of egress route while moving to TSR	0.0123	0.0572	0.3057
12	Choose alternate route if egress path is not tenable	0.0157	0.0700	0.3570
14	Assist others if needed or as directed	0.0183	0.0489	0.2394
15	Register at TSR	0.0025	0.0165	0.1190
16	Provide pertinent feedback attained while enroute to TSR	0.0141	0.0472	0.2900
17	Don personal survival suit or TSR survival suit is instructed to abandon	0.0094	0.0258	0.1184
18	Follow OIM's instructions	0.0104	0.0228	0.1266

Appendix L

HEPI PSF n-Weight Reference Graphs

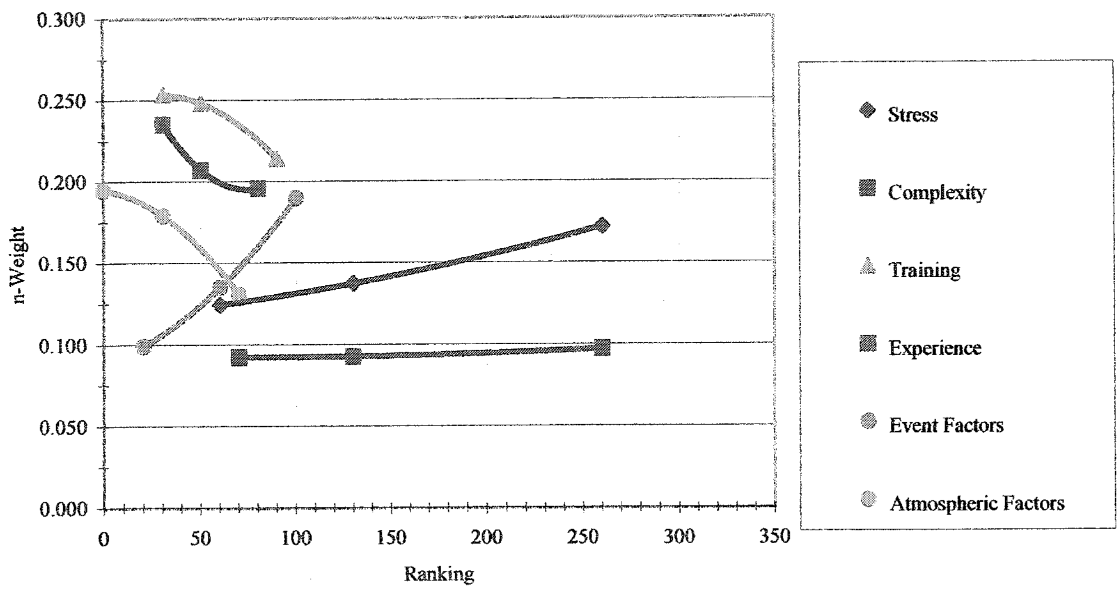

Figure L.1 Action 2 PSF n-weight reference graph.

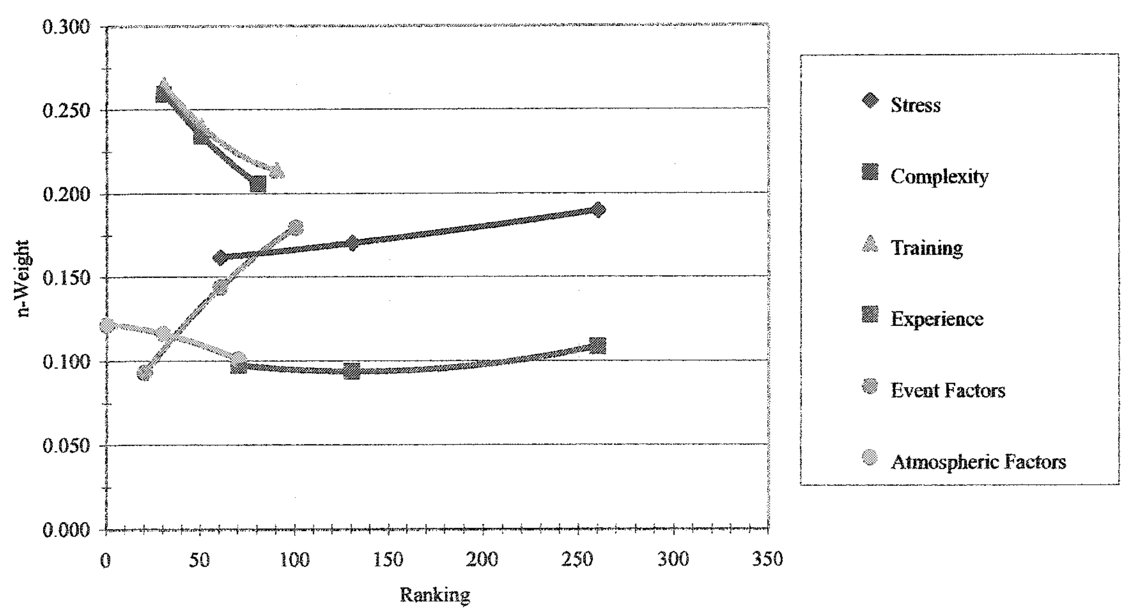

Figure L.2 Action 3 PSF n-weight reference graph.

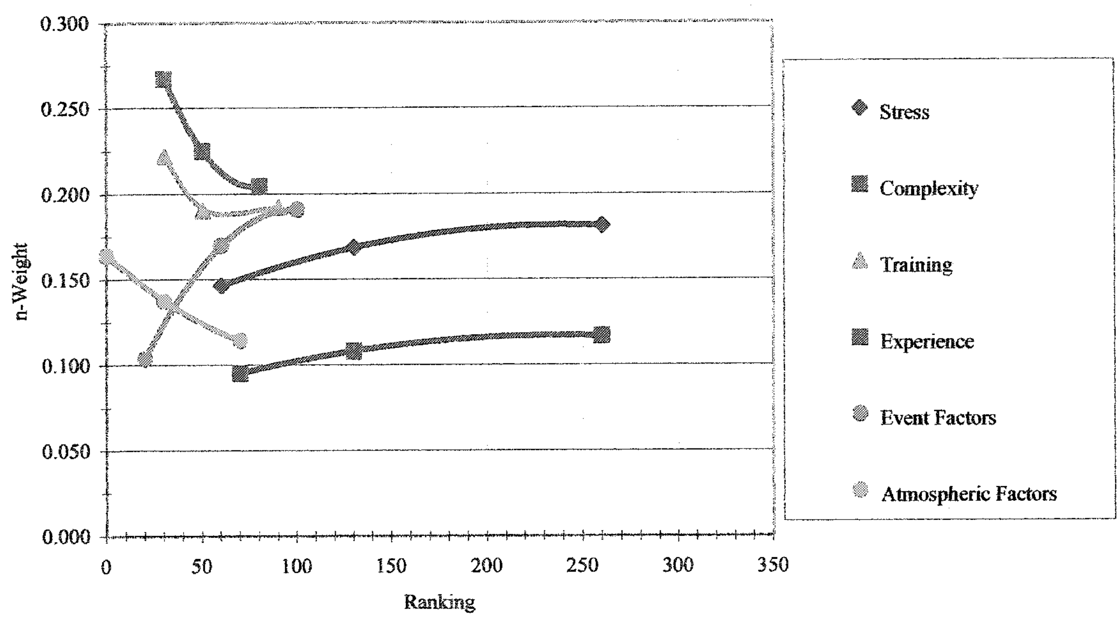

Figure L.3 Action 4 PSF n-weight reference graph.

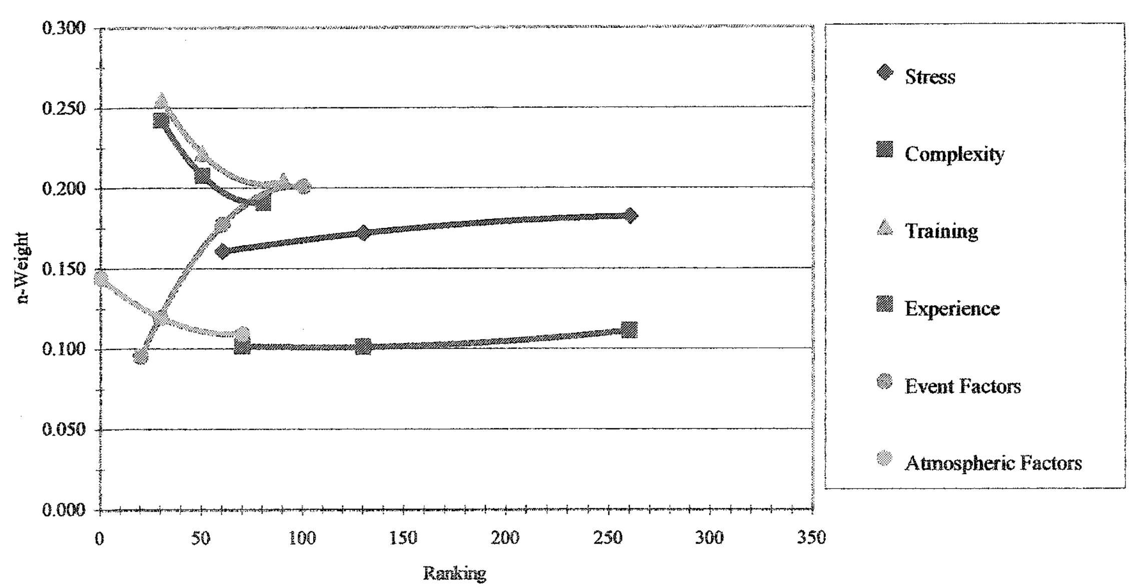

Figure L.4 Action 5 PSF n-weight reference graph.

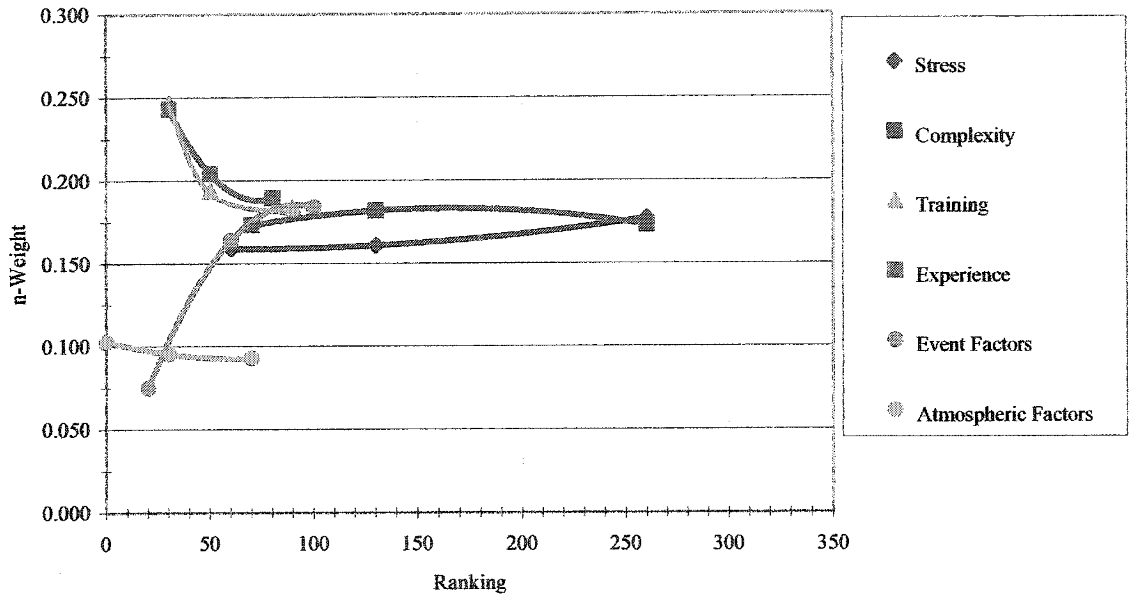

Figure L.5 Action 6 PSF n-weight reference graph. .

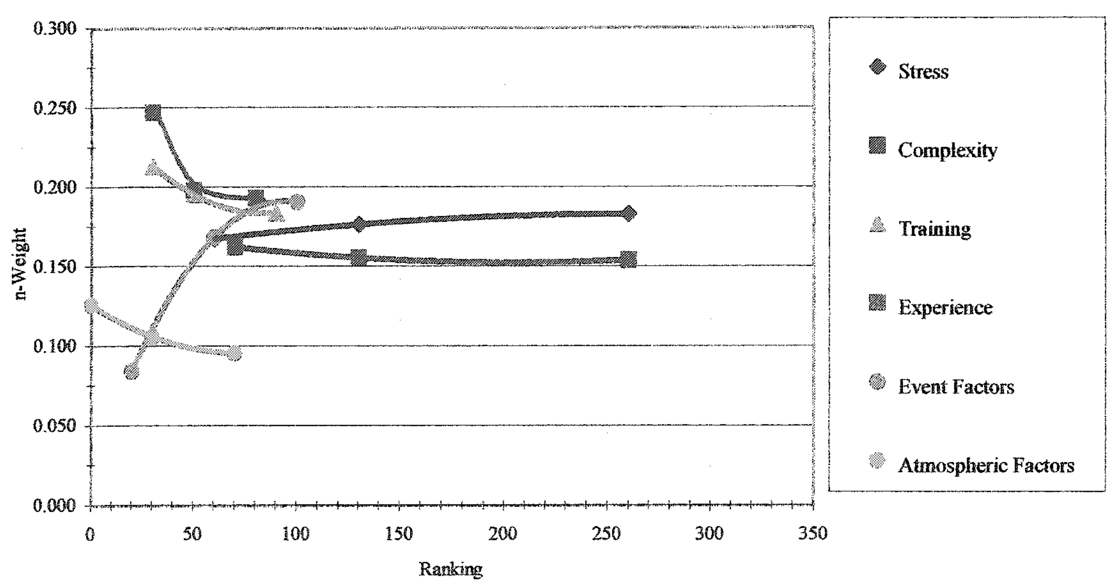

Figure L.6 Action 7 PSF n-weight reference graph.

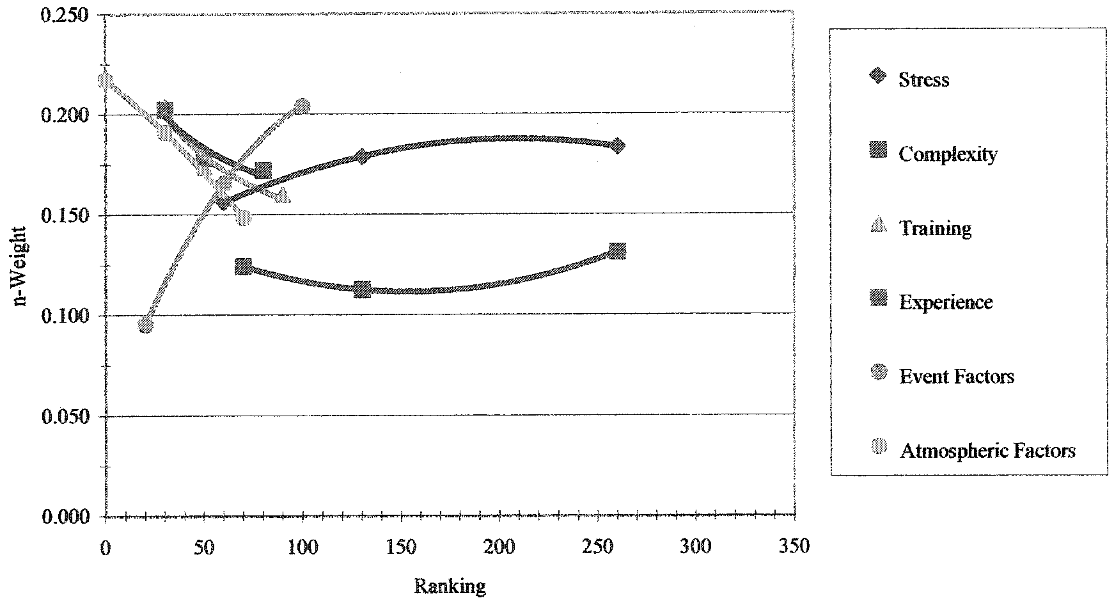

Figure L.7 Action 8 PSF n-weight reference graph.

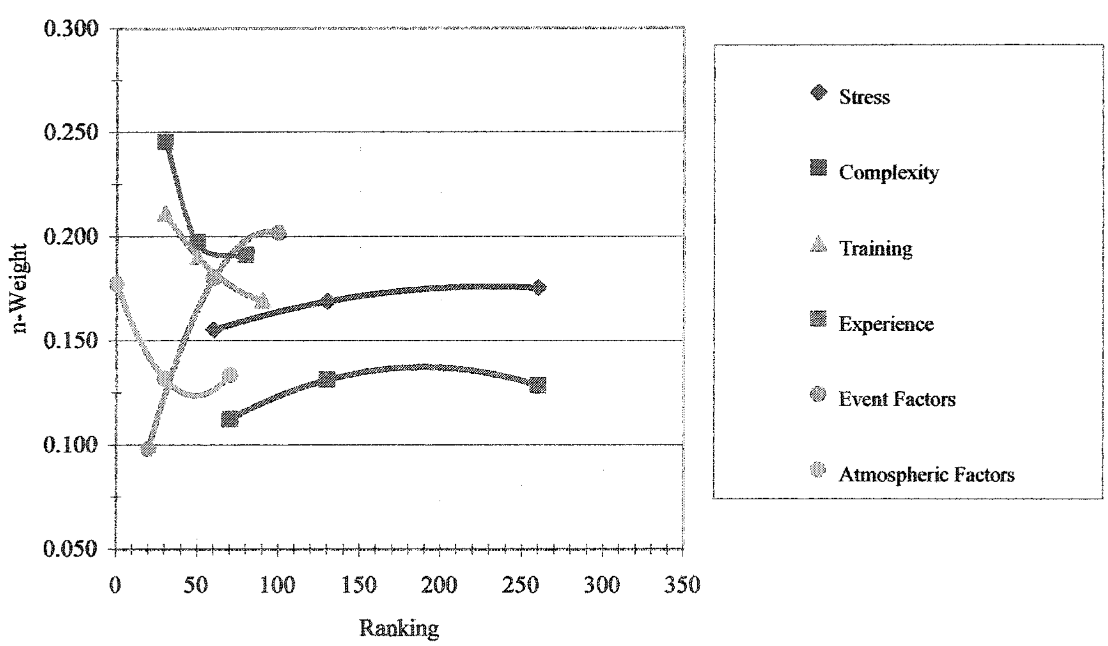

Figure L.8 Action 9 PSF n-weight reference graph.

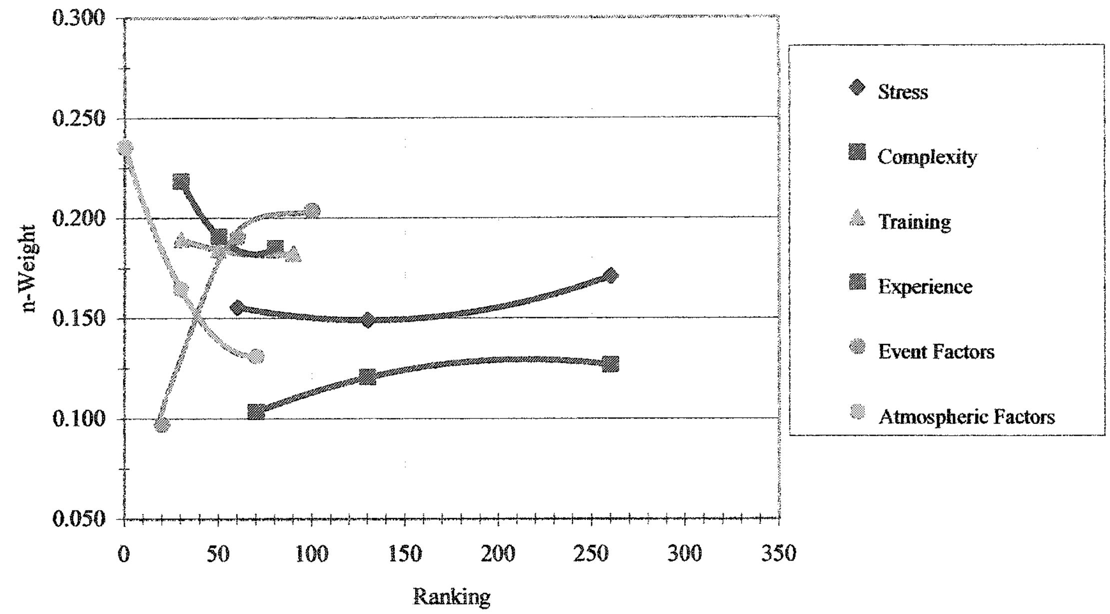

Figure L.9 Action 10 PSF n-weight reference graph.

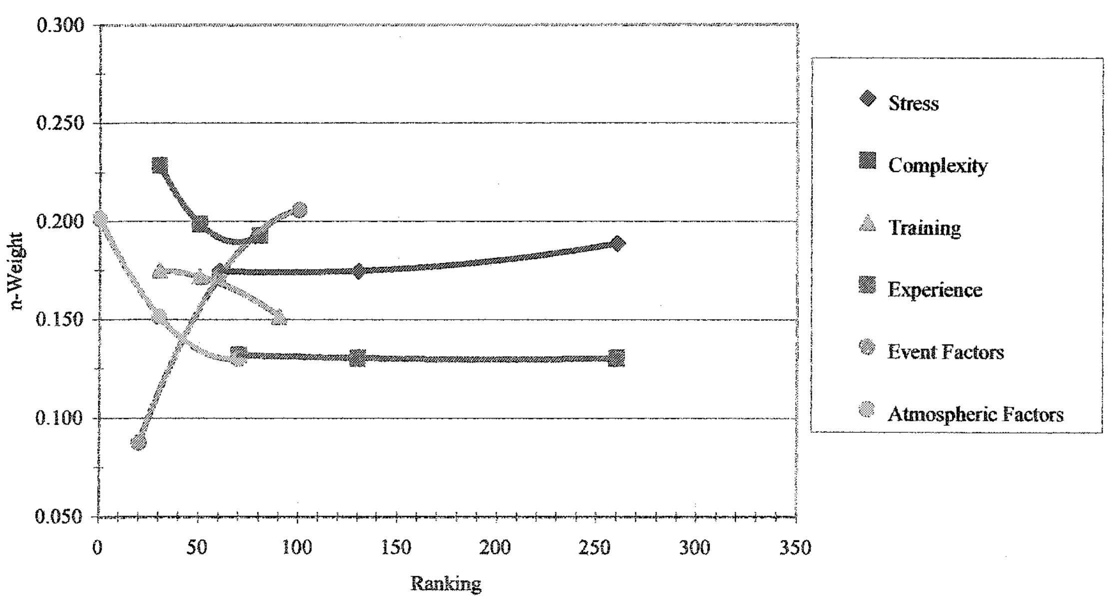

Figure L.10 Action 11 PSF n-weight reference graph.

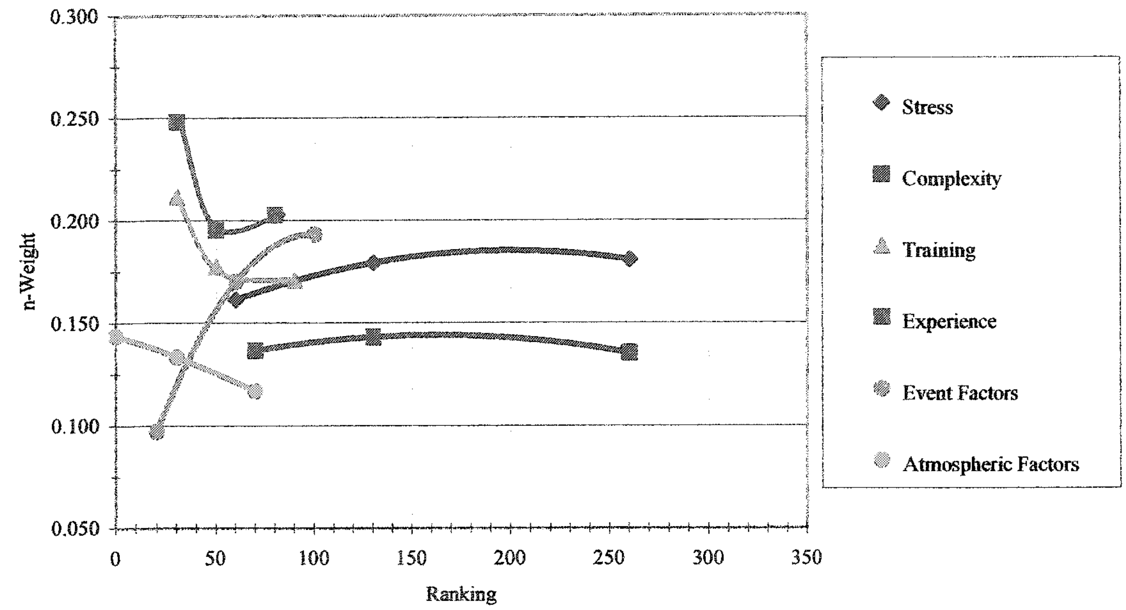

Figure L.11 Action 12 PSF n-weight reference graph.

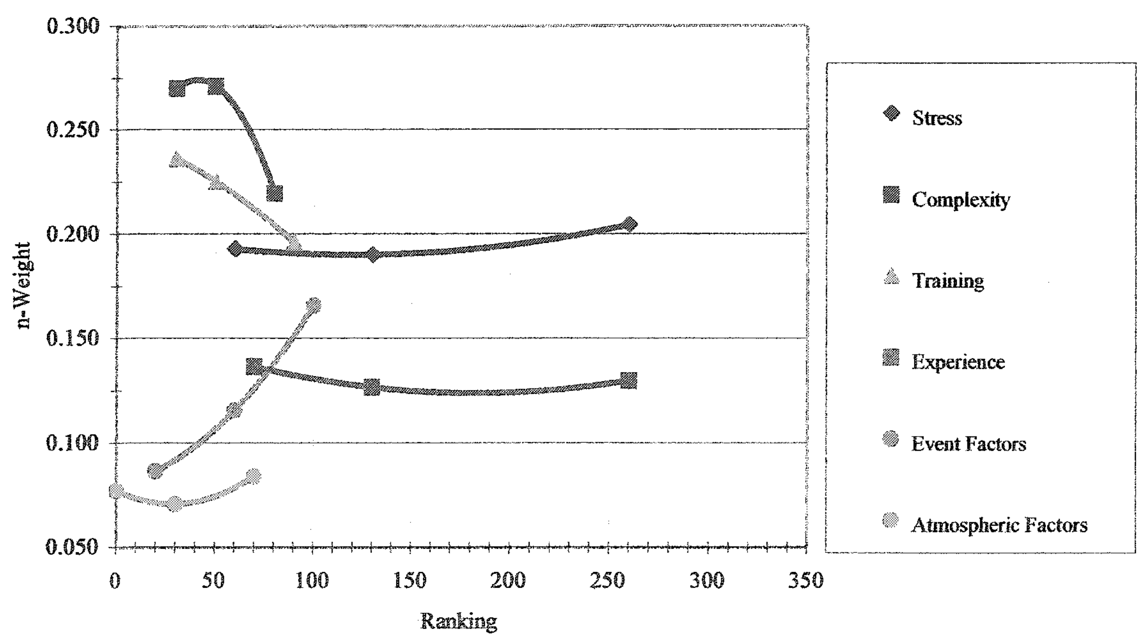

Figure L.12 Action 14 PSF n-weight reference graph.

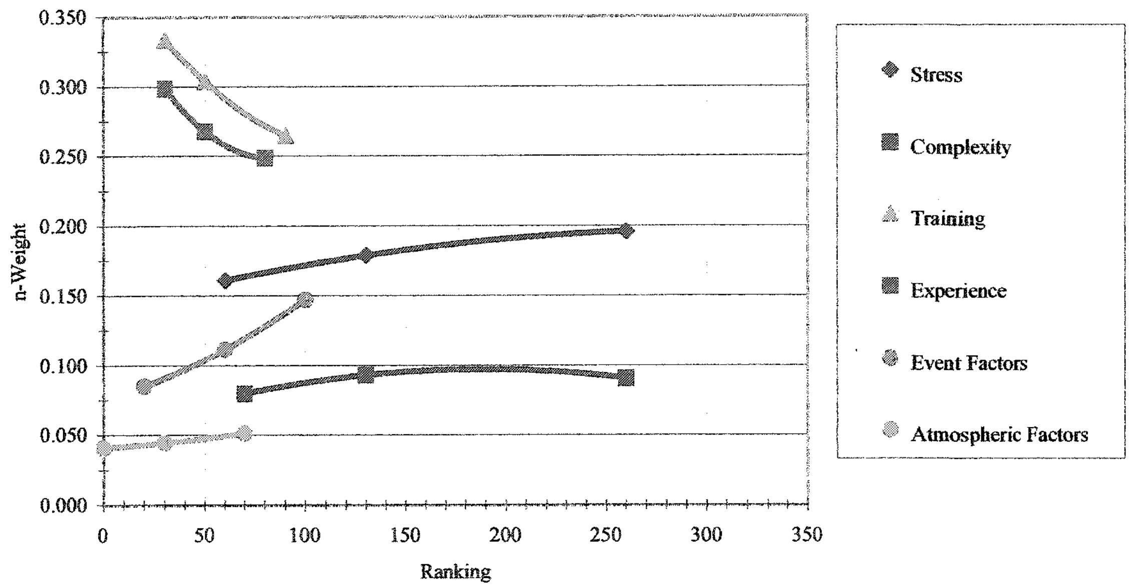

Figure L.13 Action 15 PSF n-weight reference graph.

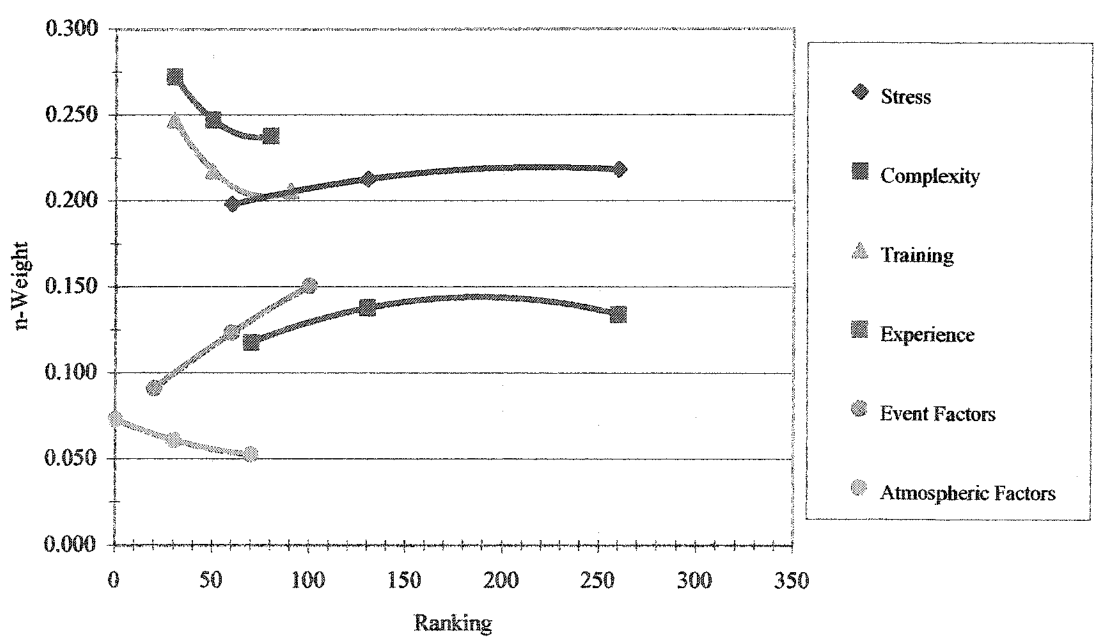

Figure L.14 Action 16 PSF n-weight reference graph. .

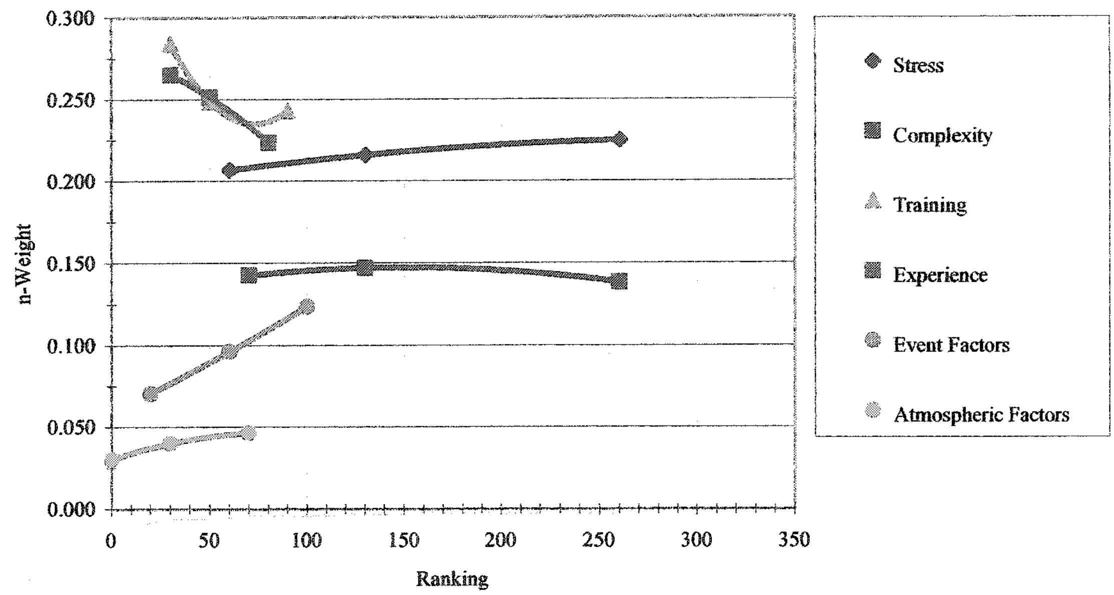

Figure L.15 Action 17 PSF n-weight reference graph.

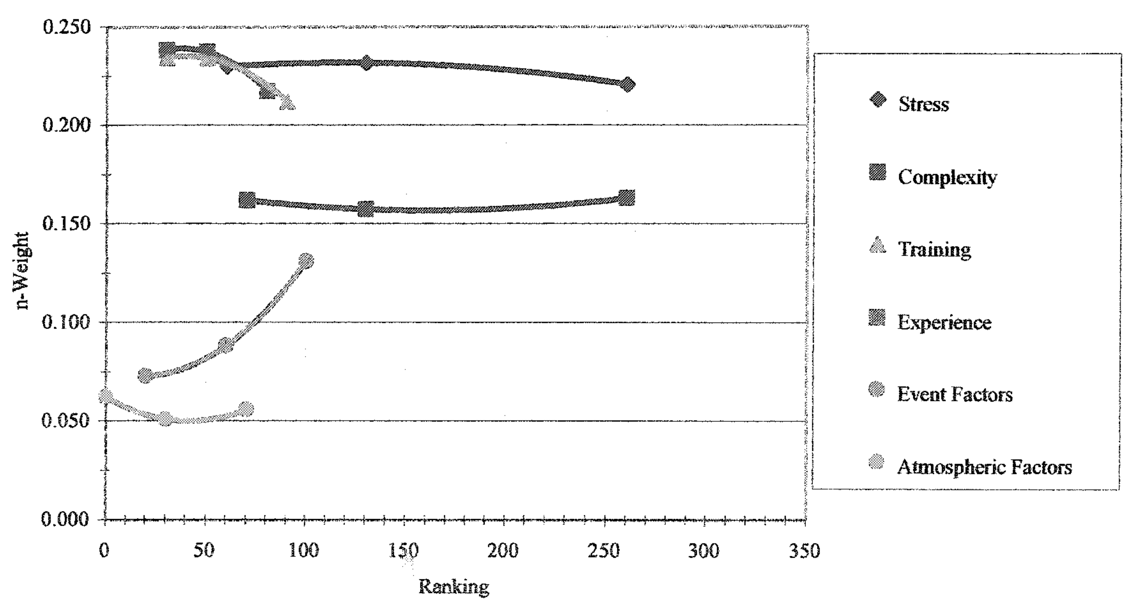

Figure L.16 Action 18 PSF n-weight reference graph.

Appendix M

HEPI PSF Rating Reference Graphs

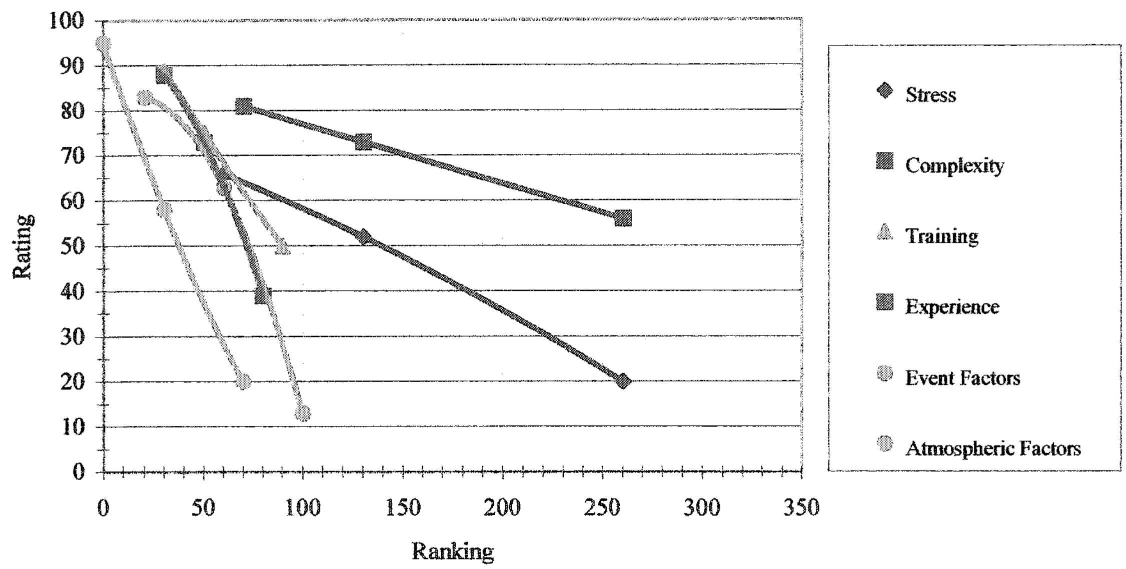

Figure M.1 Action 2 PSF rating reference graph.

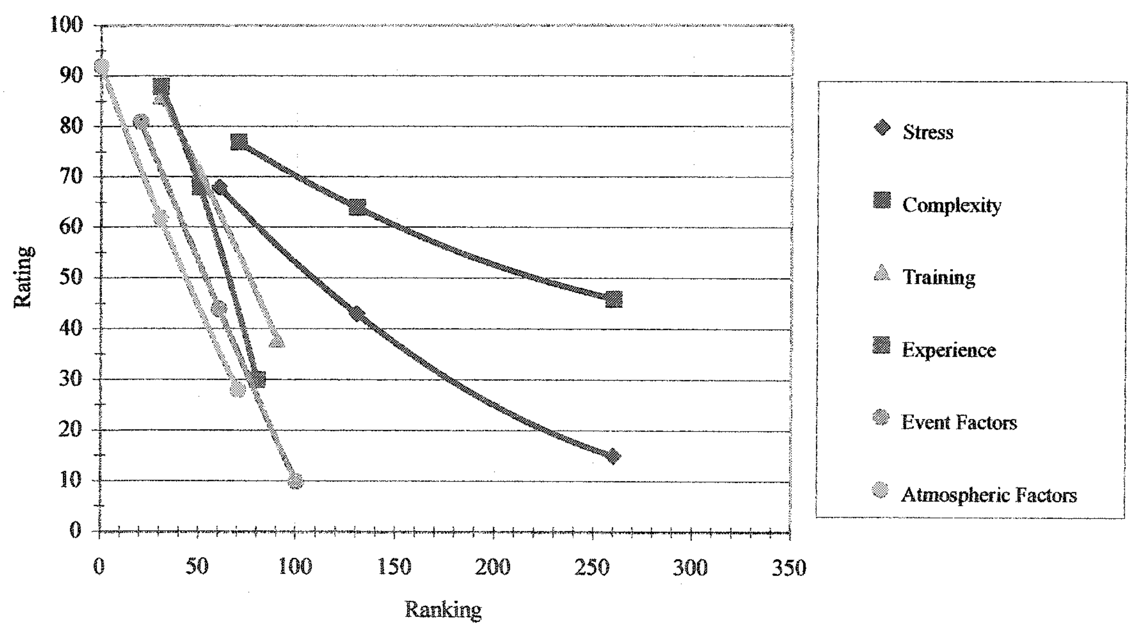

Figure M.2 Action 3 PSF rating reference graph.

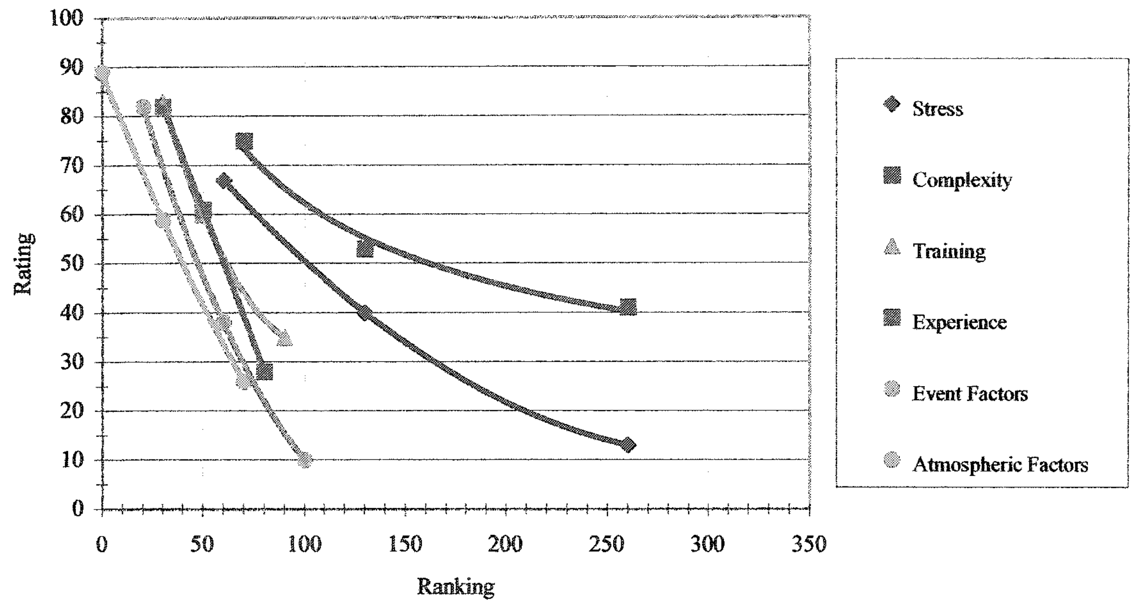

Figure M.3 Action 4 PSF rating reference graph.

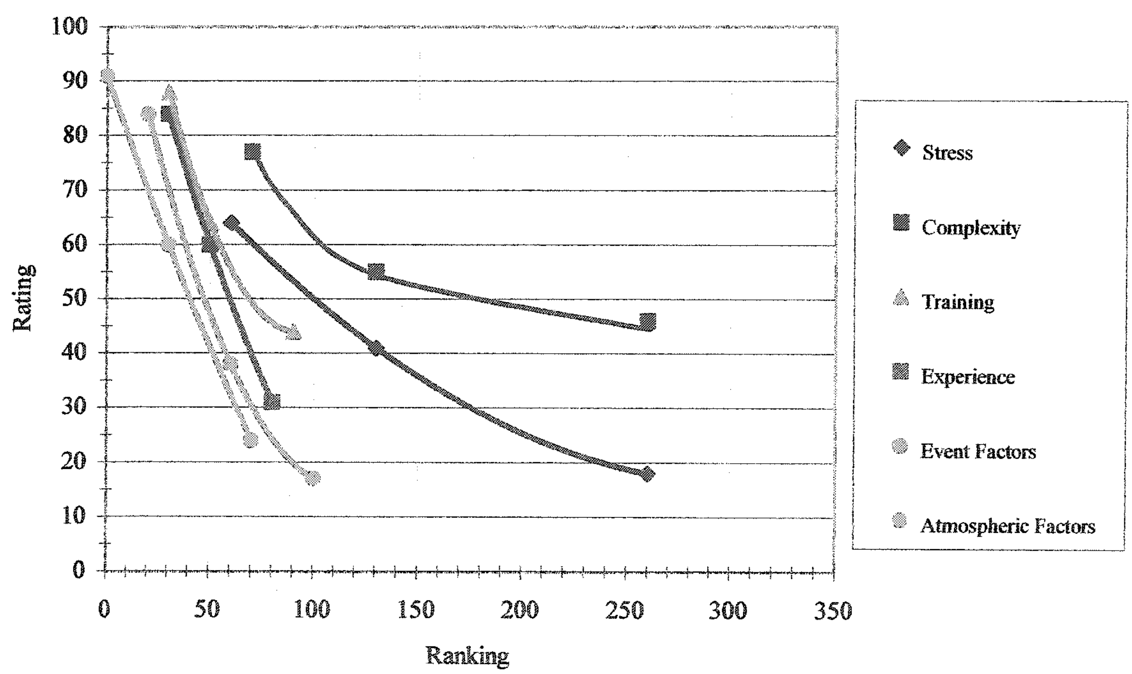

Figure M.4 Action 5 PSF rating reference graph.

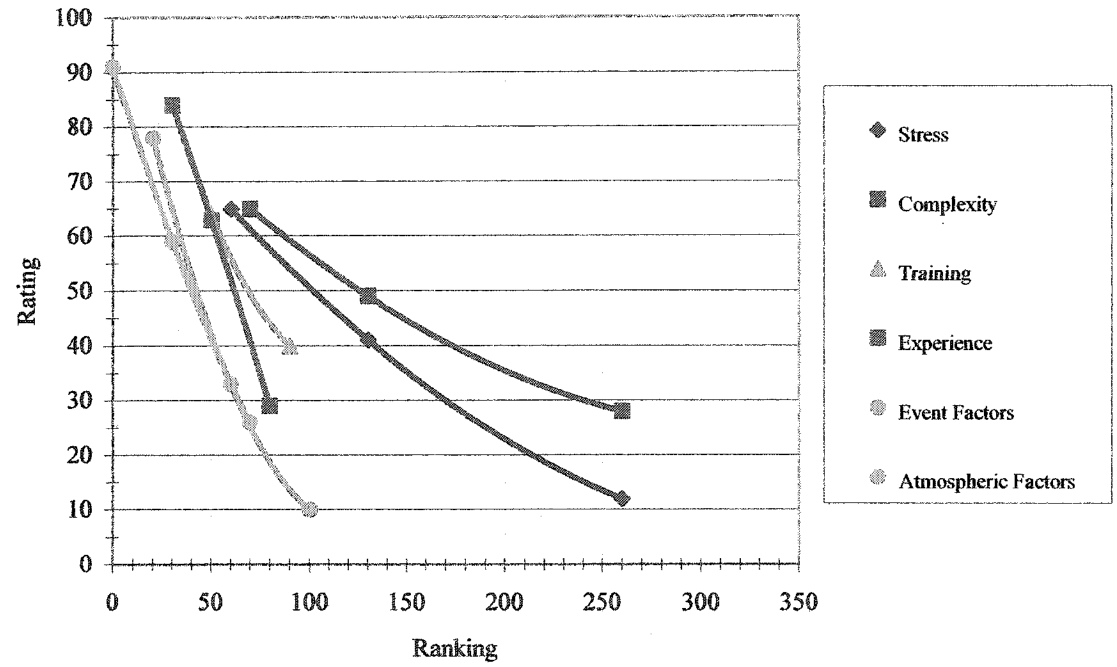

Figure M.5 Action 6 PSF rating reference graph.

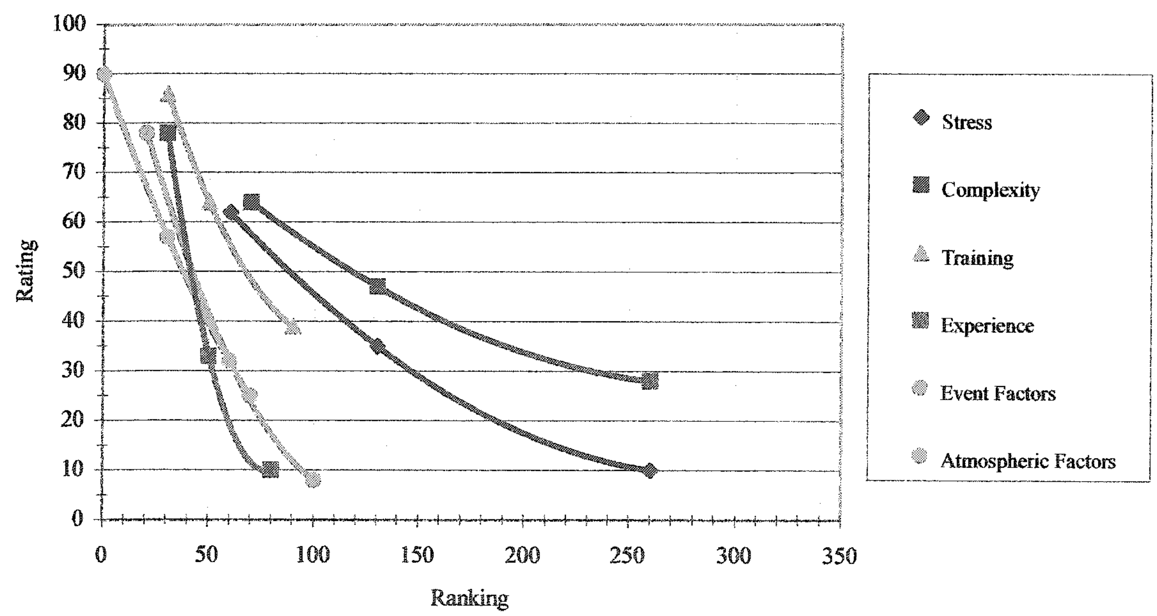

Figure M.6 Action 7 PSF rating reference graph.

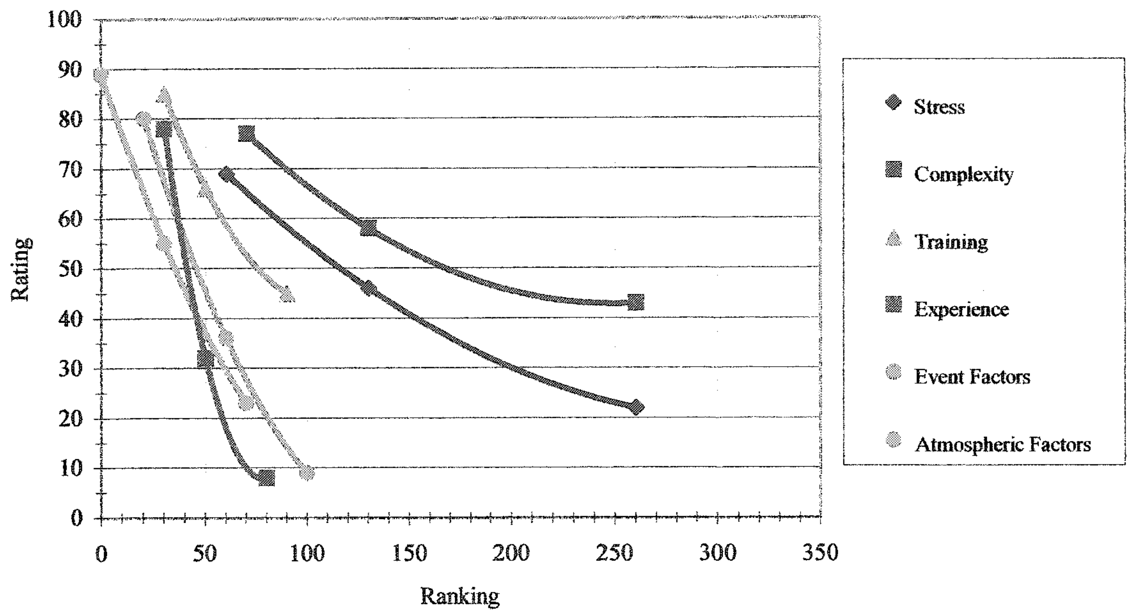

Figure M.7 Action 8 PSF rating reference graph.

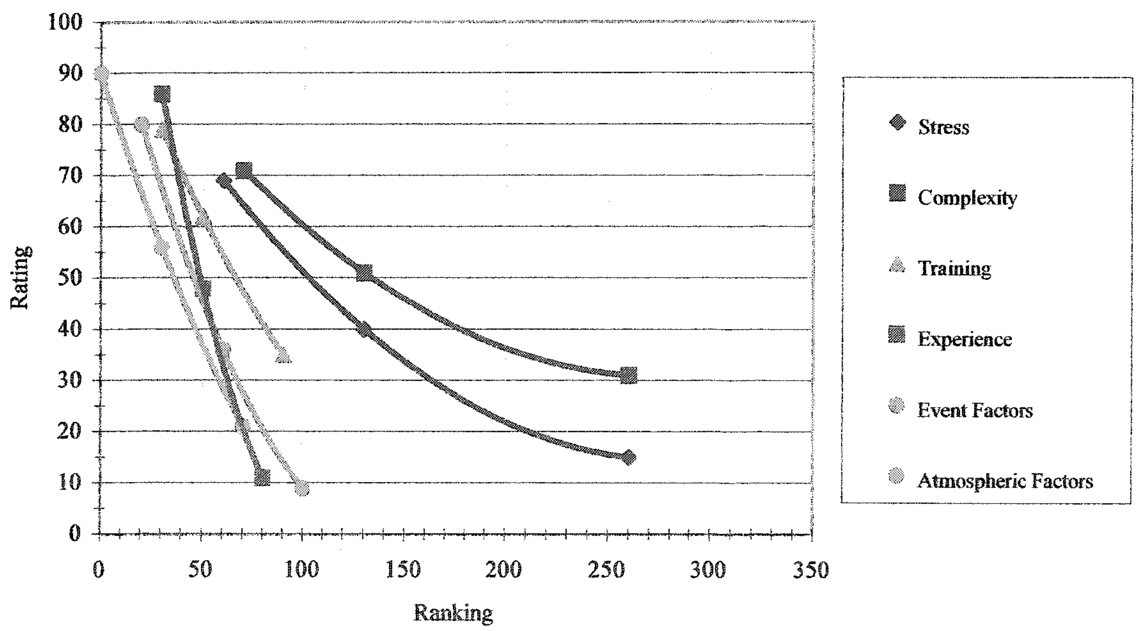

Figure M.8 Action 9 PSF rating reference graph.

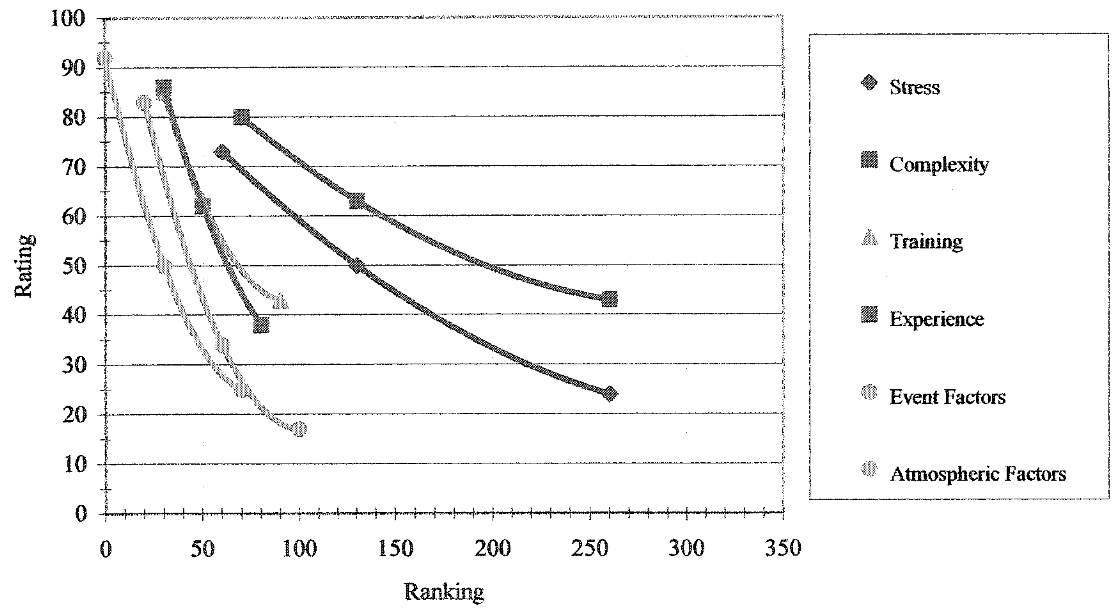

Figure M.9 Action 10 PSF rating reference graph.

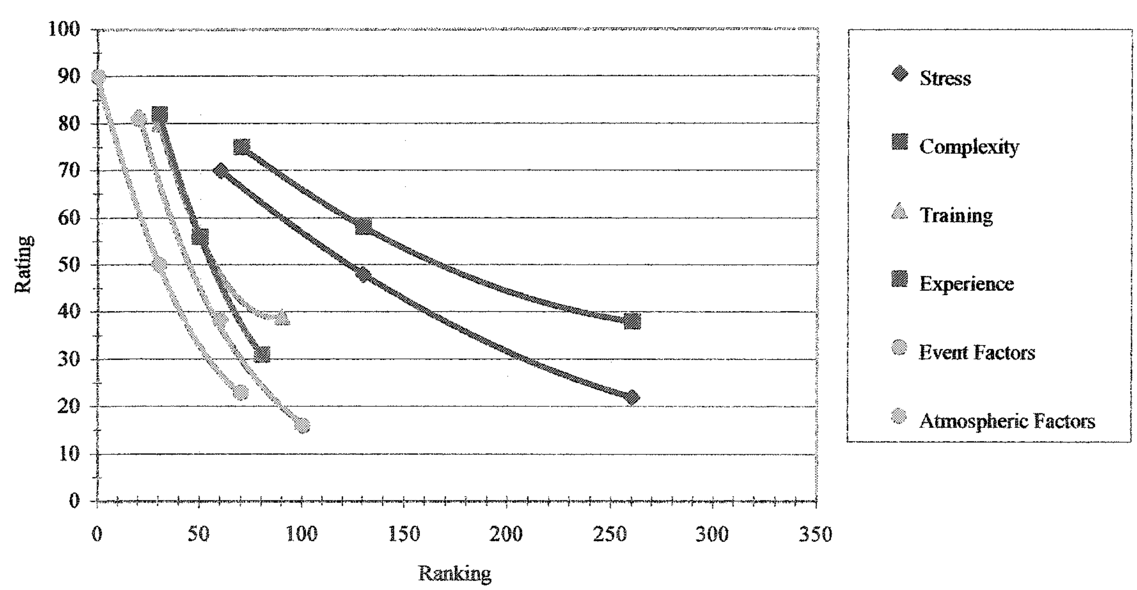

Figure M.10 Action 11 PSF rating reference graph.

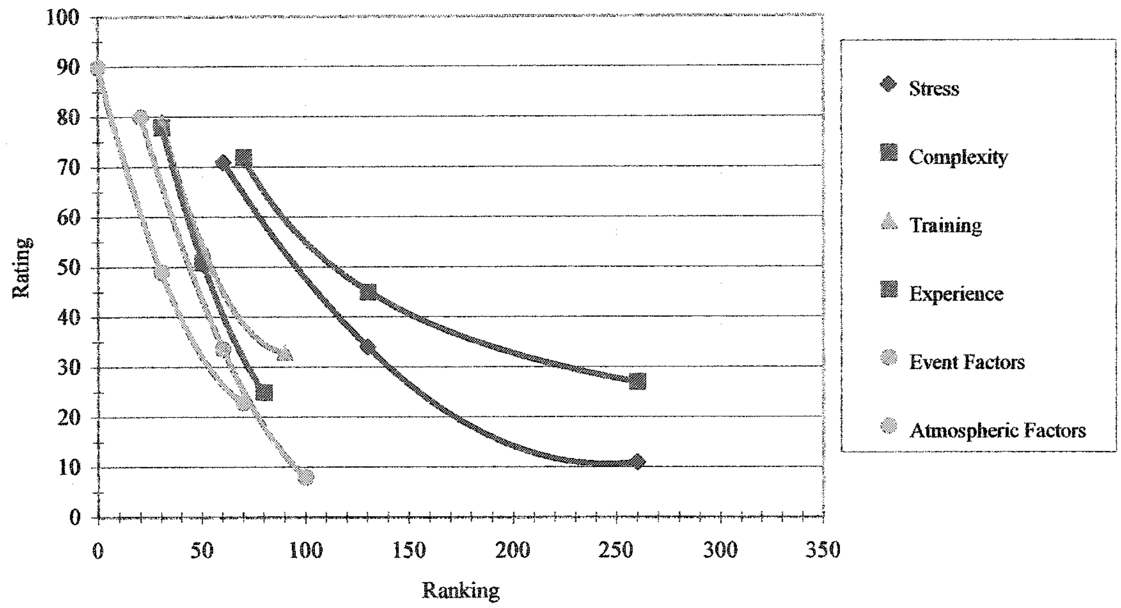

Figure M.11 Action 12 PSF rating reference graph.

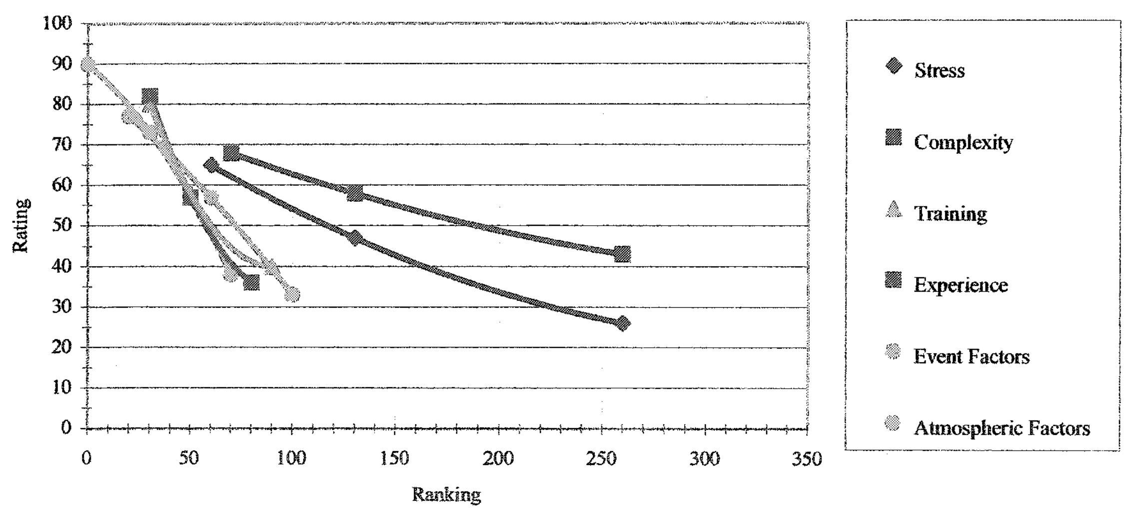

Figure M.12 Action 14 PSF rating reference graph.

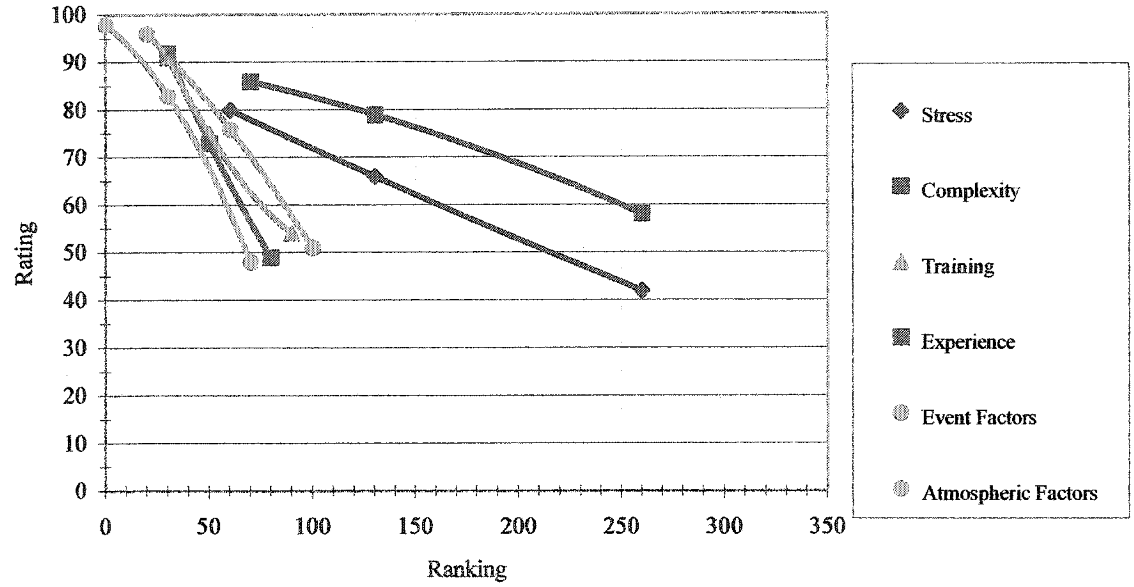

Figure M.13 Action 15 PSF rating reference graph.

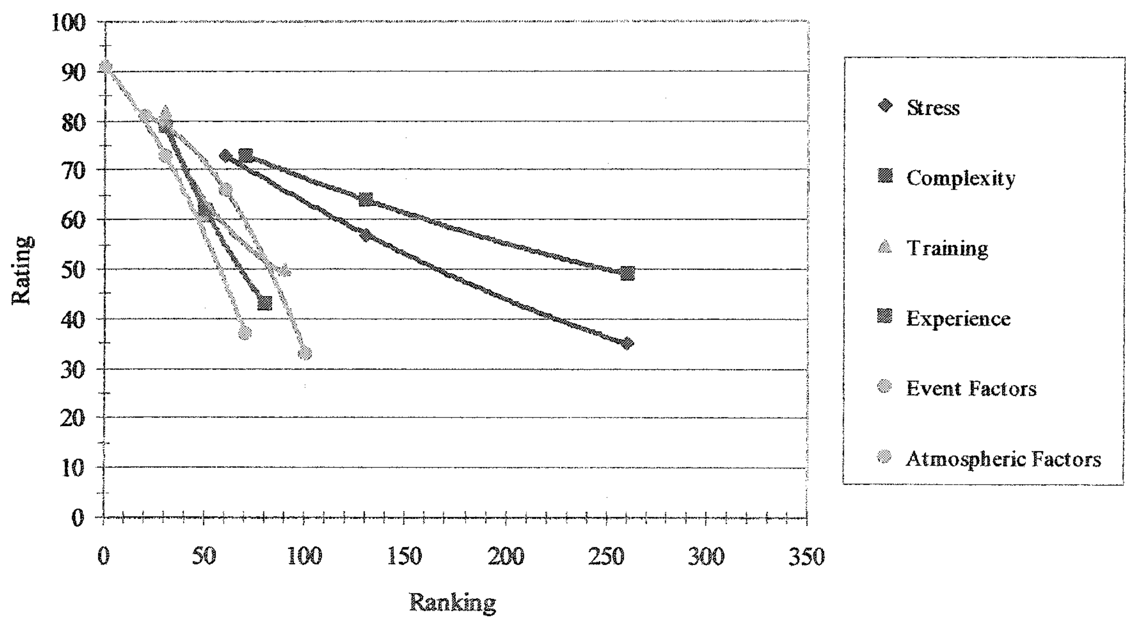

Figure M.14 Action 16 PSF rating reference graph.

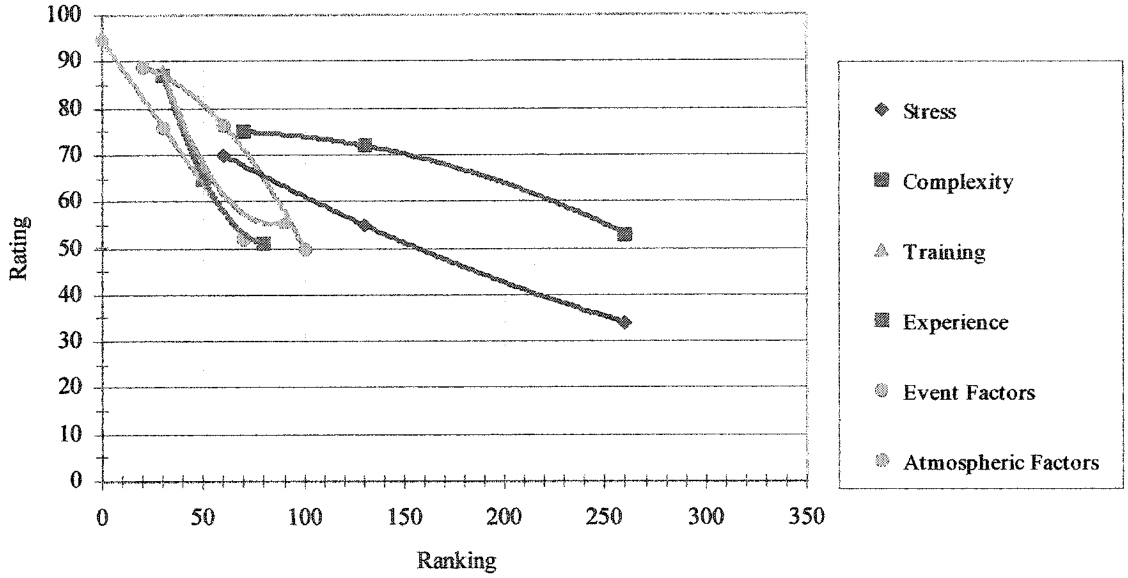

Figure M.15 Action 17 PSF rating reference graph.

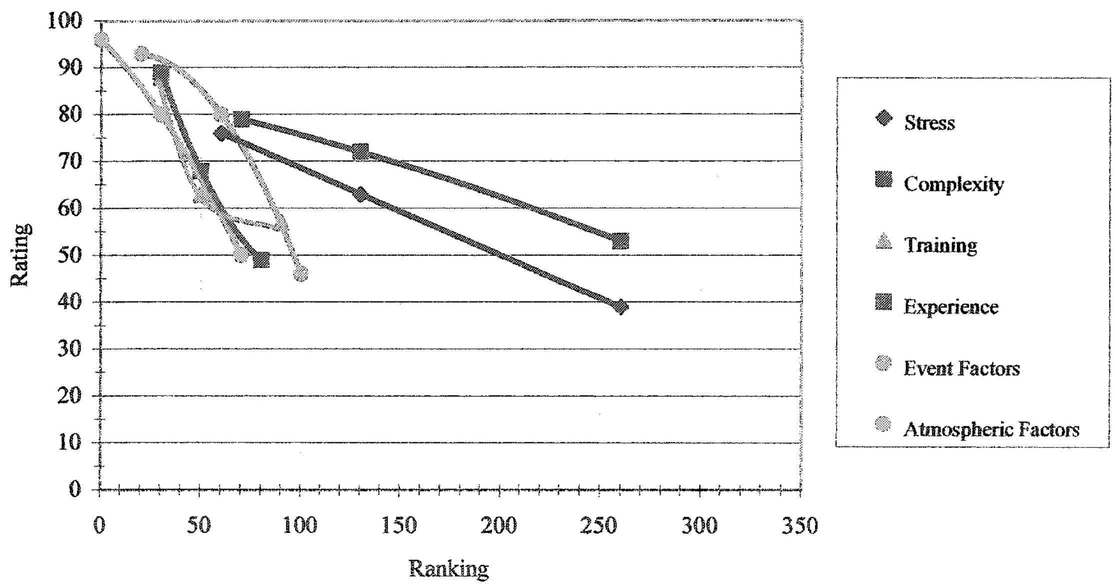

Figure M.16 Action 18 PSF rating reference graph.

Appendix N

Risk Mitigation Measures Tables

Table N. 1 Risk mitigation table for action 2.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
2. Identify alarm	1. Competency testing 2. Make available audio equipment or recording of alarms to permit personnel to remind themselves of alarm sounds 3. Muster training at infrequent intervals 4. Train POB to distinguish between alarms 5. Enlist feedback after training exercises on alarm effectiveness 6. CCR operators trained to issue PA announcements as soon as possible after muster alarm activated 7. Behavioural testing to determine panic potential 8. Experienced personnel trained to assist others	1. Alarm key next to station bills to help identify alarms 2. Muster alarm to be easily distinguishable among audible alarms 3. Eliminate nuisance alarms from audio system, restrict to control room 4. Muster procedure to include PA announcement as soon as possible after alarm instigated 5. Personnel equipped with 2-way radios to contact CCR 6. Alarm checklist provided to all personnel 7. Station bill card provided to all personnel 8. Identify new personnel with different coloured clothing	1. Alarm systems strategically placed to ensure coverage in all areas 2. Alarm redundancy design to include both audio and visual components 3. Alarm system review based on advances in technology

Table N. 2 Risk mitigation table for action 3.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
3. Act accordingly	1. Competency testing 2. Muster training at infrequent intervals 3. Enlist feedback after training exercises on alarm effectiveness 4. CCR operators trained to issue PA announcements as soon as possible after muster alarm activated 5. Behavioural testing to determine panic potential 6. Experienced personnel trained to assist others as identified	1. Muster procedure located on opposite side of station bill card 2. Muster procedure to include PA announcement as soon as possible after alarm instigated 3. Personnel equipped with 2-way radios to contact CCR or be contacted from CCR 4. Identify new personnel with different coloured clothing	

Table N. 3 Risk mitigation table for action 4.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
4. Ascertain if danger is imminent	1. Competency testing 2. Muster training that teaches POB to ascertain danger levels 3. Enlist feedback after training exercises on alarm effectiveness 4. CCR operators trained to issue PA announcements that provide information on the severity of muster 5. Behavioural testing to determine panic potential 6. Experienced personnel trained to assist others as identified	1. Muster procedure located on opposite side of station bill card 2. Muster procedure to include PA announcement from CCR updating POB on muster status 3. Personnel equipped with 2-way radios to contact CCR or be contacted from CCR 4. Identify new personnel with different coloured clothing	1. Informative warning systems which indicate type and location of muster initiator

Table N. 4 Risk mitigation table for action 5.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
5. Muster if in imminent danger	1. Competency testing 2. Muster training that teaches POB to ascertain danger levels 3. Enlist feedback after training exercises on alarm effectiveness 4. CCR operators trained to issue PA announcements that provide information on the severity of muster 5. Behavioural testing to determine panic potential 6. Experienced personnel trained to assist others as identified	1. Muster procedure located on opposite side of station bill card 2. Muster procedure to include PA announcement from CCR updating POB on muster status 3. Personnel equipped with 2-way radios to contact CCR or be contacted from CCR 4. Identify new personnel with different coloured clothing	1. Information warning systems which indicate type and location of muster initiator

Table N. 5 Risk mitigation table for action 6.

Action	**Risk Mitigation Measures**		
	Training	**Procedure and Management Systems**	**Equipment**
6. Return process equipment to safe state	1. Competency testing 2. Muster training that places individuals in specific tasks which require the a return of process equipment to a safe state 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified	1. Personnel equipped with 2-way radios to contact CCR if help is required 2. Work teams to conduct difficult jobs 3. Inexperienced individuals teamed with experienced personnel for a defined period of time 4. Limit inexperienced individuals to day shifts only 5. Identify new personnel with different coloured clothing 6. Limit work during poor weather 7. Identify individuals and work activities on CCR work board 8. Control activities through permit to work system 9. Pre-job safety discussion	1. Proper labeling of equipment to avoid mistakes in actions such as closing a similar but incorrect valve in making workplace safe 2. Conduct prolonged work activities in sheltered environments 3. Active safety systems (i.e. deluge) to protect individuals during work activities 4. Passive systems such as wind walls to protect individuals in the process area from extreme weather

Table N. 6 Risk mitigation table for action 7.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
7. Make workplace safe as possible in limited time	1. Competency testing 2. Muster training that places individuals in specific tasks which require the a return of process equipment to a safe state 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified	1. Personnel equipped with 2-way radios to contact CCR if help is required 2. Work teams to conduct difficult jobs 3. Inexperienced individuals teamed with experienced personnel for a defined period of time 4. Limit inexperienced individuals to day shifts only 5. Identify new personnel with different coloured clothing 6. Limit work during poor weather 7. Identify individuals and work activities on CCR work board 8. Control activities through permit to work system 9. Pre-job safety discussion	1. Proper labeling of equipment to avoid mistakes in actions such as closing a similar but incorrect valve in making workplace safe 2. Conduct prolonged work activities in sheltered environments 3. Active safety systems (i.e. deluge) to protect individuals during work activities 4. Passive systems such as wind walls to protect individuals in the process area from extreme weather

Table N. 7 Risk mitigation table for action 8.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
8. Listen and follow PA messages	1. Competency testing 2. Muster training that emphasizes quality PA announcements from CCR 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified 6. Muster training that uses PA announcements to test POB	1. Personnel equipped with 2-way radios to contact CCR if PA announcement missed 3. Inexperienced individuals teamed with experienced personnel for a defined period of time 4. Limit inexperienced individuals to day shifts only 5. Identify new personnel with different coloured clothing 6. Limit work during poor weather	1. PA systems strategically placed to ensure coverage in all areas 2. PA system design reviews

Table N. 8 Risk mitigation table for action 9.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
9. Evaluate potential egress paths and choose route	1. Competency testing 2. Muster training that blocks egress paths forcing route evaluation 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified 6. Conduct muster observations that permit constructive feedback to POB 7. Train individuals to recognize danger signs that indicate areas are of low tenability	1. Personnel equipped with 2-way radios 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 3. Limit inexperienced individuals to day shifts only 4. Identify new personnel with different coloured clothing 5. Station bills signage located at strategic location shows route to TSR 6. Plastic station bill cards for each individual showing egress routes to TSR	1. Egress paths clearly labeled through marking on platform deck 2. Egress paths marked with signage throughout process 3. Egress paths marked with photo-luminescent tape within accommodations module to help identify egress path in the event of power loss 4. Egress paths marked with illuminated signage and emergency lighting

Table N. 9 Risk mitigation table for action 10.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
10. Move along egress route	1. Competency testing 2. Muster training that blocks egress paths forcing route evaluation 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified 6. Conduct muster observations that permit constructive feedback to POB 7. Train individuals to move among the process units in a controlled fashion but under a simulated compromised situation	1. Personnel equipped with 2-way radios 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 3. Limit inexperienced individuals to day shifts only 4. Identify new personnel with different coloured clothing 5. Station bills signage located at strategic location shows route to TSR 6. Plastic station bill cards for each individual showing egress routes to TSR	1. Egress paths clearly labeled through marking on platform deck 2. Egress paths marked with signage throughout process 3. Egress paths marked with photo-luminescent tape within accommodations module to help identify egress path in the event of power loss 4. Egress paths marked with illuminated signage and emergency lighting

Table N. 10 Risk mitigation table for action 11.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
11. Assess quality of egress route while moving to TSR	1. Competency testing 2. Muster training that blocks egress paths forcing route evaluation 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified 6. Conduct muster observations that permit constructive feedback to POB 7. Train individuals to recognize danger signs that indicate areas are of low tenability	1. Personnel equipped with 2-way radios 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 3. Limit inexperienced individuals to day shifts only. 4. Identify new personnel with different coloured clothing 5. Station bills signage located at strategic location shows route to TSR 6. Plastic station bill cards for each individual showing egress routes to TSR	1. Active warning systems that provide feedback on local area and egress path tenability

Table N. 11 Risk mitigation table for action 12.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
12. Choose alternate route if egress path is not tenable	1. Competency testing 2. Muster training that blocks egress paths forcing route evaluation 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified 6. Conduct muster observations that permit constructive feedback to POB 7. Train individuals to recognize danger signs that indicate areas are of low tenability	1. Personnel equipped with 2-way radios 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 3. Limit inexperienced individuals to day shifts only 4. Identify new personnel with different coloured clothing 5. Station bills signage located at strategic location shows route to TSR 6. Plastic station bill cards for each individual showing egress routes to TSR	1. Egress paths clearly labeled through marking on platform deck 2. Egress paths marked with signage throughout process 3. Egress paths marked with photo-luminescent tape within accommodations module to help identify egress path in the event of power loss 4. Egress paths marked with illuminated signage and emergency lighting 5. Active warning systems that provide feedback on local area and egress path tenability

Table N. 12 Risk mitigation table for action 14.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
14. Assist other if needed or as directed	1. Competency testing 2. Muster training that sets up situations where certain POB require assistance 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified 6. Conduct muster observations that permit constructive feedback to POB 7. Train individuals to recognize others that require help during muster	1. Personnel equipped with 2-way radios 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 3. Limit inexperienced individuals to day shifts only 4. Identify new personnel with different coloured clothing 5. Station bills signage located at strategic location shows route to TSR 6. Plastic station bill cards for each individual showing egress routes to TSR	1. Egress paths clearly labeled through marking on platform deck 2. Egress paths marked with signage throughout process 3. Egress paths marked with photoluminescent tape within accommodations module to help identify egress path in the event of power loss 4. Egress paths marked with illuminated signage and emergency lighting 5. Active warning systems that provide feedback on local area and egress path tenability

Table N. 13 Risk mitigation table for action 15.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
15. Register at TSR	1. Competency testing 2. Conduct muster observations that permit constructive feedback to POB 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Experienced personnel trained to assist others as identified	1 Signage in TSR reminding individuals to register upon entry during a muster 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 4. Identify new personnel with different coloured clothing 5. Individual responsible for head count trained to prompt POB to register	1. TSR registration (i.e. card rack) to be located in an area that permits the maximum free flow of individuals so that queues are quickly reduced 2. Automated registration, unique identification tag for all POB that a sensor reads upon entering the TSR

Table N. 14 Risk mitigation table for action 16.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
16. Provide pertinent feedback attained while enroute to TSR	1. Competency testing 2. Conduct muster observations that permit constructive feedback to POB 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Muster training to include opportunities for information transfer in the TSR	1 Signage in TSR reminding individuals to register upon entry during a muster 2. Inexperienced individuals teamed with experienced personnel for a defined period of time 4. Identify new personnel with different coloured clothing 5. Individual responsible for head count trained to prompt POB to register	1. Telephone link to OIM or CCR personnel to provide feedback

Table N. 15 Risk mitigation table for action 17.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
17. Don personal survival suit or TSR survival suit if instructed to abandon	1. Competency testing 2. Conduct TSR muster observations that permit constructive feedback to POB 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Muster training to include opportunities for donning survival suit	1 Signage in TSR reminding individuals to register upon entry during a muster 2. Inexperienced individuals teamed with experienced personnel 3. Identify new personnel with different coloured clothing 4. Muster procedures designed so that a team approach is taken getting suited up with survival gear to reduce competition for space in the TSR 5. Diagrammatic instructions on how to don survival suit in the TSR 6. Written procedure on how to don survival suit in the TSR 7. Survival suits stored properly for easy retrieval	1. Provide high quality survival suits in the TSR and not the traditional "gumby suit" which is awkward to don and reduces mobility

Table N. 16 Risk mitigation table for action 18.

Action	Risk Mitigation Measures		
	Training	**Procedure and Management Systems**	**Equipment**
18. Follow OIM's instructions	1. Competency testing 2. Conduct TSR muster observations that permit constructive feedback to POB 3. Enlist feedback after training exercises 4. Behavioural testing to determine panic potential 5. Muster training to include opportunities for evacuation staging	1. Inexperienced individuals teamed with experienced personnel 2. Identify new personnel with different coloured clothing 3. Familiarize POB with TEMPSC and other survival/evacuation equipment 4. Checklist in TSR to remind POB of prerequisites prior to evacuation	