Assessing the Impact of Management and Organizational Factors on the Risk of Tanker Grounding

by

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B.S. Ocean Engineering
Texas A&M University, 1996

SUBMITTED TO THE DEPARTMENT OF OCEAN ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN OCEAN SYSTEMS MANAGEMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FEBRUARY 1998

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Abstract

Management and organizational factors have contributed either directly or indirectly in a number of marine accidents. Unfortunately, these factors are still under-represented in both human reliability analysis and probabilistic risk assessment. The International Safety Management Code, which is a much needed instrument in focusing on management and organizational aspects of the maritime industry, motivates the ship operator to identify the management factors that may increase risk and to develop preventive and corrective measures for those factors. In order to successfully incorporate effective and efficient measures to prevent accidents, a systematic approach must be utilized. The overall objective of this thesis is to develop a probabilistic risk model for oil tanker groundings, which includes the relationship between management, performance shaping factors, and individual errors.

The thesis quantitatively links management and organizational factors to the human errors and equipment failures which are involved in oil tanker groundings. The analysis is based on a grounding model, previously developed, which applies the risk assessment methodologies of the nuclear power industry, utilizing fault/event trees and the technique for human error rate prediction data to quantify individual errors. In this thesis, the model is taken one step further by examining performance shaping factors, as well as management and organizational factors. This extension is significant considering the number of management deficiencies contributing to accidents. The performance shaping factors and the management and organizational factors are weighed utilizing expert opinion and the analytical hierarchy process, in order to determine relative importance. Finally, management and organizational factors, found to have the greatest impact on the probability of grounding, are compared to those factors emphasized by the International Safety Management Code.

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1 Introduction

A number of highly visible oil spills in both US national and international waters have increased the public's awareness of the dangers involved in transporting oil at sea. As a result, the marine industry has come under substantial pressure to reduce the risks of such accidents. Traditionally, the risks associated with oil tankers have been approached from a technical point of view. More recently the need for focusing on the human and organizational factors involved in tanker operations has been realized.

1.1 Motivation

Oil spills are classified as low probability/high consequence events [3]. That is, the probability of an oil spill is considered relatively low; however, the consequences are in some cases extremely high, resulting in significant overall risk. The potential consequences, including environmental, economic, and health impacts, typically result in significant adverse public reactions.

Until the late 1980s, the attitude of the maritime industry was primarily reactive. The focus was on the mitigation efforts following accidents to minimize the consequences of the oil spills. However, as a result of problems and costs experienced with containment, removal, and treatment of oil spills, it has been generally realized that the primary line of defense should be the prevention of accidents resulting in oil spills. This view has been further strengthened after the March 1989 Exxon Valdez spill in Prince William Sound, Alaska. Following this accident, in which the Exxon Valdez grounded on Bligh Reef spilling approximately 238,000 BBL of Alaskan crude oil [26], the US enacted the Oil Pollution Act of 1990 (OPA-90) on August 18, 1990.

Under OPA-90, which applies to all owners, operators, and bareboat charterers of vessels that operate in US waters, responsible parties are liable on a "joint and severally" basis for discharges of oil, including oil spill containment and cleanup costs and other damages arising from the spill. The act places a limit on the liabilities of the responsible parties; the greater of $1,200 per gross ton or $10 million per tanker [24]. However, this limit does not apply in the cases where the spill is caused by a violation of US federal safety, construction, or operating regulations, gross negligence or willful misconduct, or if the responsible party did not report the accident or assist with the oil removal. In addition, there are no limits to the US state law liability [24]. As a result of the potential unlimited liability, the tanker industry has become increasingly aware of the necessity of reducing the risk of oil spills, as well as limiting all factors that may result in liability.

The possibility of experiencing an offshore or coastal oil spill is related to the amount of oil being transported at sea. Nearly half of all seaborne trade consists of the transportation of petroleum products, and oil tankers represent 38 percent of the world fleet by tonnage [60]. Tankers are the largest contributor by vessel type to oil spill volume in the world. In the period from 1986 to 1994, tanker spills accounted for 60 percent of all oil spilled from maritime sources [17]. Figure 1-1 illustrates oil spill volume by vessel type. Similarly, in 1993 the United Kingdom Protection and Indemnity (UK P&I) Club reported that tankers were involved in half of their total pollution claims.

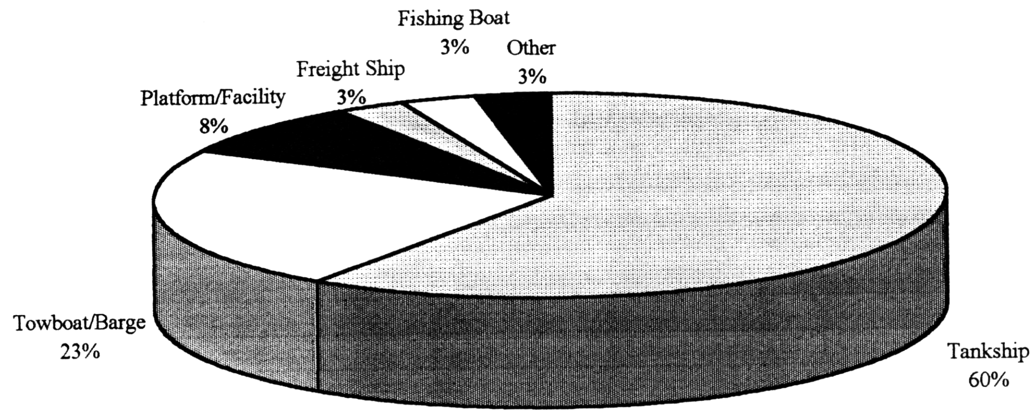

Figure 1-1: Maritime Oil Spill Volume by Vessel Service [17]

The primary causes of accidental oil spills are grounding, collision, explosion/fire, and structural failure. The percentage of incidents and volume of oil spilled resulting from the different causes are illustrated in Figure 1-2. Both with respect to the number of incidents and volume, groundings and collisions together represent the largest contribution to oil spills. Grounding, which occurs in the event that a tanker enters water in which the draft of the tanker exceeds the depth, is a significant cause of oil spills [43]. For instance, in the period from 1987 to 1991, tanker groundings resulted in 20 percent of the world's tanker losses [58], and in the period from 1981 to 1990, groundings resulted in 45 percent of major spill volume in the US [36]. Due to the importance of and the frequency with which grounding occurs, this thesis will focus on oil tanker groundings in order to evaluate tanker risk. (The analysis of groundings differs primarily from collision analysis with respect to the number of vessels involved; grounding involves only one vessel compared to collision which involves the dynamics of two vessels.) By analyzing tanker groundings, the failures and errors which lead to groundings may be identified and quantified, which enables tanker owners and operators to implement the necessary corrective measures.

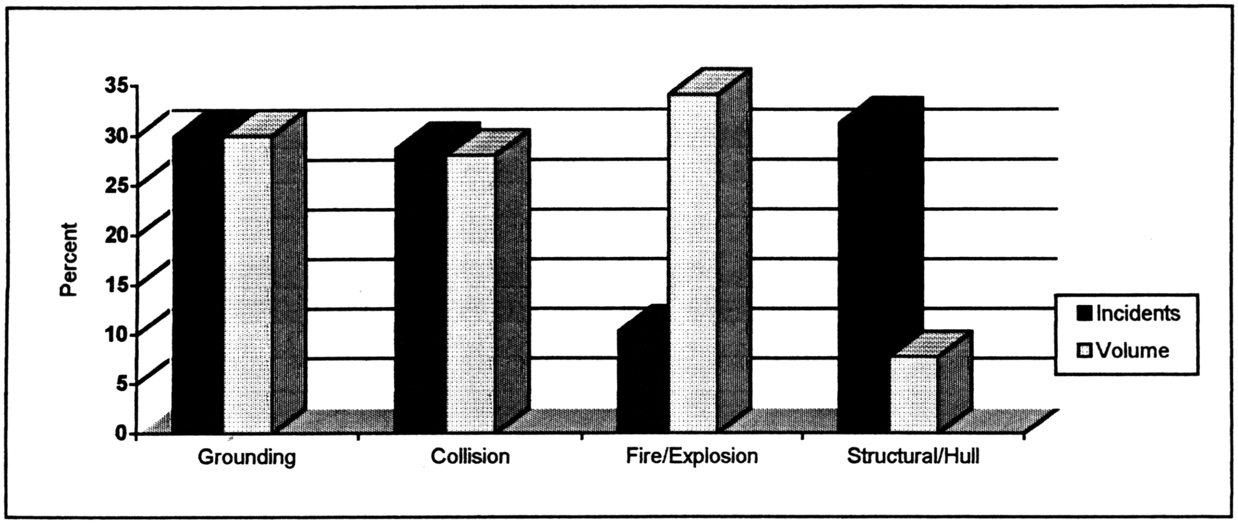

Figure 1-2: Causes of Major Accidental Oil Spills by Tankers [43]

Tanker groundings are caused by structural failure, mechanical failure, equipment failure and/or human error. Historically, the maritime community has approached safety and pollution prevention from a predominantly technical perspective. Certainly, a variety of technical systems, including systems related to propulsion, steering, anchor, electronic navigation, etc., are of great importance for the operation of tankers. However, at the core of the majority of the accidents are management and organizational factors. Management and organizational factors greatly influence both the technical and the human elements involved in the design and operation of the vessel. The ability of the technical systems to perform in a satisfactory manner depends on proper design, maintenance, and operation, all of which are directly affected by the management of the tanker. Similarly, the crew operating the tanker is greatly affected by policies, procedures, and decisions made by the management.

Recently, the necessity of addressing human and organizational factors affecting safety has been realized. The International Safety Management (ISM) Code is a much needed instrument in focusing on these factors in the maritime industry. The ISM Code requires vessel operators to develop and implement a safety management system. In order to meet the requirements of the ISM Code, a ship operator must identify those factors that involve the most risk and develop preventive or corrective measures for those factors. Therefore, in the process of complying with the ISM Code, companies have an opportunity to identify undesirable practices and improve their operations.

1.2 Approach

In order to successfully incorporate effective and efficient preventive and corrective measures for failures resulting in tanker groundings, a systematic approach for evaluating the risks involved in the tanker operation must be utilized. This thesis builds on a grounding model, developed in a previous study [3], which estimates the probability of tanker grounding. The model employs the method of probabilistic risk assessment (PRA), which is a method of identifying and quantifying problems and hazards, as well as identifying areas with the greatest risk reducing potential. PRA includes the use of fault trees and event trees, as well as the incorporation of Technique for Human Error Rate Prediction (THERP) data. The previous tanker grounding model is expanded to include Performance Shaping Factors (PSFs) and Management and Organizational Factors (MOFs).

The planning, piloting, and decision processes involved in grounding can be defined by a series of standard tasks which are common to many processes. This assumption permits the application of the THERP data assembled in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* [57]. The individual human errors are estimated using mean Human Error Probabilities (HEPs). However, the HEPs are actually functions of MOFs, with PSFs as intermediate variables. PSFs are factors that affect the ability of personnel to carry out different tasks without error [57]. MOFs are factors that affect and in some instances define the conditions of the PSFs, as well as the quality of maintenance and the condition of equipment. (The relationships between MOFs, PSFs, and HEPs are illustrated in Figure 1-3.) By adjusting the HEPs with respect to the impact of MOFs, the tanker grounding model also includes the influence on operations by management and the organization.

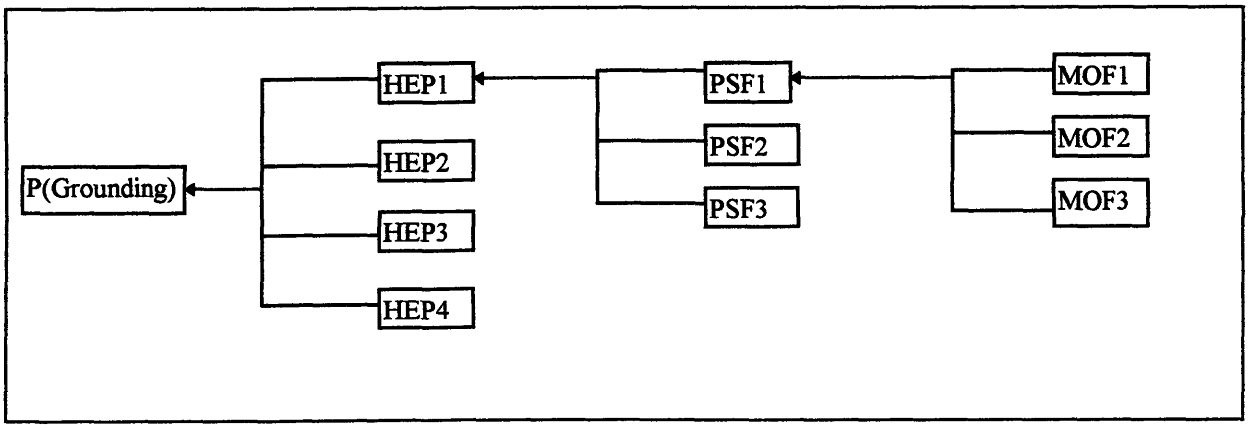

Figure 1-3: Relationships Between MOFs, PSFs, HEPs, and the Probability of Grounding

The PSFs and MOFs are weighed using expert opinion and the Analytic Hierarchy Process (AHP), in order to adjust the mean HEPs and determine their relative importance on the probability of grounding. The final set of MOFs, having the greatest impact on the probability of grounding, is then compared to the organizational factors explicitly and implicitly emphasized by the ISM Code.

1.3 Outline

Following this introduction, Chapter 2 introduces and discusses human factors involved in processes and operations of tankers, while Chapter 3 focuses on the management and organizational aspects of tanker operations, as well as grounding. Chapter 4 presents the ISM Code and discusses some of the implications of this code. The risk assessment and the AHP utilized to estimate the probability of grounding are outlined in Chapter 5. Chapter 6 discusses the grounding model, while the specific PSFs and MOFs adjusting each HEP are presented in Chapter 7. Chapter 8 presents the results of the modified grounding model, sensitivity analyses, and a comparison of the MOFs, found to have the greatest impact on tanker grounding, with the factors addressed by the ISM Code. The conclusions of the analysis are presented in Chapter 9, accompanied by some recommendations concerning further research.

2 The Human Element

Human failure has a substantial impact on the reliability of complex systems, and it may occur in any phase of design, construction, and operation. Various studies have determined that human errors cause the majority of the accidents [17, 44]. Based on an analysis of 100 accidents at sea, it was found that 96 of these were preceded by human failure [25]. The United Kingdom P&I Club performed an analysis of claims filed in 1993 in which it was discovered that human error was the primary cause of 63% of those accidents [17]. Figure 2-1 shows the apparent causes of the accidents.

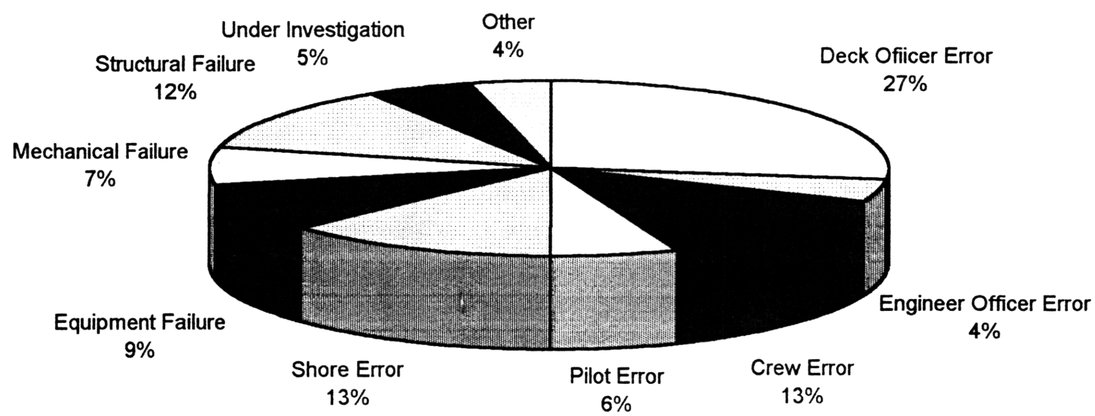

Figure 2-1: Apparent Causes of Major Claims Filed with the UK P&I Club [17]

Due to the large number of accidents caused by human error, success in reducing operational risk in shipping depends directly on measures to improve human performance [42]. Traditionally, human errors have been classified as individual errors, which imply that those failures are part of human nature. The result is that the high percentage of human error is accepted as the norm of the industry [3], and rather than properly addressing the human element, the industry has focused on technological improvements and punitive measures aimed at the operators. With the implementation of the ISM Code this focus is changing. It has finally been realized that in order to reduce the risks associated with tanker operations, it is necessary to identify and quantify human related failures, gain an understanding of human behavior and reliability, and make improvements accordingly.

Accidents, which are defined as occurrences with negative and unintended consequences, are caused by factors that are either internal or external to the system. Internal factors that result in accidents are considered system failures. Even though some system failures are directly caused by human error, it is the design of the system itself that is prone to errors [3]. The attitudes and practices of different groups within the organization may faciliate the occurrence of human errors. The types of errors defined as general classes of organizational failures are discussed in the following chapter. The errors defined as specific failures related to individuals are considered human errors.

Human beings are born with certain traits and abilities, while some are acquired through training and experience. A person will act in a certain manner according to his/her personal characteristics and as a result of the environment. In order to understand the environment in which a person functions, the different levels of environment may be illustrated as follows [40]:

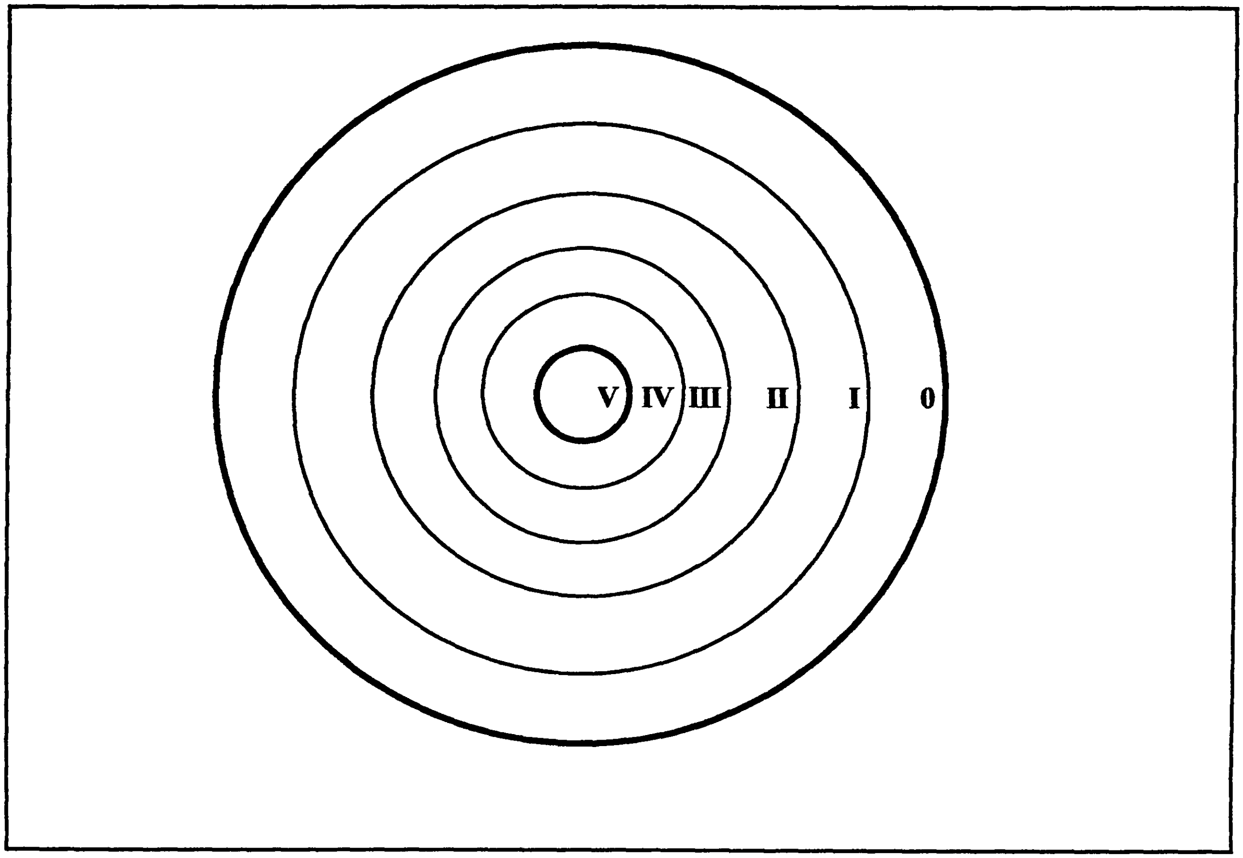

Figure 2-2: Environments Influencing Personnel

Figure 2-2 depicts generic factors and environments that influence a crew member's productivity and reliability [40]. The influences and environments are modeled as an onion in which the different environments represent different layers of the onion. Each layer may be described as follows [40]:

- **Layer 0**
  General regulatory and economic environment
- **Layer I**
  Environment/culture of the company or organization
- **Layer II**
  Environment/culture of the tanker on which the person works

- **Layer III**
  Environment/culture of the company division in which the person works, i.e. teams and units
- **Layer IV**
  Physical and social environment in which the person lives and works
- **Layer V**
  Personal characteristics of the specific person, i.e., knowledge, skills, abilities, motivation, attitude, and morale

The outer influence is the general environment in which the person is existing and the company is operating. This layer, which is not a true layer and therefore labeled Layer 0, consists of the regulatory environment, the economic environment, and various relationships outside the company. The first layer is the corporate environment or the organization, and it consists of the management structure and the culture of the organization, as well as size, age, and efficiency. The second layer is the shipboard environment, which includes the management style of the master, master/officer/crew relations, technology levels, task definitions, procedures, rules, and standards. The third layer is the division such as the bridge or deck division, and this layer consists of the management style within the division, reward and punishment structures, communication within work units, inter-cooperation among work units, and the availability of career paths. The fourth layer is the work area and teams that are the workers' immediate physical, social, and technical environment. This layer concerns the level of ergonomic or human factors engineering, effects of the physical environment and the social and technical environment, on-the-job training quality and availability, structure of work teams, and the overall professionalism of team and workers. Finally, the fifth layer is the individual worker, and it involves the knowledge, skills, abilities, motivation, attitudes, and morale of the person. (Attitude and morale are similar; however, attitude is considered a "state" variable, while morale is considered a "trait" variable [40].)

The personnel are affected by all the different levels of environment illustrated by the concentric fields. However, the layers closest to the center typically influence the personnel to a larger degree with respect to daily operations. Each of the factors within the layers may influence more than one layer, which results in dependencies among the parameters. Also, the different fields mutually interact but nevertheless preserve the general identity at each level [40].

2.1 Human Behavior and Errors

As already discussed, human beings are the most risk-contributing constituent in the maritime activity, and therefore the understanding of human behavior is critical to reduce risk. In order to achieve an understanding of the behavior of human beings, this behavior may be characterized as skill-based, rule-based, or knowledge-based [57]. These terms describe behavior as progressively more complex. Skill-based behavior represents behavior which is almost automatic, rule-based behavior represents behavior which requires a more conscious effort, while knowledge-based behavior requires even more involvement by the person performing a task [57]. These terms are useful as a guidance to understand the characteristics of the behavior of an individual; however, the distinction between the terms sometimes becomes blurred and the terms may overlap.

Human errors are defined as actions that result in unacceptable consequences. A human error may be caused by a person not having the sufficient skill or motivation, and/or some aspect of the situation or environment that induces an error. The term normally excludes malevolent behavior or deliberate misactions, because this is not due to error but rather due to deliberate behavior meant to produce negative effects [57]. Human errors are normally divided into the categories of intentional and unintentional errors. An intentional error is an error which results when an operator intends to perform an act that is incorrect, in the belief that it is correct or it represents a superior method. An unintentional error results without any intended action.

Dependent on the type of task and the type of error, human errors are often divided into errors of omission and errors of commission. Table 2-1 illustrates subsections of each of these groups [57]. The different processes involved in tanker operations may be divided into tasks of a series of different steps, and the errors of omission concern the omission of either one or more steps in the task, or the omission of the entire task. Errors of commission concern an error in selection, an error of sequence, the performance of a step or task too early or too late, as well as quantitative errors in which the performance is not adjusted correctly.

Table 2-1: Human Errors of Omission and Commission [57]

Errors of omission	Omits step in task Omits entire task
Errors of commission	Selection error Error of sequence Time error (too early/too late) Quantitative error (too little/too much)

As already mentioned, a human error may be caused by the individual or by some aspect of a situation or the environment. Often, human errors have been concluded to be caused by an accident prone person in order to justify inadequate safety procedures. The fact is that some groups of people are more accident prone than others, such as male automobile-drivers under 25 years of age; however accident prone people in professional/work situations are rare [57]. Normally, the people experiencing a greater percentage of accidents than others are those who have the greatest exposure to situations involving risks, or it is due to temporary conditions such as an illness, emotional distress, etc. [57].

2.2 Factors Influencing Behavior

A number of factors directly or indirectly influence human behavior. The PSFs, previously described as performance shaping factors, represents factors that impact the personnel in a fairly direct manner. MOFs, previously defined as management and organizational factors, represents factors that impact the PSFs directly, and in this way impact the personnel more indirectly. In order to analyze the human errors influencing tanker risk, the factors having the most effect on performance must be considered.

Factors influencing the performance of personnel may be classified as either internal or external [57]. Internal factors consist of the personal attributes; the internal factors determine the potential level to which an individual is able to develop. Internal factors include personality and intelligent variables, emotional state, expectations, physical attributes and potential, tolerance to stress, etc. External factors concern the situation and environment in which the personnel lives and works. These factors include the physical, technical, and social environment, procedures, policies, and standards of the company, instructions, actual and perceived task requirements, etc. Appendix I includes a list of internal and external PSFs identified by NUREG 1278 [57]. In order to achieve optimum level of performance, there should be a match between the internal and the external factors. The relationship between internal and external factors is illustrated in Figure 2-3.

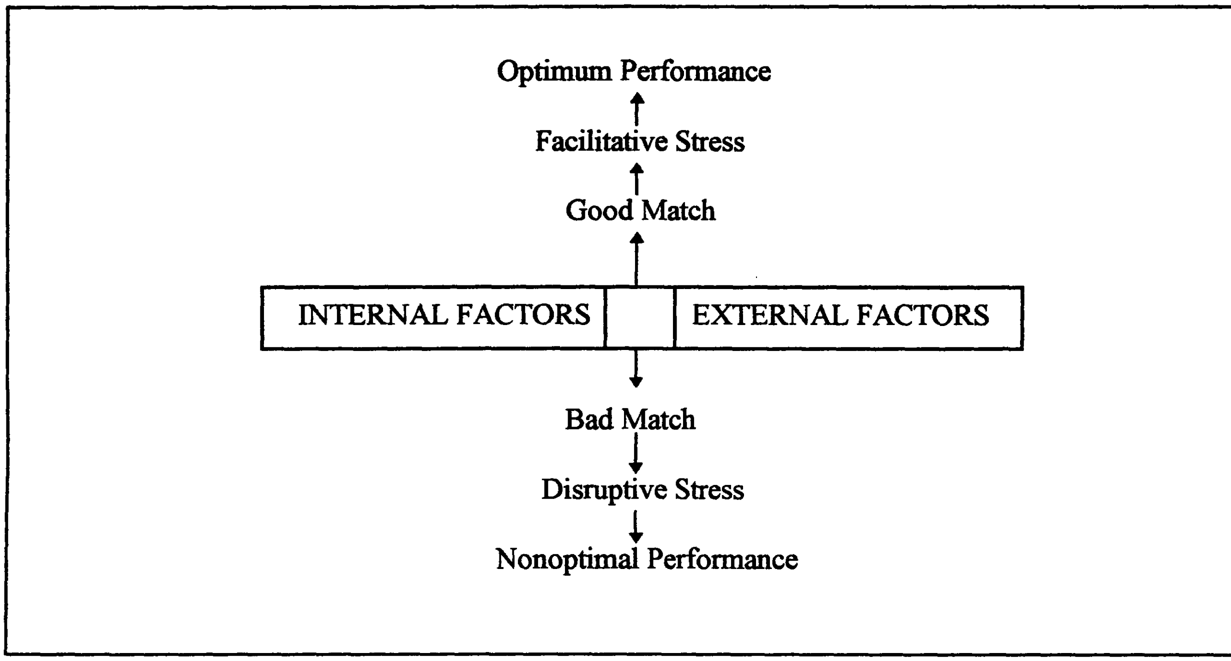

Figure 2-3: Relationship between Internal and External Factors Impacting Performance [57]

Figure 2-3 illustrates how a mismatch of internal and external factors may result in disruptive stress and therefore nonoptimal performance. Disruptive stress is associated with situations in which individuals feel threatened, worried, angry, and/or uncertain. The degree to which these feelings are experienced depends on the individual characteristics of the person, as well as the situation. A good match of internal and external factors is likely to result in facilitative stress, which alerts, thrills, and makes a person eager to perform the task at hand. The degree to which these feelings are experienced also depends on the individual and the situation, as well as the level of education and skill. Generally, a highly educated or skilled person requires a higher degree of challenge to perform well.

Stress, which is defined as physiological or psychological tension [57], is in some cases considered purely negative; however, in the operation of a tanker, a certain level of stress is necessary in order to provide sufficient challenge. Naturally, too much stress as well as too little stress will result in nonoptimal performance, and therefore a balanced stress-level in between the two extremes is considered desirable. In the case that high levels of stress are experienced, two natural tendencies of human behavior often occur:

- A limited number of response alternatives are considered
- Cultural stereotypes become dominant

In a stressful situation, the individual often loses the ability to consider all the aspects of problems and solutions, and in most cases only the response alternatives the person knows by heart are truly considered. Similarly, the individual reverts to his/her cultural stereotypes. Cultural stereotypes are the expectations of groups of people regarding operations, controls, outcomes, meanings, etc. [57]. Examples of cultural stereotypes include turning a valve counterclockwise to open, turning the volume control on a radio counterclockwise to decrease the volume, etc. With extensive training it is possible to change cultural stereotypes; however, under high stress situations most people will naturally revert to their cultural stereotype.

The level of stress should be considered in risk analyses for situations of very low levels of stress and in situations of very high stress levels. In addition, the level of skill of the individual performing the task should be included. In periods of extremely high levels of stress, the levels of training and experience of an individual are the factors most likely to affect performance. A highly skilled person is less likely to make mistakes compared to an unskilled person. The *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* recommends that the HEP values are multiplied by varying constants, dependent on the level of stress involved in the specific situation [57]. These constants are listed in Table 2-2.

Table 2-2: Modifiers for Estimated HEPs for Situations with Varying Levels of Stress [57]

	Multipliers	
Stress Level	**Skilled Personnel**	**Unskilled Personnel**
Very low	2	2
Optimum	1	1 - 2
Moderately high	2 - 5	4 -10
Extremely high	5 - (HEP=0.25)	10 - (HEP=0.50)

The variances in the multipliers for the different stress levels result from the different rates of error that are likely, depending on whether step-by-step tasks or dynamic tasks are involved. That is, if the tasks follow step-by-step procedures, the lower value is used, and if the task is dynamic, the higher value is used.

3 Management and Organizational Issues

Management and the organization contribute either directly or indirectly in most accidents. It has been shown that approximately 80% of major maritime accidents are the results of human and organizational errors [10, 41]. The MOFs affect human behavior through policies, procedures, and decisions made that affect the extent to which the PSFs influence the performance of tasks by personnel. In addition, the MOFs affect the performance of equipment and technical systems through decisions made regarding design, maintenance, and operation.

The dominant types of errors found by the PTP Team[1] in casualty reports are shown in Figure 3-1 [17]. As seen from the figure, the direct management category, which involves shipboard, waterway, and company policies and procedures, represents the most dominant type of error. The other types of error, which also are related to management, are operator status, work environment, decision making, and knowledge. Operator status involves errors due to mariner attributes such as fatigue, inattention, vision deficit, and work load. The working environment category describes errors caused by the natural and onboard working environments. Decision making includes items such as faulty understanding of situations and decisions based on inadequate information. Finally, the knowledge category deals with the mariner's knowledge and experience [17].

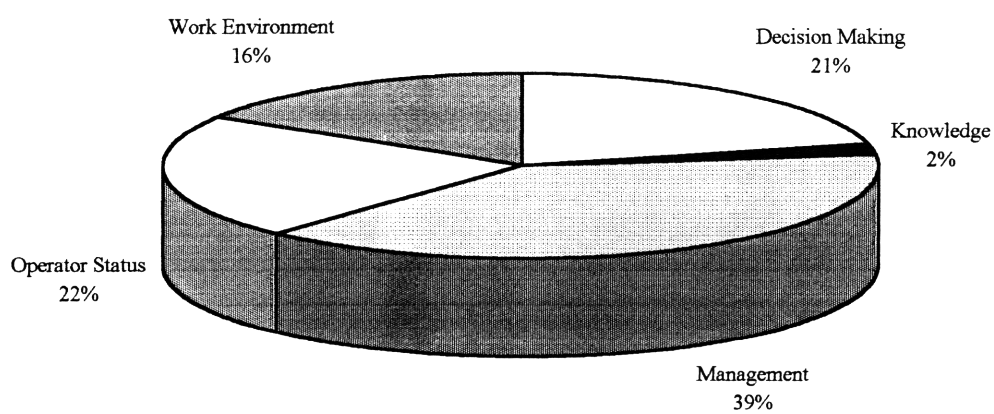

Figure 3-1: Dominant Types of Error Found by the PTP Team in Casualty Reports [17]

The management of a shipping company makes a number of strategic decisions which directly influences the risk associated with a tanker, and it is generally accepted that management and organizational factors strongly influence accident probabilities. Therefore, identification and improvement of management factors directly related to barrier or control provide a great degree of safety assurance [12].

[1] US Coast Guard Prevention Through People (PTP) Quality Action Team

3.1 Tanker Operations and the Industry

The tanker industry is operating in a volatile market, which is prone to oversupply and uncertainty. After the 1973 oil crisis, the tanker industry entered into a depression and freight rates fell, demoting tankers to a cost item of minor importance. The result was a decrease in time chartering and decrease in productivity [56]. In addition, the availability of financing and government subsidies have minimized the barriers to the market. However, due to the highly fragmented market, the shipping companies exercise little pricing power. The result is an over supply of tankers which compete for below cost freight rates. This leads to tanker owners attempting to reduce cost as much as possible [3].

Cost cutting strategies involve the reduction or absence of proper maintenance, extending the life of the tanker, registering the tanker under a "Flag of Convenience" (FoC), and reduction in training and resources offered to the crew. Reducing the amount of maintenance is a short-term solution at best. By investing in the proper maintenance, the vessel will operate more efficiently, the life of the vessel may safely be extended, and the probabilities of malfunctions and failures are dramatically reduced. Therefore, in the long-term, proper maintenance represents a more cost-efficient type of operation. Extending the life of a substandard vessel involves a large amount of risk due to the possibility of material failure. It has been determined that 99 percent of tanker losses in 1992 involved ships which were at least 17 years old [27]. Unfortunately, the average tanker age is increasing by 5 percent per year [47]. Registering vessels under a FoC may result in tax benefits, the possibility of crewing ships with low-wage labor, as well as less stringent inspections and classifications. A tanker registered under a FoC may, although not necessarily, imply a substandard vessel or substandard operations. That is, a tanker under a traditional flag implies a vessel in good condition, operated in a responsible manner, while this is not necessarily the case with a FoC registered vessel. Regarding training and resources provided, these factors are dependent on the organization or company operating the tankers. Third party management, in which the shipowner pass the responsibilities for operations to a professional ship management organization, is widespread. On one hand, it may be argued that these organizations consist of experienced professionals and therefore are able to perform the tasks as well as any. The experience of the operating company greatly influences the operation; an experienced company is likely to utilize knowledge gained from past experience in order to improve future performance. On the other hand, these organizations are merely paid for doing a job, i.e., these organizations are less involved in the fate of the operations and therefore decisions may be more focused on the short-term aspects of the operations than the long-term aspects.

There are still too many substandard vessels in operations; however, especially due to the large awards arising from the Exxon Valdez accident and punitive legislation such as OPA-90, the tanker industry is now attempting to reduce their potential liability [56]. Large oil companies, in particular, are taking a very responsible and conservative approach to reducing tanker risk. In order to decide upon the most cost-effective approach, companies and legislators need methods to systematically analyze tanker risk, including factors related to the organization and the management of the vessels.

3.2 The Organization

The influence of the organization on the reliability of maritime systems is one of the most pervasive of human failure-related root causes [8]. Even though errors may be directly caused by the front line operator, it is the design of the system or the organization that influences the operator. It is necessary to move away from the tendency to treat human failure at the local level, and to focus rather on the global context of the organization. The search for root causes must replace the practice of punishing the final human link [15].

The organization defines the environment in which the personnel work and live, sets policies, and makes major decisions regarding the operations of the tanker. When the organization is successful, the result is likely to be a well-functioning, safe, and efficient crew. The opposite is true when the organization is not performing adequately. Organizations have an impact on individual response through their structure and culture, both of which are functions of each other [2]. In addition, there must be congruence between the different aspects of the organization, e.g., congruence between objectives, goals, policies, matching of personnel and tasks, etc.

3.2.1 Organizational Structure

The organizational structure, which is the necessary framework within the organization and the responsibility of the management, greatly impacts the operation of the vessel. In the maritime industry, both the hierarchical and horizontal types of organizational structures, representing two extremes, are present. The organizational structure most commonly adapted in traditional maritime nations is the hierarchical structure. Leadership is important to maintain order and discipline, and the hierarchical structure provides for an overall monitoring of and influence on activities. However, the hierarchical structure, which is associated with unidirectional, top-down communication and coordination, may result in discouragement regarding participation by the crew. In some instances, detected problems and potential solutions may not reach the management of the organization due to inadequate bottom-up channels. The hierarchical structure is often associated with the absence of role flexibility, i.e., a departmental structure with narrow, fixed roles [61]. An additional characteristic associated with the hierarchical structure is the class distinctions among the crew, which may result in tension in certain situations. The social structure onboard ships has traditionally been fragmented and stratified, but recent changes in some companies have resulted in a structure that is more flexible, with a deemphasis of status symbols [61]. The horizontal type of organizational structure allows for increased participation by the crew with respect to decision making and communication. The horizontal structure is often accompanied by role flexibility, in which the roles are more broadly defined and assignment patterns are more flexible. This involves crossing of traditional boundaries, such as the boundary that exists between the deck and the engine room. However, the horizontal structure may also result in problems with order and discipline if not carried out correctly. Regardless of the type of organizational structure, effective and efficient lines of responsibility, coordination, and communication should be established.

The division of labor and coordination of effort largely determine the structure of the organization [22], while administrative control reinforces the organizational structure. Division of labor enables an overall task to be decomposed into subtasks to be performed by groups or individuals. It consists of the creation of teams formed according to functional specialization, and it may include shorebased and shipbased divisions, bridge and deck divisions, officers and crew divisions, etc. Coordination of work integrates the subtasks into a single effort. It consists of information-based decision processes developed to accomplish the overall task. Both formal and informal coordination mechanisms, such as policies, procedures, vertical and horizontal channels, scheduled and unscheduled meetings, should be utilized in support of the decision making processes [16]. Administrative control, which refers to the extent to which policies are carried out and adequately monitored, reflects the type of organizational structure inherent in the company. Administrative control reinforces the lines of responsibility and coordination, and good administrative control systems can significantly reduce the probabilities of certain types of errors [57].

The organization should establish an effective and efficient structure of communication. In the case that an organizational structure is to complex, the established communication flow-paths may lead to faulty decisions and result in little or no feedback to the management. In addition, the existence of clearly defined incentive structures is critical to the success of the organization. The incentive structures should specify how individuals are rewarded, what decision criteria are used, and how the criteria fit the overall objectives of the organization [3].

3.2.2 Organizational Culture

In addition to organizational structure, management and organizational impacts are results of the culture of the organization; the structure and the culture are functions of each other. For instance, the hierarchical structure, even though the optimal structure in some cases, may result in a culture not encouraging bottom-up communications or the provisions of reward [42].

The organizational culture refers to the shared perception of the organization, and it involves the traditions, values, and goals by which the organization may be characterized. The culture of the organization influences to a large extent the manner in which the personnel act, carry out tasks, and socialize. For example, the goals set by an organization may induce otherwise rational people to make irrational decisions. Pressures to reduce costs and maintain schedules may result in unsafe operations and are currently a problem in the maritime industry. Another problem with respect to culture that is often encountered in organizations is related to the manner in which messages and feedback are handled. Typically, two natural tendencies are likely to be encountered; critical messages tend to flow downward and commendatory messages tend to flow upward [23]. That is, the management does not adequately provide positive feedback to the crew, while the crew does not adequately provide constructive criticism to the management. In order to achieve a more effective system, these tendencies should be reversed. In conjunction with emerging technologies, corresponding emphasis should be placed on the organizational aspects of utilizing the technology to manage operations more effectively and safely. The maritime industry generally responds slowly to technological changes; however, this part of the maritime culture is gradually changing. A number of companies have realized that the potential useful aspects of different information technologies.

The safety culture of an organization encompasses issues of multidimensional domains, both structural and attitudinal, and it relates to both organizations and individuals [6]. It is one of the fundamental management principles necessary for the safe operation of the tanker, i.e., the achievement of total system safety is dependent on the existence of a safety culture which is properly defined. In order to operate safely, the organization should have both a formally established safety culture and an environment of safety consciousness. If this is not the case, the layers of safety precautions may more easily be breached. Four characteristics defining the adequacy of the safety culture are the following [63]:

- Knowledge acquired by personnel regarding safety
- Attitude of personnel toward safe operations
- Choice of performance goals
- Establishment of lines of responsibilities and communication

The safety culture is largely influenced by the attitude of personnel at all levels of the organization in responding to and benefiting from the organizational structure.

3.2.3 Organizational Congruence

An organization is ideally a dynamic structured entity which changes and adapts to meet activities and the environment, and it has the ability to either enhance or degrade individual performance. In addition to the organizational structure and culture, congruence with respect to the different aspects of the organization is of importance. When evaluating system performance of an organization, congruence between the following factors should be considered [23]:

- Objectives, goals, and policies
- Practices and organizational characteristics
- Personnel and tasks
- Rewards and requirements
- Personnel and environment

Congruence between company objectives, goals, and policies at all levels of the organizational structure is important. In the case that this is not achieved, the result is often confusion as well as conflicting motives with respect to performance. The management practices should also be consistent with the characteristics, or the culture, of the organization. In order to optimize the manning situation on a vessel, the people performing the tasks should be matched with the characteristics of the tasks. In order to maximize the effect of rewards and incentives, the rewards must balance the performance requirements. Finally, the work environment should be matched to the employee needs.

3.3 Categories of Organizational Factors

In a root-cause analysis of work processes, a number of organizational factors influencing the behavior of workers are identified by R.W. Tulli and G.E. Apostolakis [59]. Each of the factors are associated with various organizational categories, shown in Figure 3-2 [59]. (The organizational factors are defined in Appendix II.) The five organizational categories identified are decision making, communication, administrative knowledge, human resource allocation, and culture [59]. The decision making category consists of centralization, goal prioritization, organizational learning, and problem identification, while the category of administrative knowledge consists of coordination of work, formalization, organizational knowledge, and defined roles and responsibility. The communications category consists of external, interdepartmental, and intradepartmental communication, and the human resource allocation category consists of performance evaluation, personnel selection, technical knowledge, and training. The category titled culture is not a regular organizational factor category in that it influences all the other four categories. The culture is divided into organizational culture, ownership, safety culture, and time urgency. The organizational factors are discussed in further detail in Chapter 7.

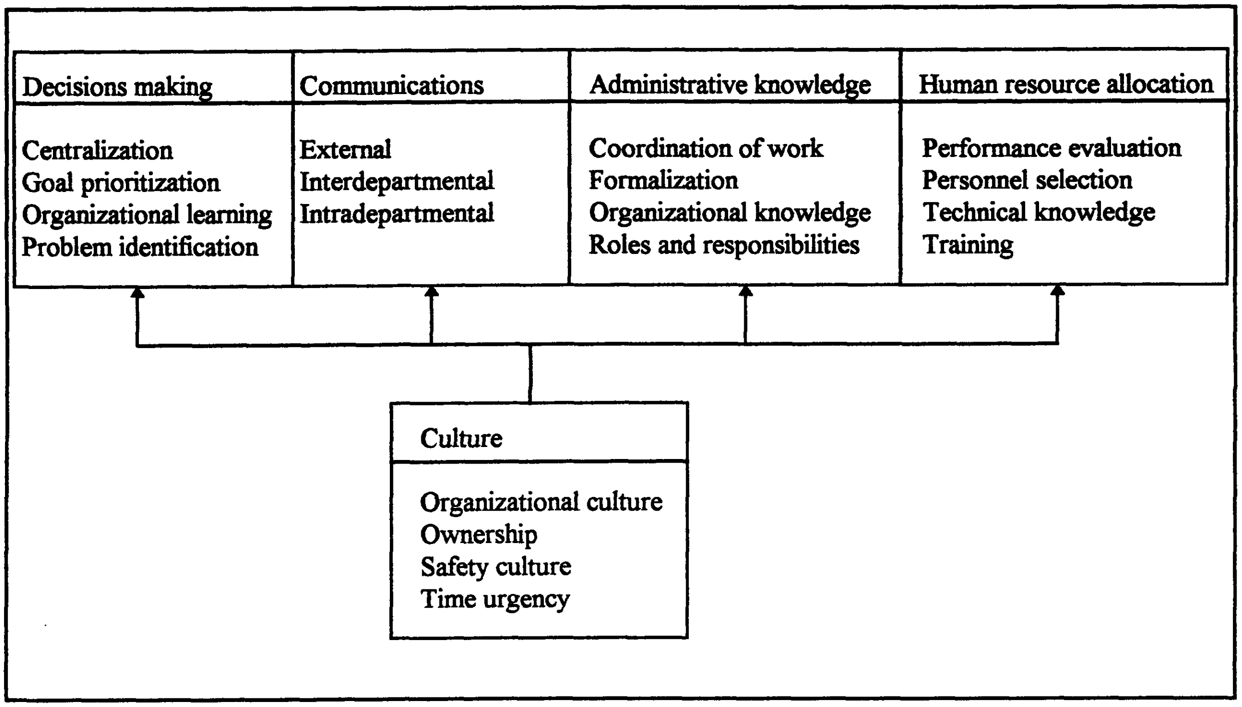

Figure 3-2: Organizational Factor Categories

4 The International Safety Management Code

Management and organizational impacts on human performance may be improved through the implementation of the International Safety Management (ISM) Code. In a move away from traditional technical and hardware requirements, the International Maritime Organization (IMO) mandated the ISM Code to include human and organizational aspects associated with both vessel and shoreside management. The preamble to the ISM Code states:

> The cornerstone of good safety management is commitment from the top. In matters of safety and pollution prevention it is commitment, competence, attitudes, and motivation of individuals at all levels that determines the end result [28].

The intent of IMO is to provide a framework for a safety management system that will result in better policies and procedures, and thereby create more knowledgeable, trained, motivated, and safer crews [3]. The ISM Code provides an opportunity for companies to identify, evaluate, and manage risks identified. In order for a management policy to be effective it must be active and constantly evolving; an active management policy will increase the understanding of responsibilities and interactions within the system, and in that way result in improved performance.

> With sensitive natural resources potentially affected by poor management of risk, it is axiomatic that a vessel owner or operator adhere to a management model which minimizes marine environmental risks and ensures compliance with all applicable laws [42].

IMO Resolution A.741(18) was adopted on November 4, 1993, as the "International Management Code for the Safe Operations of Ships and for Pollution Prevention - The International Safety Management (ISM) Code." This resolution places responsibility on the company's management for the manner in which the ships are operated, which is different from developing regulations covering ship structure and equipment, or from establishing requirements on how to train and certificate seafarers such as in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). The ISM Code mandates that shipowners and operators have a management system which ensures that both safety and pollution prevention are central in operations. The code introduces to a certain extent the concept of self-regulation; the requirements involve internal audits and management reviews. In addition, it requires each company to develop instructions and procedures for the safe operation of their ships.

The voluntary period for ISM certification began in May 1994, when the Code was incorporated in Chapter IX of the Safety of Life at Sea (SOLAS) regulations. In order to comply with Chapter IX of the SOLAS Convention, ships must be operated by a company complying with the requirements of the ISM Code and therefore holding a Document of Compliance (DOC). The ships are issued with a Safety Management Certificate (SMC) by the Flag State Administration or by an organization recognized by this administration. The requirements of the ISM Code will become mandatory for different vessels as follows [28]:

- July 1, 1998: - Oil tankers, chemical tankers, gas carriers, bulk carriers, and high speed cargo crafts of 500 gross tonnage and upward

- Passenger ships including high speed passenger crafts
- July 1, 2002: - Other cargo ships and mobile off shore drilling units of 500 gross tonnage and upward

IMO has encouraged member states to urge shipowners to voluntarily adopt the ISM Code prior to these dates. However, only a relatively small percentage of companies and ships have achieved certification to this date.

4.1 Summary of the ISM Code

The objectives of the ISM Code, as stated in the text of Resolution A.741(18), are as follows:

> The objectives of the ISM Code are to ensure safety at sea, prevention of human injury or loss of life, and avoidance of damage to the environment, in particular, to the marine environment, and to property [30].

In order to comply with the ISM Code, and for the company to be awarded the DOC and the ships to be issued with the SMC, the objectives of the company must include the following:

> The safety management objectives of the company should provide for safe practices in ship operation and a safe working environment, establish safeguards against all identified risks, and continuously improve safety management skills of personnel ashore and aboard ships [30].

The company must develop, implement, and maintain a Safety Management System (SMS), which ensures the compliance with all mandatory rules and regulations, as well as consideration of all applicable codes, guidelines and standards recommended by IMO, governments, classification societies, and maritime organizations and industry. The SMS should be a structured and documented system ensuring the implementation of safety and environmental protection policies. It must include a safety and environmental protection policy, including procedures to ensure safe operations of the vessels and protection of the environment in compliance with mandatory international and flag state legislation. The SMS must contain defined levels of authority and lines of communication between and amongst shore and shipboard personnel, procedures for reporting accidents and non-conformities, procedures to prepare for and respond to emergency situations, and procedures for internal audits and management reviews.

The term "company" means the owner of the ship or any other organization or individual who has assumed the responsibility of the ship, while the term "administration" means the government of the state whose flag the ship is entitled to fly [30].

4.1.1 Safety and Environmental Protection Policy

The purpose of the safety and environmental protection policy is to describe how the objectives regarding safety and environmental protection are to be achieved. The company must ensure that the policy is implemented and maintained throughout all levels of the organization. The safety and environmental protection polices should be in harmony with other existing company policies, such as quality policies and mission statements. In order to be effective, the policy, consisting of goals, objectives, and strategies, should be an element of the general policy [38]. It is also important that the safety and environmental protection policy receives the same attention as all other policies.

4.1.2 Authority, Responsibility, and Lines of Communication

The company must define and document responsibility, authority, and interrelation of all personnel, and it should ensure that adequate resources are provided. All personnel must be given clear and unambiguous definitions of their responsibilities and authorities. The resources needed will vary, but typically resources will include such items as equipment, financial support, competent personnel, and training.

One or more persons ashore, having direct access to the highest level of management, must be designated in order to provide a link between the company and the people on board. The designated persons should be responsible for verifying the effectiveness of the SMS, reporting deficiencies to management, and for ensuring that adequate resources are received in a timely manner. The master should function as the designated person's shipboard counterpart regarding reporting deficiencies to management and ensuring that corrective actions are completed.

The responsibilities of the master must be defined and documented with regard to implementing the environmental protection policy, motivating the crew, issuing orders and instructions, verifying that specified requirements are observed, and reviewing the SMS. The company must also ensure that the SMS contains a statement emphasizing the master's authority. The management of the company should allow the master's overriding authority in the best interest of safety and the environment. The company must also ensure that the master has the required level of training and is fully competent to perform all duties within the scope of the SMS. More specifically, the ISM Code requires the company to ensure that the master is [30]:

- Properly qualified
- Fully conversant with the company's SMS
- Given the necessary support to safely perform his/her duties

Each ship must be manned with a qualified, certified, and medically fit crew in accordance with national and international requirements. (This requirement establishes a link between the ISM Code and the STCW Convention.) Procedures must be established to ensure that new personnel transferred to new assignments related to safety and protection of the environment are given proper familiarization with the relevant tasks. All personnel involved in the SMS must have adequate understanding of the rules, regulations, codes, and guidelines that apply, and the training required in support of the SMS must be provided. It is also important that the personnel receive the information regarding the SMS in languages understood by them.

4.1.3 Procedures for Operation and Emergency Situations

Procedures must be established for the preparation of plans and shipboard operations concerning safety and pollution prevention. The company should ensure that all planned activities for normal operations are carried out correctly by specifying clear procedures and instructions, and that all the existing procedures are in harmony with each other.

The ISM Code requires the company to establish procedures to identify, describe, and respond to potential emergency situations. Programs for drills and exercises to prepare for emergencies should be developed, and the SMS should provide for measures ensuring that the company can respond to an emergency situation at any time. The emergency response plans should be developed with respect to the particular ship, the ship's equipment, and the type of operation in which the ship is involved. It is also important that contact information is included in the plans and is updated whenever necessary.

4.1.4 Reporting of Accidents and Non-Conformities

The SMS must include procedures ensuring that non-conformities, accidents, or hazardous occurrences are reported, investigated, and analyzed with the objective of improving the situation. The company should also establish procedures for implementation of corrective action. These requirements ensure that the company is maintaining the SMS and that it is continuously improving the safety management skills of the personnel. Continuous improvement is of importance because as the SMS matures, the benefits of the system increase.

4.1.5 Maintenance of Systems and Equipment

The company must also establish procedures in its SMS to identify critical equipment systems that may result in hazardous situations in the case of failure. Also, the ship must be maintained in conformity with the provisions of the relevant rules and regulations. In meeting this requirement, the company should ensure that [30]:

1. Inspections are held at appropriate intervals
2. Any non-conformity is reported
3. Appropriate corrective action is taken
4. Records of these activities are maintained

The reporting of accidents, near-misses, and non-conformities will provide for more complete databases which may be utilized in risk analyses.

4.1.6 Documentation

The company must distribute and maintain Safety Management Manuals, describing the SMS, and relevant information to all personnel associated with the SMS. Also, each ship must carry on board documentation relevant specifically to the ship. Procedures must also be established and maintained to control all the documents relevant to the SMS. The procedures must ensure that [30]:

- Valid documents are available at all relevant locations
- Changes to documents are revised and approved by authorized personnel
- Obsolete documents are promptly removed

4.1.7 Internal Audits and Reviews

The company must carry out internal safety audits, and periodically evaluate the efficiency of the SMS in accordance with established procedures. The audits and possible corrective actions must be carried out in accordance with documented procedures, and the personnel carrying out audits must be independent of the areas audited unless this is too impracticable. (This will normally depend on the size of the company.) The results and reviews must be brought to the attention of the appropriate personnel, and corrective action should be taken immediately when deficiencies are found.

4.1.8 Certification

The DOC is issued to companies complying with the requirements of the ISM Code by the administration or an organization recognized by the administration. A copy of the DOC is placed on board the ship, together with a SMC issued to the ship. When issuing the SMC, the administration verifies the proper functioning of the SMS and that the company and its shipboard management operate in accordance with the approved SMS.

4.1.9 Implementation

In order to meet the requirements of the ISM Code, the company should analyze all aspects of design, construction, maintenance, and operation of their vessels, identify those items that have the greatest impact on risk, and develop preventive measures for these items. If properly done, this can assist the company in improving the safety and the economy of their operations [10]. The ISM Code provides a link between safety and the officers and crew on board; if the crew only considers the SMS as a piece of paper, without including the principles in their daily practice, deficiencies and non-conformities will continue. In order to effectively delegate the tasks involved in safety and pollution prevention, the crew must fully understand the reasons behind the specific tasks, and the management delegating the tasks must realize the potential consequences of the requirements not being met [37]. Effective implementation of the ISM Code concerns important factors impacting vessel operation including training, experience, fatigue, maintenance, motivation, morale, etc. [13].

4.2 Benefits of the ISM Code

The benefits of the ISM Code include reduction in marine accidents and economic savings. The implementation of the code is very likely to result in fewer casualties and a reduction in pollution incidents resulting in environmental damage. The reduction in casualties will lead to reductions in cost due to reduced shipboard personnel injuries and the associated liabilities, as well as reductions in costs with respect to insurance claims. The decreased numbers of pollution incidents will reduce company and vessel liability as well as regulatory fines. In addition, due to the established and clearly defined lines of authority and communication, fewer delays might be expected as a positive outcome. Cost savings will also be a result of such factors as reductions in lost work hours due to injury, loss of vessel operation due to repairs, and costs associated with legal problems. These cost savings should outweigh the startup and maintenance expenses for the company.

4.3 Organizational Factors Emphasized by the ISM Code

The ISM Code provides an instrument for shifting the focus towards the management of the companies involved in tanker operations. A number of management issues are emphasized by the ISM Code, and some of the organizational factors associated with these issues deserve special attention. The MOFs specifically emphasized by the ISM Code are the following:

- Organizational Culture
- Safety Culture
- Organizational Learning
- Formalization
- Coordination of Work
- Communication
- Personnel Selection
- Training Process

The company seeking certification must develop objectives and policies related to the safe operation of the ship and it must ensure that personnel at all levels of the organization understand and accept the purpose and relevance of these goals. The culture of the company influences every aspect of the organization. Organizational culture refers to the personnel's shared perception of the organization, and it includes traditions, values, customs, and practices found in an organization; it is what sometimes is referred to as the "personality" of the organization. Related to the organizational culture is the safety culture, which refers to the characteristics of the work environment which influences the personnel's perception of the importance the company places on safety. The importance of an organizational safety culture is the underlying concept of the ISM Code. It is stated that the company is required to develop a management system which ensures that safety and pollution prevention is central in the way they operate. It is also emphasized that the SMS should be in harmony with all other company policies.

The emphasis on inspections, internal audits, investigations, and reporting of non-conformities is important for organizational learning. Organizational learning refers to the degree to which the organization uses knowledge gained from past experience to improve future performance. The reviews and analyses of reports, as well as corrective actions that are carried out by the company, are of great importance in order to reduce risks.

Formalization refers to the extent to which there are well-identified procedures and standardized methods for routine activities as well as unusual occurrences. The importance of formalization is highlighted throughout the ISM Code. It is mandated that instructions and procedures are established, implemented, and maintained for normal operations, audits, non-conformities, emergencies, and accidents. In addition, documents and records should be valid, changed as required, and removed when they have become obsolete.

Coordination of work is underscored as the company is required to define and document levels of authority, responsibility, and interrelations. The company must also designate persons who should function as a link between the company and shipboard personnel. Regarding communication, the code stresses the establishment of lines of communication between shore and shipboard personnel, which may be defined as interdepartmental communication. This refers to informal and formal communication lines between different departments or units within a company. The code states that information regarding the SMS should be provided in languages understood by all personnel, which may refer both to the type of language as well as the level of difficulty.

Personnel selection refers to the degree to which personnel have the required knowledge, experience, skill, and ability to perform the specific tasks. The ISM Code makes it clear that the ships should be manned with qualified, certified, and medically fit seafarers. Even though training requirements comes more specifically under the STCW Convention, it is also a concern of the ISM Code. In addition, the importance of emergency drills and exercises are emphasized by the Code. The training process factor refers both to the availability and quality of the training provided.

5 Risk Assessment and Management

The maritime industry is regularly identified as one involving high risk operations, which requires active risk management programs [4]. Risk assessment and analysis, which involves the identification and evaluation of risks involved in operations, reduce risk as knowledge and awareness are gained. Similarly, risk management is a systematic approach utilizing risk assessment methodologies to determine risk and risk reducing potential, and in this way assist in the management of limited economic resources. That is, instead of alleviating for all conceivable risk, risk management enables the allocation of resources to risk relevant areas.

5.1 Probabilistic Risk Assessment

Risk analyses have been developed in a number of industries; however the method of probabilistic risk assessment (PRA) has primarily evolved in the nuclear industry. Nuclear power stations and oil tankers both result in public concern and anxieties, and therefore similar risk reducing methods as those utilized in the nuclear industry may be developed for maritime operations.

The PRA analysis has its foundation in fault and event tree methodology. The fault and event tree approach consists of discrete logical diagrams explicitly showing the casual relationships within a system, which determine the probability of accident scenarios [3]. The event tree is an inductive model, whereas the fault tree is a deductive model [57]. Both of these approaches are discussed in the following section.

5.1.1 Fault and Event Trees

The fault tree approach is a widely used method of analysis for systems with multiple failure modes. It is a graphic representation of basic component failures which in various combinations may result in an overall system failure state. The fault tree method is a qualitative approach; however it provides a framework for a quantitative evaluation. The method involves identifying the system failure or undesirable event in as broad form as practicable in order for all possible combinations to be evaluated. By deductively working backwards, all combinations of failure may be explored. The appropriate probabilities are assigned to the basic component failures, and finally the probability of the top event is calculated using Boolean form calculations. The result is a reduced Boolean form expression representing the fault tree [3].

The event tree approach is a logic model demonstrating the relationships among the different events occurring, enabling the investigation of risk systematically in an integrated fashion. The event tree is a graphic representation of the progression of system events, following the occurrence of an initiating event, in which the events are represented by limbs in the tree. The branches show the success or failure mode and the combinations of actions and barriers in a specific task. Each limb of the event tree represents a binary process; as an event is carried out, it is either completed successfully or unsuccessfully. Success is designated by a left limb in a branching and failure is designated by a right limb. The values assigned to the limbs are conditional probabilities, and in any branching in the tree the sum of the limbs is 1.0 [57]. The event trees consist of three parts; initiating events, barriers, and end-states. The initiating event is an event which may set off an accident sequence. The barriers are safeguards placed in the path of the potential accident sequences and consist of operator actions and safety system responses. The end-state is the consequence of an accident sequence based on whether or not the sequence was stopped by any of the barriers [15]. The system is modeled with sequential logic, the sequence moves forward in time, and it is assumed that each path is mutually exclusive.

The different portions of the fault tree may be further analyzed and quantified by utilizing event trees. That is, event trees may be developed to determine failure probabilities to be assigned to the fault tree. By developing event trees for the different work processes, the fundamental components of the processes are sequenced in a manner that incorporates the basic faults identified in the fault tree [3].

5.1.2 Human Reliability Analysis

In PRA, Human Reliability Analysis (HRA) is utilized to estimate human error contribution to the failure of system components and functions. Human reliability is defined as the probability of successful human performance, and HRA is a method by which human reliability is estimated [57]. The method combines schematic representations of human events and related system events, as well as their interactions. The HRA method involves the identification, analysis, and estimation of Human Error Probabilities (HEPs) for human tasks critical to the system [57]. The method of HRA involves the following steps [3]:

1. Define system and process failure
2. Perform task analyses
3. Estimate relevant error probabilities
4. Determine effects of individual errors on system failure events
5. Recalculate system failure probabilities

The first step, identifying system and process failures, involves defining the system functions that may be influenced by human errors and for which error probabilities are to be determined. The second step involves performing task analyses. Task analyses, discussed in Section 5.1.2.2, include listing and analyzing the related human operations. The third step is the estimation of the relevant human error probabilities, while the fourth and fifth step involve the estimation of human errors on system failure events.

Human error was previously defined as a departure of acceptable or desirable practice on part of an individual or group of individuals when performing specific tasks. It includes any element of a set of human actions which exceeds some defined limit of acceptability [57]. HEPs are the probabilities that errors will result from the performance of specific tasks. The Technique for Human Error Rate Prediction (THERP) is a method employed to quantitatively predicting individual HEPs. The original data, used to support the THERP data tables, was developed at Sandia National Laboratories. The basic HEPs are estimated for fundamental generic tasks which may collectively comprise a specific series of tasks.

5.2 Process Analysis

The planning, piloting, and decision processes involved in grounding can be defined by a series of standard steps which are common to many processes. That is, the processes may be defined as standardized sequences of tasks, following predictable flow paths from beginning to end, designed within the operational environment of the organization to achieve specific goals [15]. The assumption that the processes involved in tanker operations follow set patterns permits the application of the data developed at Sandia National Laboratory, assembled in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* [57].

The processes whose constituent tasks have direct influence on operation of the ship may be classified as front-line work processes, while those whose impact is felt indirectly may be classified as supporting work processes [15]. The key processes, both front-line and supporting work processes, involved in the operation are normally identified by reviewing documents and industry reports, as well as conducting interviews. For each process analyzed, the goal is to determine in which way the accumulation of failures may lead to unsafe conditions.

5.2.1 Task Analyses

A task analysis is an analytic process which involves determining in detail the performance required of individuals and equipment within a system, as well as effects due to unexpected events. A task analysis consists of the following steps [3]:

1. Evaluate performance required in carrying out tasks
2. Evaluate capabilities of personnel performing tasks
3. Determine possible deviations from anticipated tasks
4. Determine possible recovery actions

The task analysis focuses on tasks that are involved in the relevant processes and the personnel involved in each of the tasks. It includes actions involved in each task and their failure modes, as well as the defenses or barriers involved in each task and their failure modes. The defenses or barriers are components built into the system to capture potential unsafe acts. A typical task involves two sequential steps; the actions taken to achieve specific goals and the defenses or barriers to capture errors made during the action step [15].

Normally, the product of the task analyses is flow diagrams, cross-reference tables, and design/implementation checklists. The flow diagram identifies the tasks and their sequential relationships, the cross-reference table specifies the actions, defenses, divisions, and personnel involved in each task, while the checklist is a series of questions aimed at comparing design and implementation of tasks in a given work process. The event trees may be graphic representations of task analyses; the decision processes are modeled as binary events which result in either success or failure [57]. By decomposing the tasks, the PSFs influencing the performance of tasks can be identified. In assigning the error probabilities to the branches of the event tree, the data-tables developed at Sandia National Laboratory may be used as the data source for estimating individual error probabilities [57]. The results of the event trees are then incorporated into the system fault tree.

5.3 Incorporating Organizational Influences Into PRA

Current PRA models do not explicitly model management and organizational dependencies of human errors and system failures. In order to assess the impact of organizational factors on tanker operations, it is necessary to develop models which allow for quantification and incorporation of this impact into PRA. This gives rise to problems due to the informal aspects of the organization which is often superimposed upon the formal organization. That is, in their daily routine individuals within the organization often depart from formally set standards [15]. In order to evaluate an organization, a number of tasks must be performed, some of which are the following:

1. Determine how the organization functions
2. Determine how well the organization functions with respect to best and worst industry practices
3. Evaluate the safety and environmental implications
4. Develop recommendations with respect to how the organization may be improved

The organizational structure of a company involved in tanker operations may be divided into the functional areas illustrated in Figure 5-1. The primary coordinating mechanism of the functional organizational areas is the standardization of tasks and types of work.

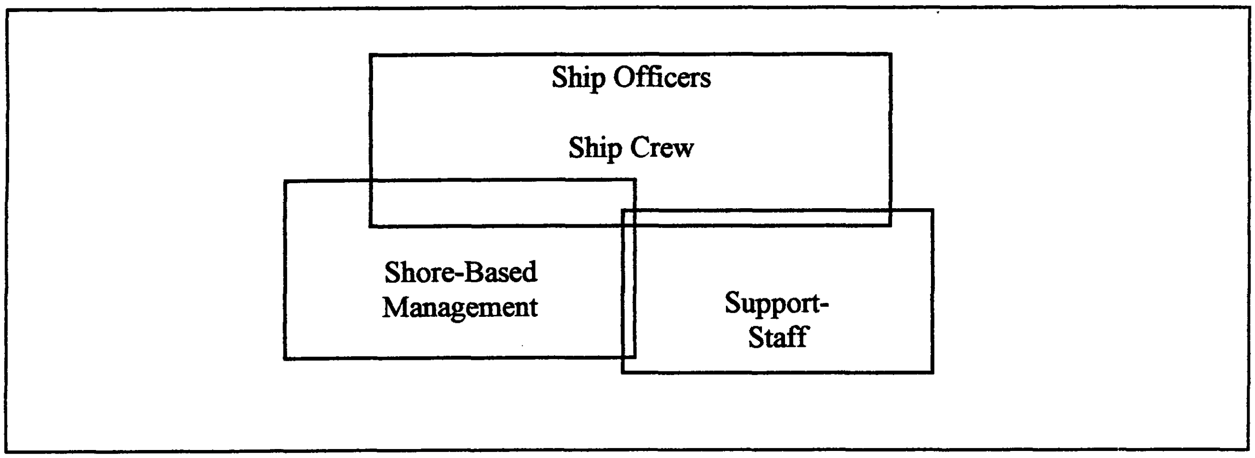

Figure 5-1: Functional Areas of a Company Involved in Tanker Operations

Studies of major accidents from a variety of industries indicate that accidents rarely arise only from random technical failures; usually disasters arise from a combination of a variety of human errors influenced by organizational factors. In order to model organizational influences in accident causations, a process involving the following three levels may be utilized [20]:

1. Human errors that lead to accident
2. Major immediate influences or error inducing factors which determine the likelihood of the errors implicated (PSFs)
3. Higher level factors influencing lower level error inducing factors (MOFs)

The quantification of these influences may be achieved through influence diagram quantification methods. Figure 5-2 demonstrates the pattern of the factors influencing human error [20].

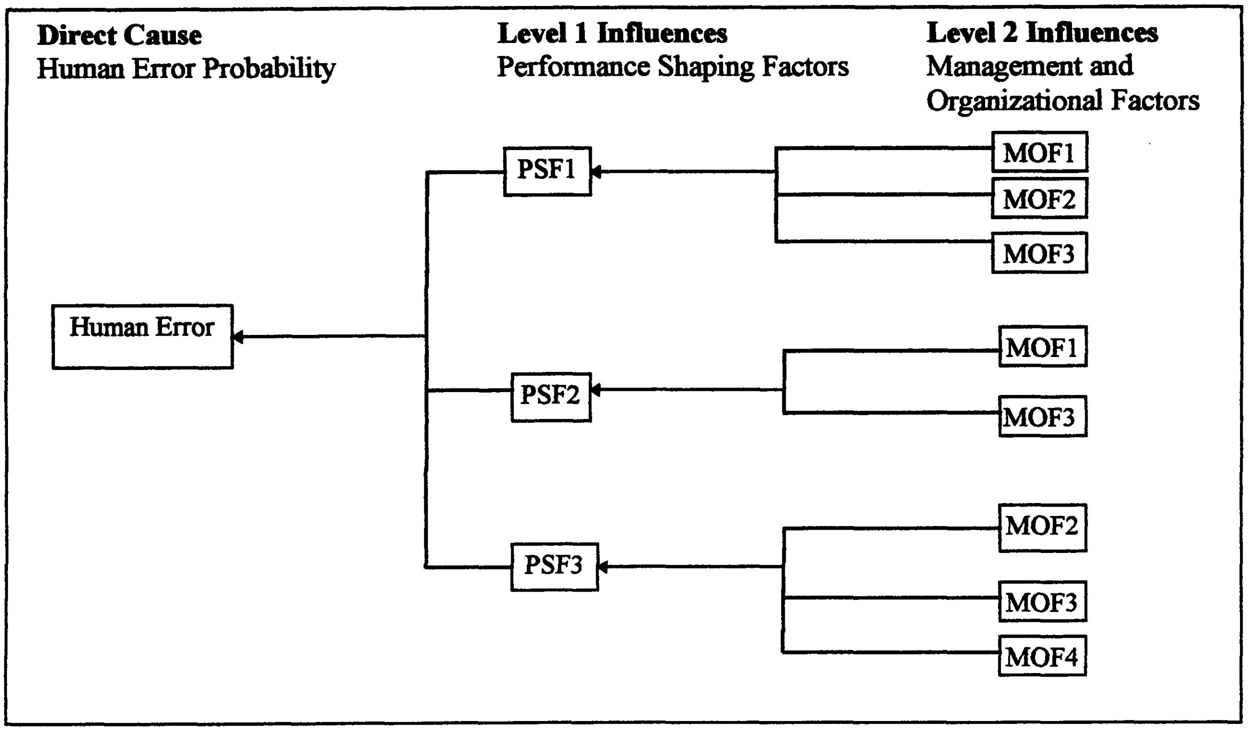

Figure 5-2: Mapping of the Human Error Influences

The first level influences are the factors that represent a direct effect on the likelihood of occurrence of the direct causes. The second level influences are management and organizational influences which determine the likelihood that first level influences will be negative or positive. It is also possible to include levels in between, such as division managers who interpret and implement directives from upper management. The detailed structures of influences should be captured, and this may be accomplished by conducting interviews or acquiring inputs from teams and individuals at all levels of the organization, collecting related documents on work processes of interest, collecting information on operating experience, and investigating accident and near-misses reports [20].

The first level influences should be weighed with respect to the specific human error, while the second level influences should be weighed with respect to the first level influences. The second level influence assessment is applicable across a range of systems, and therefore the assessment may only be performed once for a generic model. The weights may be obtained from experts utilizing pairwise comparison, i.e., assigning relative weights to organizational factors two at a time. The resulting values are not probabilities, but assessments of weights of evidence regarding the variable being assessed. However, the values can be treated as probability values for the purpose of calculations [20].

5.4 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) may be used to obtain the relative influence of the PSFs and MOFs on human error relevant to the grounding scenario. The AHP method, discussed below, has received widespread attention from academics and professional practitioners.

5.4.1 Background

The AHP method, developed by Thomas L. Saaty, is designed to solve complex problems involving multiple criteria [32]. The method is similar to other decision process models, which are utilized for cases in which numerous factors of decisions challenge people's cognitive abilities to evaluate and process information and in which using intuition alone is not satisfactory [21]. AHP is designed as a scaling procedure for measuring priorities in hierarchical structures, involving pairwise comparison of attributes in terms of relative importance [53]. The process requires the decision maker to provide judgments about preference and relative importance regarding alternatives, and the resulting product is a prioritized ranking indicating the overall preference for the various alternatives [32].

5.4.2 Description

The AHP method reflects human beings' inclination to organize complex structures in hierarchies and their tendency towards relative judgments [53]. A hierarchy is a linear structure used in decision theory to represent the simplest type of dependence of one component/level of the system on another in a sequential manner [50]. Outer dependence is the dependence on an attribute possessed by many or all of the components, while an inner dependence is the dependence of one component on another component [50]. The relative importance of the components in the hierarchy are ranked with respect to the component above. The comparisons of two components at the time are fundamental to the AHP method; it utilizes pairwise comparison in order to establish priority measures. AHP employs a scale with values from 1 to 9 to rank the relative importance of two components. This nine unit scale, which was arrived at empirically by Saaty and is consistent with Miller's magical number - seven plus two [39], is a reasonable scale for discriminating between preference for two components [32, 53]. The AHP method emphasizes consistency, but it can tolerate certain levels of inconsistency. However, if inconsistency is very high, the decision should be re-examined or rejected as unreliable [51]. The weights of the components are determined by normalizing the eigenvector associated with the maximum eigenvalue of the ratio matrix resulting from the comparisons [53]. Generally, if the derived weights for components 1 and 2 are w_1 and w_2, respectively, the relative degree of preference or importance of component 1 to component 2 is w_1/w_2 [6a].

5.4.3 Criticism

Critics of AHP claim that the method is flawed as a procedure for ranking alternatives because the rankings produced are arbitrary. That is, it is claimed that the process, which is based on the assumption that the hierarchy compositions produce rankings based on consistent response, does not result in rankings consistent with preference [19]. In addition, opponents of AHP contend that rank reversals and distortions, due to addition or deletion of a component, demonstrate a fundamental flaw. Proponents of AHP argue that the rank reversals and distortions are acceptable [52]. Thomas L. Saaty argues that, in contrast to traditional utility theory, rank reversal is not an issue with respect to AHP [51]. Central to the controversy is the utility theory axiom which holds that bringing an additional, irrelevant alternative into a decision should not affect the order of the old alternatives. In the case that the additional alternative changes the order, even though it is irrelevant, there is a paradox because the axiom is contradicted. However, Saaty holds that AHP does not include this axiom, and that irrelevant alternatives are not part of the problem because in pairing the alternatives with existing relevant ones, the additional alternatives are assigned importance, thus contradicting their irrelevance [51].

The primary advantage of AHP is that, with the exception of the eigenvalue calculations, the method is very easy to understand [46]. Easily understood methods are appreciated by decision makers and the people performing comparisons of alternatives. However, one criticism raised is that the method often involves too many pairwise comparisons, and that balancing all the attributes may not always be straightforward [46].

5.4.4 Expert Choice

AHP is widely and conveniently available through the computer interactive tool Expert Choice, which is the leading software implementation of AHP [21]. The software provides easily understandable questionnaires to be used in the pairwise comparisons. Following the recording of the comparisons, Expert Choice determines the relative weights of the components. In addition, the software provides various sensitivity analyses.

5.5 Ranking of Influence Factors

Usually in AHP models, the top level of the hierarchy is a single element or goal from which influence emanates to the next level below. The remaining levels each have several elements to which influence flow from the level above. The influences are determined by the performance of pairwise comparisons on the elements with respect to the element above [50]. However, in the grounding analysis, the flow of influence is from the lower level to the elements above. That is, the lowest level, consisting of the MOFs, influences the level above, consisting of the PSFs, which again influences the top level, consisting of the human error.

With the HEP as the top level of the hierarchy, all the PSFs impacting the specific HEP are identified and ranked according to degree of influence. Similarly, all MOFs impacting each of the specific PSFs are identified and ranked with respect to degree of influence. The rankings are obtained from experts assigning relative importance to the factors two at a time, i.e., pairwise comparison. Once all the factors are ranked and recorded, Expert Choice calculates relative weights for each factor with respect to the given HEP. The weights are normalized, i.e., the weights add up to 1.0.

The factors being weighed should be mutually exclusive, which ensures that weaknesses or strengths of management and the organization will not be disregarded or double-counted. However, this requirement is seldom completely met when evaluating organizational factors [15]. For example, factors related to culture do influence most of the other MOFs. Nevertheless, the AHP method may still be used since, as long as reasonably mutually exclusive factors are used, it will produce meaningful results [15].

The experts performing the pairwise comparisons should be familiar with AHP and Expert Choice, as well as the various aspects of the problem/situation being analyzed. For the grounding analysis, the individuals performing the pairwise comparisons must be familiar with all aspects of vessel operations.

5.6 Summary

In conventional risk assessment, the impacts by management on operations are typically not taken into account. Because of this, risk is nearly always underestimated [62]. An understanding of the risks involved in tanker operations is necessary to achieve a balanced approach to safety and pollution performance. Risk based management and decision processes provide the ability to identify and evaluate uncertainties inherent in complex marine systems, and it may greatly improve general management because all factors in the organization are analyzed and evaluated.

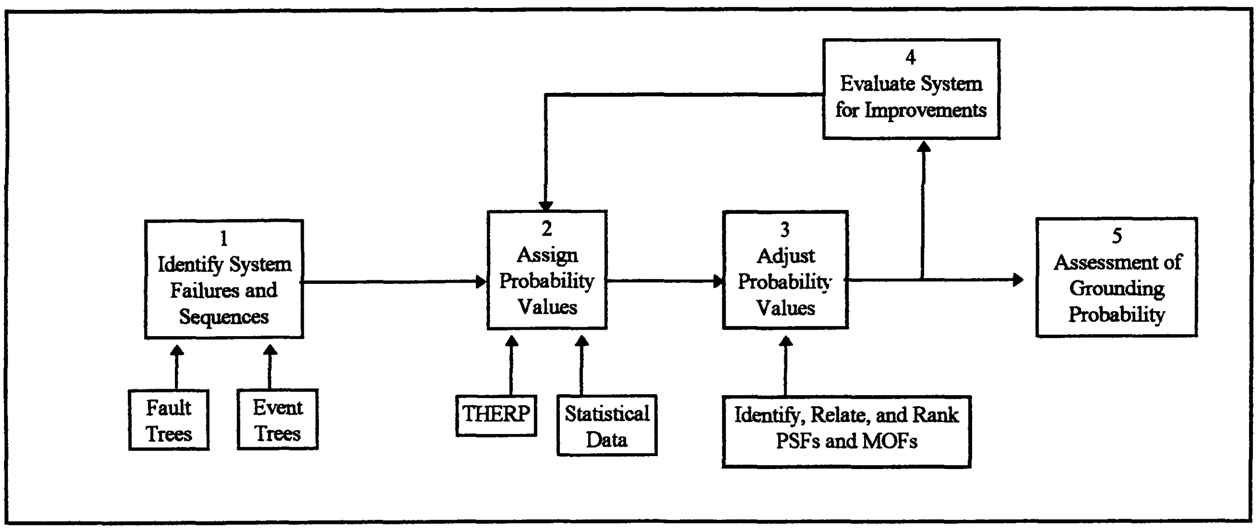

Figure 5-3: Probability Determination Process [3]

A systematic approach to manage risk, involves the process of identifying the tasks involved in the company's operation, identifying the components influencing the processes, and evaluating the risks associated with these. By utilizing this procedure, it is possible to make sound decisions regarding policies, procedures, and possible corrective actions, as well as proposed legislation. Figure 5-3 demonstrates the sequence of steps utilized in order to evaluate the risks and estimate the probability of grounding [3].

6 Grounding Model

In order to carry out a meaningful analysis, a general waterway channel, ship, and typical ship track characteristics are chosen.[2] The channel is chosen to be 200 m wide, have two lanes, and the number of turns required are 10 left turns and 10 right turns. The ship is assumed to maintain a speed of 12 knots, and the average piloting cycle is assumed to be 3 minutes, i.e., the fix rate is 1/3 minutes^{-1}. The track is taken to be along the center of the right hand lane in the two-lane channel. The total transit distance is approximately 116 km, and the total transit time is approximately 5.2 hours. The track is represented by a normal distribution with a mean of -50, and a standard deviation of 25 m. The probability distribution function for the location of the ship relative to the center of the channel is assumed to be a normal distribution around the center of the right hand lane, and is given by:

$$f(z) = \frac{1}{\sqrt{2 \cdot \pi} \cdot \sigma} \cdot e^{\frac{-(z-\mu)^2}{2 \cdot \sigma^2}} \qquad ; z = [-100, 100] \quad \mu = -50 \text{ m} \quad \sigma = 25 \text{ m}$$

Given this distribution, the probability that the ship is outside the channel is 0.023, and the time the ship is outside the channel, given the ship speed of 12 knots, is 7.108 minutes. The described waterway is illustrated in Figure 6-1.

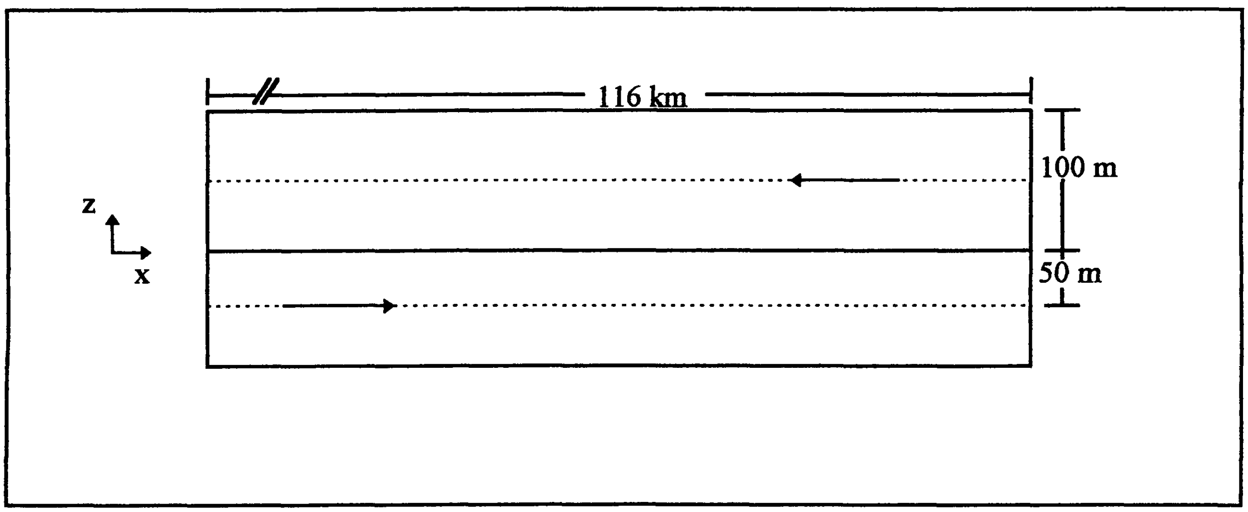

Figure 6-1: General Waterway Channel

By selecting an assumed transiting scenario, the analysis is more easily understood, and it enables the calculation of an estimated probability of grounding. It also enables a sensitivity analysis to be done

[2] The grounding model is based on previous work done by M.D. Amrozowicz and A. Brown [2, 3, 4, 13].

quantitatively for MOFs. The variables related to the scenario may easily be changed to represent an actual scenario to calculate the probability of grounding for a specific waterway.

As discussed in Section 5.1.1, fault trees may be utilized when analyzing potential accident scenarios. The top portion of the fault tree developed for grounding is shown in Figure 6-2. The gate immediately preceding the grounding event in the fault tree has inputs from two types of grounding events; powered grounding and drift grounding.

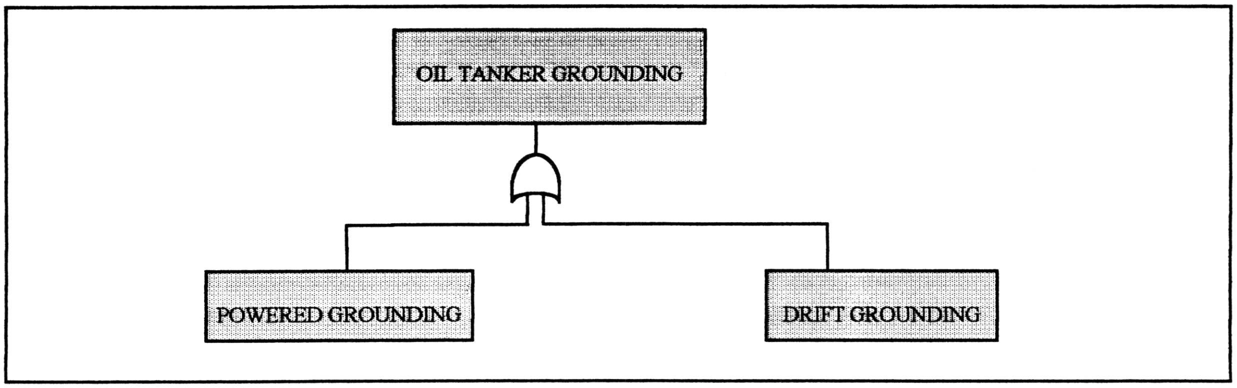

Figure 6-2: Top Portion of Grounding Fault Tree

The Boolean expression for the probability of grounding, resulting from the structure of the fault tree, is as follows:

$$P_{Grounding} = P_{PoweredGrounding} + P_{DriftGrounding}$$

As seen from this expression, tanker groundings result from either powered grounding or drift grounding.[3] Powered grounding and drift grounding, related to the types of failures resulting in grounding, are defined as follows [18]:

- **Powered grounding**
  An event in which grounding occurs because the tanker proceeds down an unsafe track, even though it is able to follow a safe track, due to errors related to planning or piloting failure.
- **Drift grounding**
  An event in which grounding occurs because the tanker is unable to follow a safe track due to mechanical failure, anchor failure, assistance failure, and adverse environmental conditions.

Powered grounding, with the accompanying fault tree, is discussed in Section 6-1, while drift grounding, with its accompanying fault tree, is discussed in Section 6-2. Event trees are utilized to analyze and quantify some portions of the fault trees; the event trees incorporate basic faults identified in the fault trees and enable the calculation of the probability of failure of the different sequenced

[3] In Boolean expressions, "+" is read as OR and "·" is read as AND.

events. In the cases where human error is involved, the probabilities are determined from the data table in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* [57].

6.1 Powered Grounding

The powered grounding portion of the grounding fault tree is shown in Figure 6-3. Due to the importance of the bridge as the controlling station of the tanker, the majority of the contributing events preceding accidents are caused by decisions made and actions taken on the bridge. These decisions and actions are especially of interest when analyzing powered grounding. The fundamental failures involved in a powered grounding are failures in planning and in piloting. The planning failures are represented in Figure 6-3 by the *Planned Track Unsafe*-branch, while the piloting failures are represented by the *Course Deviates from Safe Desired Track*-branch.

6.1.1 Passage Planning

Prior to departure and arrival, the mariner must make sure that the charts reflect the most current and accurate information. This process involves checking various publications and notices to correct and update navigational publications. Therefore, when analyzing the process of passage planning, it must be determined whether or not the published changes affect the safe track. The probability of the published changes affecting the track is conservatively estimated to 0.1. In the case that the published changes affect the safe track, the probability of errors made in planning, as well as the planning information being inaccurate, must be determined.

6.1.1.1 Error Made in Planning

Planning, and especially the passage plan, is essential elements of a successful voyage. The planning process typically consists of the following events:

1. Initiate planning process
2. Check publications for changes
3. Plot changes on charts
4. Determine waypoints
5. Lay down track
6. Checking of plan by mate
7. Verification of plan by captain

In order to carry out the planning satisfactorily, the most current charts and other navigational information must be available as well as updated to reflect the most recently published changes. (Information may also be acquired through different radio broadcast services.) Failure to have accurate and updated charts on board may result in legal implications, especially in the event that an accident does occur. In order to update the navigational charts, the mariner must check all available publications. The process involved in checking the periodicals for relevant changes is assumed analogous to following procedures with no check-off provisions. Following the checking of the periodicals, the changes must be transferred to the charts. The mariner will most likely have developed

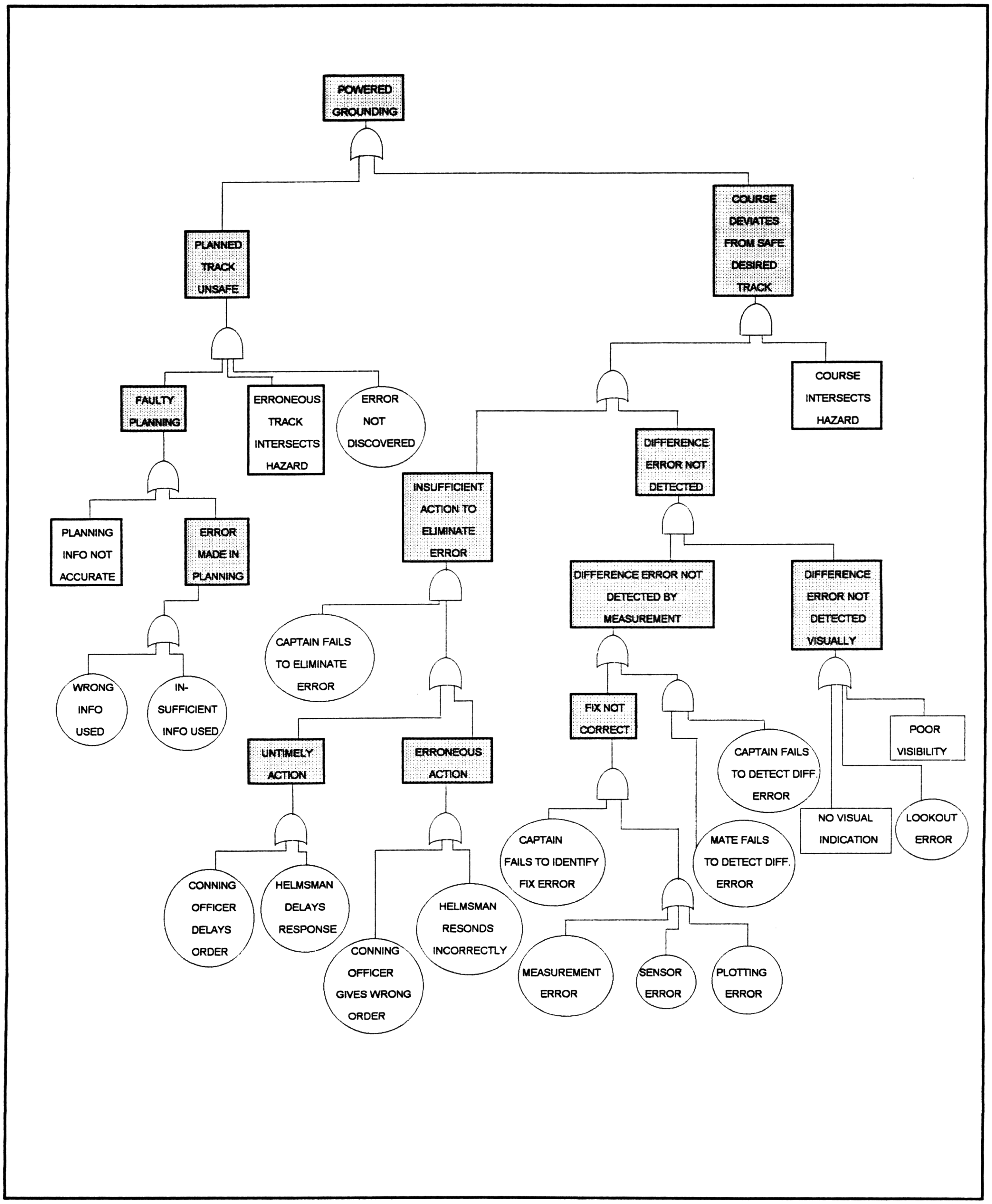

Figure 6-3: Powered Grounding Fault Tree

a list with the appropriate changes, which is similar to a check-list or procedure that a reactor technician may use. Therefore the human error related to correctly entering or plotting the changes in the appropriate charts is assumed to be similar to following procedures with check-off provisions [57].

The task of determining waypoints for the passage involves studying the updated charts to determine the track the vessel should follow in order to get from origin to destination. The task involved in determining waypoints is assumed to be analogous to that of writing a procedural item [57]. The task of laying down the track involves plotting the waypoints and determining the locations of any hazards to navigation. This process requires use of dividers and simple mathematical calculations, which is similar to a nuclear reactor technician's use of a micrometer, i.e., writing a procedural item with simple arithmetic [57].

The first four events are assumed to be independent of each other, because it is unlikely that one event will lead the operator to believe that the preceding event was performed incorrectly. However, the process of laying down the track leads into the verification stage which provides a mechanism of recovery. It is very likely that after the process of plotting the track, the plotter has a general idea of the lay-out of the track, and because of this an error is more easily recognized. This verification process functions as a recovery event, which is assumed to be analogues to the event of checking a chart recorder with limits [57]. Similarly, the approval process requires that the captain verifies the validity of the track. However, this task is assumed analogous to the task of hands-on checking [57].

A summary of the various HEPs related to the passage plan, which are analogous to various HEPs given in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* [57], are listed in Table 6-1.

Table 6-1: HEPs for Passage Planning [57]

Maritime Task	Analogous Nuclear Power Plant Task	HEP	Uncertainty
Check publications for changes	Following procedures with no check-off	0.003	0.0010-0.009
Plot changes	Following procedures with check-off	0.001	0.0003-0.003
Determine waypoints	Writing procedural item	0.003	0.0006-0.015
Lay down track	Writing procedural item with arithmetic	0.010	0.0030-0.030
Recognize faulty track	Check chart recorder with limits	0.002	0.0007-0.006
Captain properly verifies	Hands-on type checking	0.010	0.0020-0.050

In order to quantify the probability that an error is made in the process of planning the track, event trees are used. Figure 6-4 shows the event tree for the process of producing a successful or faulty plan. The probability that the process results in a faulty plan, calculated using the equation derived from the event tree, is:

$$\begin{aligned} P_{ProducingFaultyPlan} &= 1-[P_{PublicationsAffectPlan}\cdot(1-P_{CheckPub})\cdot(1-P_{Plot})\cdot(1-P_{Waypoints})\cdot(1-P_{LayTrack}) \\ &\quad +(1-P_{PublicationsAffectPlan})\cdot(1-P_{Waypoints})\cdot(1-P_{LayTrack})] \\ &= 1.336 \cdot 10^{-2} \end{aligned}$$

After laying down the track, the mate will most likely check over the plan to make sure it is correct, and finally the captain is supposed to verify the track. The probability that errors are made in the planning process is as follows:

$$\begin{aligned} P_{ErrorsMadeInPlanning} &= P_{ProducingFaultyPlan}\cdot P_{RecognizeFaultyTrack}\cdot P_{CaptainVerify} \\ &= 2.673 \cdot 10^{-7} \end{aligned}$$

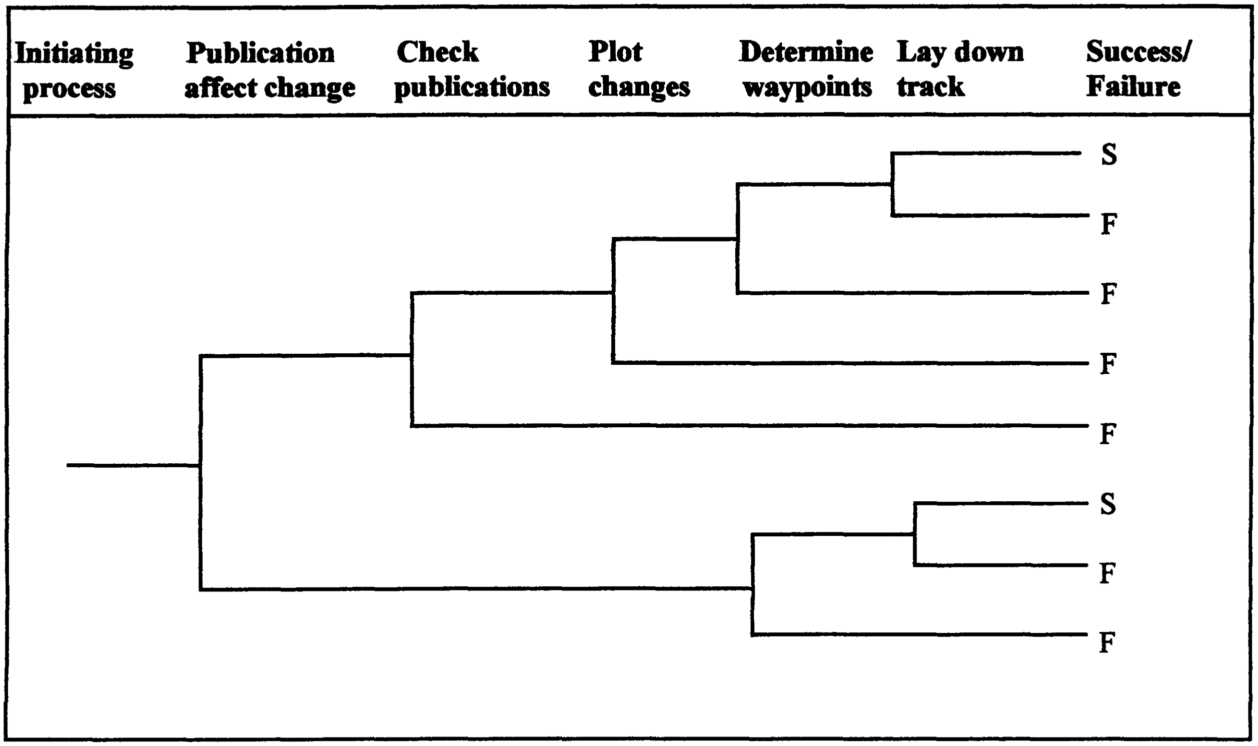

Figure 6-4: Event Tree for Producing Faulty Plan

6.1.1.2 Inaccurate Planning Information

In order to evaluate the probability that the planned track is unsafe, the probability that the information used in planning the track is inaccurate must be determined. Inaccurate navigational information is related to the following concerns:

- Unmarked channel hazards
- Channel not maintained properly
- Inadequate weather information
- Improper navigational aid location

A study analyzing data for four of the busiest ports in the US[4] (San Francisco Entrance, New Orleans, Baton Rouge, and Valdez) found that the total number of tanker accidents caused by incorrect planning information between 1986 and 1990 were 19 [3]. The accident quotient, which is the number of accidents due to faulty navigational information divided by the number of transits, was found to be $4.58 \cdot 10^{-4}$. This value provides an estimate for the probability of inaccurate navigational information causing an accident.

[4] Data obtained from the USCG CASMAIN database and from the Army Corps of Engineers

6.1.1.3 Planned Track Unsafe

The probability that the course involves an unsafe planned track is influenced by both the probability that the incorrect navigational information causes an unsafe plan and the probability of making errors in planning the passage. However, even though there are failures in the process of planning the passage, the result is not necessarily an accident event. In the case that the vessel is transiting in open water, for example, these failures may not lead to an accident. The probability that the erroneous track actually intersects a hazard is assumed to be 0.5. (This probability is already included in the probability of inaccurate information causing an accident.) The probability that the error is not discovered while underway is assumed to be equal to the error involved in hands-on type checking. The probability that the course follows an unsafe planned track is given by:

$$\begin{aligned} P_{PlannedTrackUnsafe} &= (P_{IncorrectInformation} + P_{ErrorMadeInPlanning} \cdot P_{IntersectHazard}) \cdot P_{NotDiscovered} \\ &= 4.581 \cdot 10^{-6} \end{aligned}$$

6.1.2 Piloting

The piloting process is shown by the right portion of Figure 6-3. The sequence of events in a piloting process is as follows [3]:

1. The actual course deviates from the planned track
2. A difference error between the actual course and the planned track is generated
3. A fix is taken and plotted
4. The difference error is detected
5. A correct course change is ordered
6. The helm responds correctly

The piloting error event is influenced by the probability that the course intersects a hazard, and that the difference error is not detected by the crew and the captain or the probability that the action taken once the difference error is detected is not sufficient to prevent an accident.

6.1.2.1 Difference Error Not Detected

The generation of a difference error between the actual course and the planned track is a function of the accuracy and reliability of the radar and the Global Positioning System [3]. The probability of a sensor error has been estimated to $9.5 \cdot 10^{-4}$ [3]. The process of taking a fix involves taking at least two radar ranges in order to estimate the position of the ship at the time the ranges were determined. The navigator must read the ranges off the radar and plot them correctly on the chart. The probability that a measurement error occurs when reading the ranges is analogous to an error when reading a digital display and is equal to 0.001 [57]. When recording the information obtained, some skill is required due to the use of dividers to plot the ranges at the correct scale. The task of plotting the fix is assumed analogous to the task of recording readings and is equal to 0.001 [57]. The probability that the fix is not correct is the sum of the probability of a sensor error, a measurement error, and an error involving in plotting the fix. The probability that the captain will fail to identify a fix measurement error is assumed to be analogous to the task of hands-on checking and is equal to 0.01 [57].

$$\begin{aligned} P_{FixNotCorrect} &= (P_{Sensor} + P_{Measurement} + P_{PlotFix}) \cdot P_{Captain} \\ &= 2.95 \cdot 10^{-5} \end{aligned}$$

The errors involved in the case that the mate fails to detect the plotted difference error is assumed similar to the errors involved in checking a reading with limits and is equal to 0.001 [57]. The probability that the captain fails to detect a bad fix is similar to the that for hands-on checking [57].

$$\begin{aligned} P_{DifferenceErrorNotDetectedByMeasurement} &= (P_{MateFailsToDetect} \cdot P_{CaptainFailsToDetect}) + P_{FixNotCorrect} \\ &= 3.95 \cdot 10^{-5} \end{aligned}$$

The probability that the difference error is not detected visually is the sum of the probability that there are no visual indications that the course deviates from the planned track, which is assumed to be 0.5, the probability of poor visibility, which is assumed to be 0.25, and the probability that the lookout, mate, and captain fail to detect the dangerous situation. The situation in which the lookout fails to detect the hazard or assess the situation correctly is analogous to a check-reading task where the plotted fix is checked to ensure that it is within tolerable limits of the planned track and is equal to 0.001 [57].

$$\begin{aligned} P_{DifferenceErrorNotDetectedVisually} &= P_{Indication} + P_{Visibility} + (P_{Lookout} \cdot P_{Mate} \cdot P_{Captain}) \\ &= 0.750 \end{aligned}$$

Finally, the probability that the difference error is not detected is the product of the probability that the difference error is not detected by measurement and the probability that it is not detected visually:

$$\begin{aligned} P_{DifferenceErrorNotDetected} &= P_{DifferenceErrorNotDetectedByMeasurement} \cdot P_{DifferenceErrorNotDetectedVisually} \\ &= 2.963 \cdot 10^{-5} \end{aligned}$$

6.1.2.2 Insufficient Action to Eliminate Error

The probability of insufficient or incorrect action after the difference error is detected is given by the probability of an untimely or erroneous action and the probability that the captain fails to correct the error. The probability that the captain fails to correct the error is again given by the probability of error related to hands-on checking [57]. The probability of untimely or erroneous action is influenced by both the conning officer and the helmsman. Given that the error in the course is detected, the conning officer determines the correct course change to order. The probability of error in this course change order is assumed to be analogous to nonpassive task errors of commission and is equal to 0.003 [57]. Once the order to change course is given, the helm responds to the order, which involves turning the wheel while watching the rudder angle indicator and the gyro repeater until the ordered course is achieved. The probability of failure in responding to the order is given by the failure to recall two instructions given orally and is equal to 0.003 [57].

$$\begin{aligned} P_{InsufficientAction} &= P_{CaptainFailsToCorrect} \cdot (P_{Order} + P_{Response}) \\ &= 6.0 \cdot 10^{-5} \end{aligned}$$

The HEP values related to piloting, based on the data estimated in the Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications [57], are summarized in Table 6-2.

Table 6-2: HEPs for Piloting Error

Maritime Task	Analogous Nuclear Power Plant Task	HEP	Uncertainty
Read radar ranges	Reading a digital display	0.001	0.0003-0.003
Plot ranges	Record readings	0.001	0.0003-0.003
Detect difference error (mate)	Check reading with limits	0.001	0.0003-0.003
Detect difference error (captain)	Hands-on checking	0.010	0.0020-0.050
Order course change	Nonpassive task error of commission	0.003	0.0010-0.009
Respond to order	Failure to recall two items given orally	0.003	0.0010-0.009

6.1.2.3 Course Deviates from Safe Desired Track

Based on the probabilities of failure related to not detecting the difference error and insufficient action to eliminate the error, the probability of a piloting error is calculated as follows:

$$\begin{aligned} P_{PilotingError} &= P_{DifferenceErrorNotDetected} + P_{InsufficientAction} \\ &= 8.963 \cdot 10^{-5} \end{aligned}$$

With the assumption that a fix is taken every 3 minutes, i.e., an average fix rate of 1/3 minutes^{-1}, the average piloting error rate may be calculated to be:

$$E_{PilotingErrorRate} = 2.988 \cdot 10^{-5} \text{ errors/min}$$

The probability that the course deviates from the direct or straight planned track is calculated assuming a Poisson process for errors related to taking a fix. The probability that the ship is outside the channel, as previously discussed, is 0.023, and the average time the tanker is outside the channel is 7.108 minutes. Failure is defined as at least one piloting error during the time the tanker is outside the lane.

$$\begin{aligned} P_{CourseDeviatesFromPlan\text{-}StraightTrack} &= P_{OutsideChannel} \cdot P_{ErrorWhenOutsideChannel} \\ &= P_{OutsideChannel} \cdot (1 - e^{-EPilotingErrorRate \cdot T(OutOfChannel)}) \\ &= 4.884 \cdot 10^{-6} \end{aligned}$$

In the case that a fix error occurs, the time until the tanker is outside the channel may be calculated for the assumed scenario. In the case that no fix is taken in a left turn, the distance to the point where the tanker exits the channel may be approximated by 1/4 of the total channel width. Dividing this distance by the vessel speed, the resulting time until the tanker exits the channel in a left turn is 8.089 seconds. In the case that no fix is taken in a right turn, the distance to the point where the tanker will exit the channel may be approximated by 3/4 of the total channel width. Dividing this distance by the speed of the tanker, the resulting time until the tanker exits the channel in a right turn is 24.267 seconds. The probabilities that no fixes are taken before the tanker is outside the channel during a left and a right turn, assuming Poisson processes for fixes, are as follows:

$$P_{NoFix\text{-}LeftTurn} = e^{-\lambda_{AverageFixRate} \cdot T(UntilOutsideChannel\text{-}LeftTurn)}$$
$$= 0.956$$

$$P_{NoFix\text{-}RightTurn} = e^{-\lambda_{AverageFixRate} \cdot T(UntilOutsideChannel\text{-}RightTurn)}$$
$$= 0.874$$

The probability that the course deviates in a turn from the planned safe track, assuming that the probability of failing to turn is similar to that of following procedures with check off and the probability of the captain failing to detect the failure is similar to that involved in hands-on checking, is calculated below. Failure is in this case defined as taking no fix before exiting the channel on a turn.

$$P_{CourseDeviatesFromPlan\text{-}Turn} = 1 - [1 - P_{FailToTurn} \cdot P_{CaptainFailsToDetectFailure} \cdot P_{Nofix\text{-}LeftTurn}]^{NumberOfLeftTurns}$$
$$\cdot [1 - P_{FailToTurn} \cdot P_{CaptainFailsToDetectFailure} \cdot P_{Nofix\text{-}RightTurn}]^{NumberOfRightTurns}$$
$$= 1.830 \cdot 10^{-4}$$

The probability that the course deviates from the desired safe track, and that the actual course is unsafe, is calculated as follows:

$$P_{CourseDeviatesFromSafeDesiredTrack} = (P_{CourseDeviatesFromPlan\text{-}StraightTrack} + P_{CourseDeviatesFromPlan\text{-}Turn}) \cdot P_{IntersectsHazard}$$
$$= 9.394 \cdot 10^{-5}$$

6.2 Drift Grounding

Drift grounding, as previously defined, is an event in which the tanker is unable to follow the planned, safe track. In order for drift grounding to occur, all of the following types of failures and conditions must occur:

- Unsafe winds/currents
- Assistance failure
- Anchor failure
- Loss of steerage way

These failure conditions are illustrated in the drift grounding portion of the grounding fault tree, shown in Figure 6-5.

6.2.1 Adverse Environmental Conditions

The term unsafe winds/currents means that the prevailing winds and currents lead the tanker towards a grounding hazard. In order to assess the wind and current impact, an analysis of the prevailing winds and currents must be carried out for the area of concern. For this analysis, with the assumed grounding scenario, the probability that wind/currents cause the tanker to intersect a hazard is assumed to be 0.25.

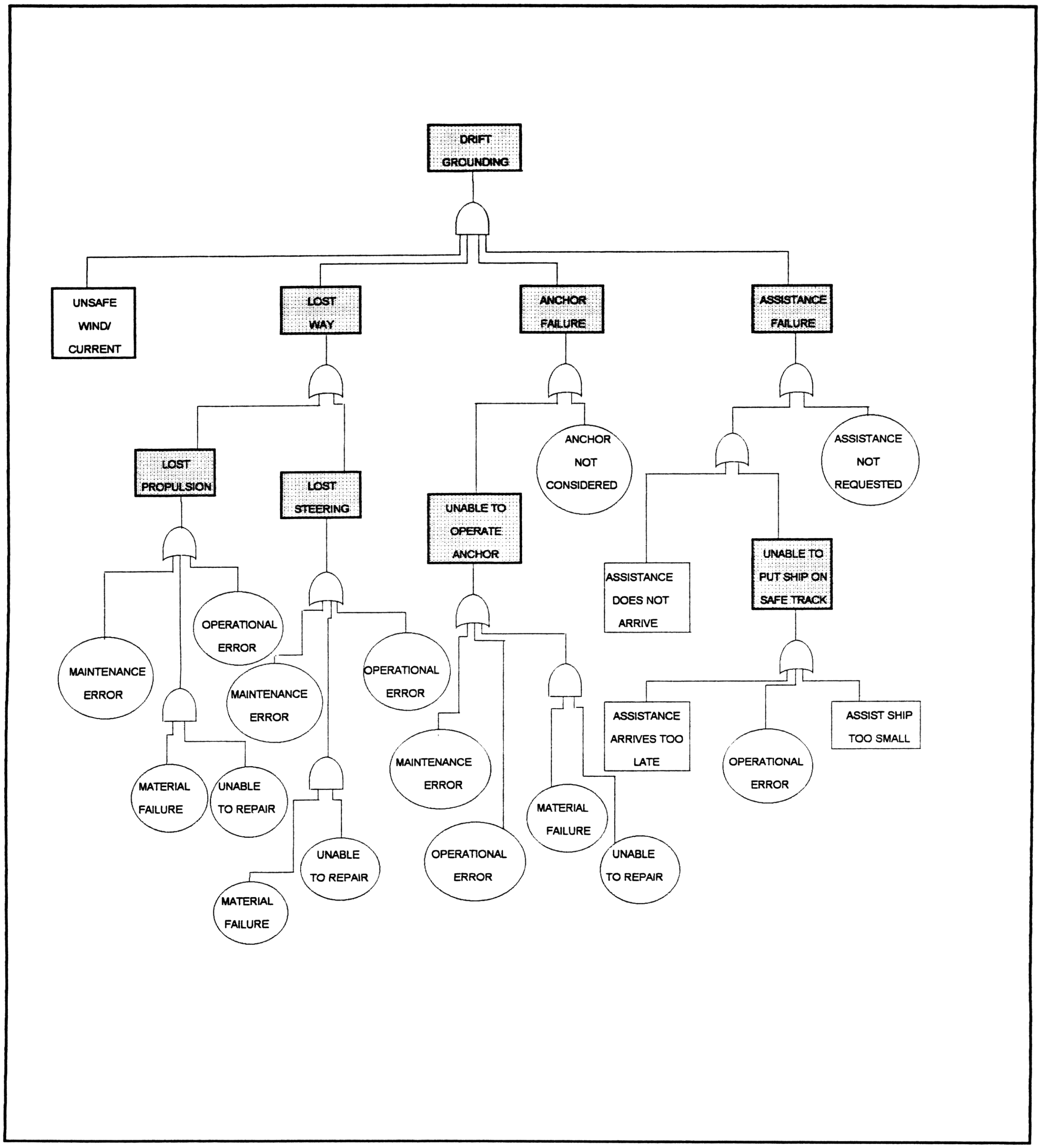

Figure 6-5: Drift Grounding Fault Tree

6.2.2 Loss of Way

Loss of steerage way is divided into two categories; loss of propulsion and loss of steering. Figure 6-6 shows the number of lost way incidents, based on a search of the USCG CASMAIN database, per year from 1981 through 1991 [3].

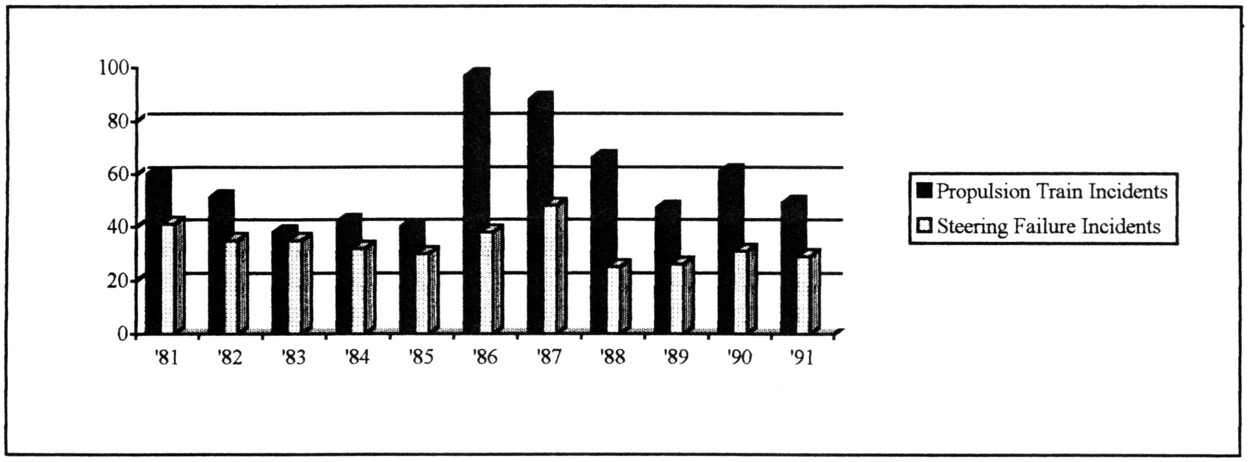

Figure 6-6: Loss of Way Incidents [3]

A study, previously discussed in Section 6.1.1.2, analyzing four of the busiest ports in the US (San Francisco Entrance, New Orleans, Baton Rouge, and Valdez) from 1981 through 1991, found that the total number of tanker transits was 32,666, while the number of propulsion failures was 36 and the number of steering failures was 14 [3]. The accident quotient was determined for propulsion failures to be $1.10 \cdot 10^{-3}$ and for steering failures to be $4.29 \cdot 10^{-4}$. The failure rates are dependent on transit lengths, and therefore the accident quotients must be divided by the total number of transit miles, estimated to be 340 miles for the four ports combined. The accident quotient for lost way, including both propulsion failure and steering failure and assuming independence and rare event approximation, is therefore calculated to be 4.5×10^{-6} per mile.

The probability of a loss of way accident is dependent on time. With a total transit time of the assumed grounding scenario, calculated by dividing the total transit length by the ship speed, of 5.214 hours, the probability of loss of way is:

$$
\begin{aligned}
P_{LostWay} &= 1 - e^{-TotalTransitTime \cdot \lambda Drift} \\
&= 1 - e^{-TotalTransitTime \cdot AccidentQuotient \cdot VesselSpeed} \\
&= 3.240 \cdot 10^{-4}
\end{aligned}
$$

6.2.3 Anchor Failure

Anchor failure is a result of mechanical failure associated with the anchor due to either maintenance or operational error, administrative control, and/or unfavorable environmental constraints. Unfortunately, as the size of many of the tankers operating has increased, the proportionate size of the anchors has decreased. In order for the anchor to function properly, the vessel must have very little momentum, i.e., less than 1 knot [18]. In the case that momentum is large, the anchoring system is likely to be destroyed.

The successful deployment of the anchor is dependent on such factors as the type of anchor and chain, the length of the anchor chain, sea depth, type of sea bottom, winds and currents, and the competence of the crew [18]. However, in many cases, the main problem is that the deployment of the anchor is not considered. A situation in which the decision has to be made regarding dropping the anchor or not, may be characterized as extremely stressful. The captain realizes that if the anchor is dropped, valuable transit time will be lost. However, in some case the consequences of not dropping the anchor greatly exceeds those associated with lost transit time. Considering the extremely high stress level, the situation is assumed analogous to that of a diagnosis after an abnormal event in a nuclear power plant. The *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, estimates the HEP associated with this situation to be 0.25, with an uncertainty range of 0.05-1.00 [57]. It is assumed that this error probability is much larger than the probability for being unable to operate the anchor.

6.2.4 Assistance Failure

Tankers escorted by dedicated tugs have a great advantage in that it permits rapid response to a steering or propulsion casualty. Currently, very few dedicated tugs exist worldwide, and therefore for this analysis, the tanker is assumed to be unescorted. Most areas rely on tugs of opportunity to provide assistance, and the sequence of events in this case, for a tanker requiring assistance, is as follows:

1. Request assistance
2. Assistance arrives
3. Assistance ship ties up
4. Tanker is placed on safe track

The event tree for the basic sequence of events involved in a situation in which a tanker needs assistance is shown in Figure 6-7.

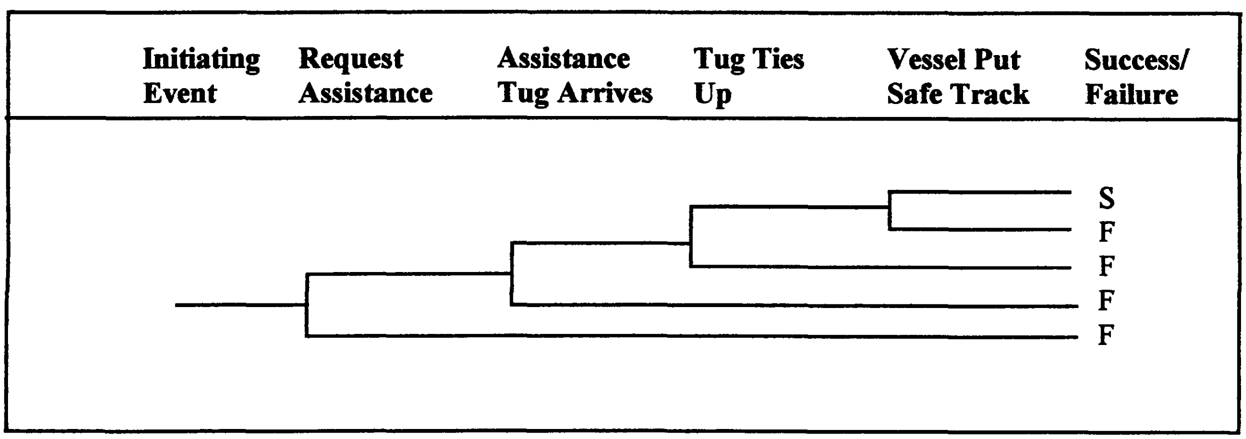

Figure 6-7: Event Tree for Assistance Failure

The largest contribution to an assistance failure is typically the failure to request assistance in time. In some cases, captains will take calculated risks by delaying the request for assistance in hope of remedying the situation without help. The main concern of many captains is that they will receive a "bad mark" if they request assistance before it is absolutely necessary. Similarly to the situation in which dropping the anchor is considered, the stress level is extremely high once the bridge crew recognizes the need for assistance. Therefore, the situation is assumed similar to the situation of diagnosis after an abnormal event. As discussed, in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* this probability of error is estimated to be 0.25, with an uncertainty range of 0.05-1.00 [57]. There is currently little information enabling the calculation of the probability of the rescue tug arriving and tying up correctly, and therefore the probability of an assistance failure is conservatively specified as 0.25. It is also assumed that the failure of requesting assistance dominates the assistance failure error.

6.3 Summary of Grounding Probabilities

The equation for calculating the total probability of grounding, as previously defined, is the sum of the probabilities of powered grounding and drift grounding.

$$P_{Grounding} = P_{PoweredGrounding} + P_{DriftGrounding}$$
$$= 1.0358 \cdot 10^{-4}$$

where $P_{PoweredGrounding} = P_{PlannedTrackUnsafe} + P_{CourseDeviatesFromSafeDesiredTrack}$

$$= 9.852 \cdot 10^{-5}$$

$$P_{DriftGrounding} = P_{AdverseEnvironmentalConditions} \cdot P_{LostWay} \cdot P_{AnchorFailure} \cdot P_{AssistanceFailure}$$
$$= 5.063 \cdot 10^{-6}$$

That is, the probability of grounding is the sum of powered grounding and drift grounding, with powered grounding consisting of the sum of the probability that the planned track is unsafe and the probability that the course deviates from the safe desired track, and the probability of drift grounding consisting of the product of the probability that the tanker intersects a hazard due to unsafe winds/currents, the probability of lost way, the probability of an anchor failure, and the probability of an assistance failure. The resulting probability of grounding is dominated by the powered grounding contribution, while the probability of powered grounding is dominated by the piloting contribution. (More detailed calculations are located in Appendix III.)

7 Modeling Human Error in Tanker Grounding

In order to determine the effect management and the organization have on human performance, PSFs are identified and ranked with respect to the HEPs relevant to the grounding analysis, and MOFs are identified and ranked with respect to the identified PSFs. By utilizing the AHP method, the MOFs of greatest importance to grounding are distinguished from those that are of less importance.

As described in Section 5.2, the PSFs are level 1 influence factors, while the MOFs are level 2 influence factors, i.e., the PSFs function as intermediate variables between the MOFs and the HEPs. The PSFs are factors which directly affect the ability of personnel to carry out tasks, while the MOFs are factors which indirectly influence human performance in that they determine the likelihood of the first level influences being positive or negative. The organizational factors also directly influence the probability of equipment failure; however, this is outside the scope of this analysis.

7.1 Performance Shaping Factors

In order to evaluate the ability of humans to perform specific tasks, the various PSFs must be identified and analyzed. By determining the PSFs, it is possible to identify means for improving performance. The PSFs determine whether individual performance is highly reliable, highly unreliable, or in between the two extremes. As previously discussed, the PSFs may be divided into two classes; internal and external. Internal PSFs are characteristics of or factors within the individual. External PSFs are factors outside the individual, i.e., factors defining the physical, social, and professional work situation. The external PSFs fall into three categories; situation characteristics, task and equipment characteristics, and instructions [57].

7.1.1 Descriptions of PSFs

A large number of PSFs have been identified and defined; however in order to simplify the grounding analysis, only the most important PSFs are chosen for the pairwise comparison. (Additional PSFs, of less importance to the grounding analysis, are listed in Appendix IV.) The following sections define important PSFs that shape the performance of the individual mariner.

Inattention

Inattention involves the lack of full vigilance, or loss of attention, regarding the responsibilities or tasks assigned. This is related to situations that result in a crew member being distracted from the primary or necessary responsibility by others [31, 44]. It is also related to the condition in which the individual is preoccupied with unrelated thoughts. Therefore, inattention is both a factor in high stress situations, as well as in low stress situations. A typical result of inattention is the failure to monitor displays [44].

Lack of Motivation

Lack of motivation refers to the lack of desire to perform required duties well [31]. In the case that an individual is unhappy with his/her situation or a task that needs to be performed, the individual is very likely to be less than highly motivated. In this way, lack of motivation refers to an individual's negative attitude towards the company, other crew members, and operations.

Poor Physical Condition

In order to perform satisfactorily, the personnel must be in decent physical condition. Poor physical condition refers to such factors as fatigue, poor physical fitness, physical problems, and the overall well-being of the personnel. Fatigue is the reduction in physical, mental, or emotional capabilities as a result of physical, mental, or emotional exertion [31]. It results in drowsiness and loss of vigilance, and it may impair nearly all physical and mental abilities such as strength, speed, reaction time, coordination, decision making, and balance. Poor fitness refers to inadequate strength, endurance, precision, or ability to move with sufficient agility (in order to climb ladders, and inspect hatches and hulls). The long periods of continuous work onboard the ship requires a certain physical stamina and endurance, and an additional problem is that medical attention is not immediately available in this environment [44]. The term physical problems is mostly related to visual problems, which refers to the reduced visual acuity due to physical disability related to eye-sight. This term includes total or partial blindness, not wearing prescribed glasses or contacts, or inability to adequately adapt to darkness or distinguish between colors [31, 44]. The overall well-being of the personnel is greatly related to the above mentioned variables. For instance, fatigue and poor fitness may result from the movement restrictions imposed by the ship, which is a situation specific to the marine environment.

Poor Performance Ability

As will be discussed later, the greater the level of skill an individual possesses, the better performance may be expected in situations with high-levels of stress. Poor performance ability includes the level of training, experience, and the aptitude of the personnel. Inadequate training refers to the level of education, instruction, and practice an individual has received. It includes all training prior to the current job, as well as all training received by the company [31, 44, 57]. Lack of experience refers to unsatisfactorily amount of time spent onboard the specific ship as well as on other ships [31, 44, 57]. Aptitude depends on the personnel's technical knowledge of ship operations and knowledge required for specific tasks. This includes the personnel's general understanding and knowledge, including phenomena and events that bear on safety [15]. The term involves knowledge regarding navigation, general seamanship, propulsion systems, cargo handling, communications, weather, etc. [31].

Inadequate Knowledge of Procedures, Standards, and Regulations

Inadequate knowledge of procedures concerns the lack of knowledge of shipboard and company policies regarding ship operations. The procedures include emergency procedures, maintenance procedures, administrative procedures, and safety system procedures [31]. Inadequate knowledge of regulations and standards relates to the lack of knowledge of company standards, national and international regulations, other port states maritime regulations, local jurisdiction regulations, shipboard regulations, cautionary notices, chart notions, or labeling [31].

Conflicting Motives Regarding Performance

Conflicting motives regarding performance expectations refers to inadequate knowledge with respect to priorities and company goals regarding safety of performance, quality of performance, schedules, profitability, etc. This PSF is especially a factor in situations where the crew must determine a course of action in which none of the alternatives are very tempting. For example, when developing the passage plan, two alternatives might be to decide on a route that is fast but less safe, or a route that will take a little longer to complete, but is much safer. In this case, the decision maker is left with the choice between choosing the least time-consuming route which will save the company money, unless an accident occurs, or choose the safer route which will be more expensive. In the case that the decision maker is uncertain regarding the course of action to take, his/her performance will be less than optimal. Conflicting motives may in some instances result in high levels of calculated risk, which is the knowing acceptance of risk to meet personal and corporate priorities [44].

Poor Architectural Features

The architectural features of the ship may greatly influence the performance of the crew, and specifically the bridge crew. Poor architectural features relate to the poor human factors engineering design of a ship, its subsystems, its environmental controls, and human-machine interfaces [31]. Onboard a ship, poor instrumentation and overall design of the control station, or bridge, are current problems [44]. The design of the bridge, such as the location of vital navigational equipment and the size of the bridge affect the bridge crew. These factors have a great impact on safety because people tend to avoid unnecessary effort and therefore attempt to read the displays from a distance. This situation may be improved if the work space is designed around the radar displays. Additional problems involve cluttered passageway and stairway design; hazardous decks and work surfaces; inadequate restraints, guards, or hand-holds; poor workstation orientation in regard to ship dynamics; poor hull seakeeping characteristics; controls which allow accidental actuation; and poor layout, sizing, and coloring of controls and displays [57]. In addition, there is the problem of feedback delay, specifically related to the marine environment, due to the slow response by large vessels[3].

Lack of Perception or Inadequate Situational Awareness

Lack of perception involves the situation in which an individual does not properly realize the existence of a problem or situation, as well as misdiagnoses the problem or situation once it has been perceived. Examples of this include misreading dials, mishearing commands, misunderstanding garbled radio messages, etc. [31, 57]. Inadequate situational awareness relates to the lack of knowledge regarding the current status of the ship, its subsystems, or its environment. This involves an incorrect understanding of the current situation which result in a faulty hypothesis regarding future situations, or a situation based upon incorrect beliefs leading to compounded errors. Examples of inadequate situational awareness include lack of knowledge of location, heading, speed, or status of ongoing maintenance [31].

Lack of Communication/Inadequate Exchange of Information

Lack of communication refers to the failure to communicate, or exchange information, regarding problems and tasks aboard ship and ashore. This PSF includes communication between bridge officers, between deck and engine room, with pilots, and with the home office [31]. The communication term also concerns mistakes in the act of giving commands, which includes the absence of proper commands, commands given at an inappropriate time or out of sequence with others, incorrect commands, or conflicting commands [31]. In addition, the term includes inadequate language skills, which involve the lack of primary language abilities necessary to communicate and perform required duties. It includes the ability to speak, read, as well as comprehend the information being communicated [31].

Unawareness of Responsibilities

Unawareness of responsibilities refers to inadequate knowledge of the specific task required, or confusion in lines of authority and responsibility. Examples of this include lack of understanding of responsibilities with respect to operations, commands, communications, safety, maintenance, and emergency situations [31]. This PSFs is especially critical in emergency situations, in which rapid response is required. However, it is also of importance in routine operations as misunderstandings with respect to responsibilities may actually cause emergency situations.

Hazardous Natural Environment

Specific to the marine environment is motion sickness in open waters. In restricted waters, the channel width, traffic density, and availability of navigational aids are major factors that may create stress. In the restricted maneuvering channels, many auditory and visual signals compete for attention, which may result in the failure of ignoring some signals. The suddenness involved in having to adjust from the open ocean scenario to the situation in restricted waterways is also a factor specific to the marine environment. The hazardous natural environment PSF refers to the situation in which the natural environment causes tasks to become more difficult than usual. Additional examples of such situations include storms, shallow water, rocks, submerged wrecks, etc. [31].

7.2 Management and Organizational Factors

MOFs are factors that either directly or indirectly influence PSFs. The organizational structure and culture affect the PSFs, and in this manner affect human performance indirectly. For instance, lines of authority and communication, pressures to reduce cost and maintain schedule, administrative control, rewards, and recognition all influence the way in which the mariners act.

The safety culture inherent in an organization influences all the MOFs and it is therefore removed from the grounding analysis. Safety culture relates to the situation in which the characteristics of the work environment, such as the norms, rules, and common understandings that influence personnel's perception of the company, do not satisfactorily place importance on safety [15]. All the human errors are functions of this factor, and with further research it may be possible to quantitatively relate the safety culture to all the HEPs, with the other MOFs as well as the PSFs as intermediate variables.

7.2.1 Description of MOFs

Similar to the methodology for the PSFs, in order to simplify the analysis, only the most important MOFs are chosen for the pairwise comparison. (Additional MOFs are defined in Appendix IV.) The following sections describe important MOFs that shape the PSFs, and in that way indirectly shape the performance of the individual mariner.

Workload

Workload refers to such factors as the number of work hours, breaks, and the overall amount of work that is to be done when the personnel is on duty, as well as the level of manning on the tanker. The workload is closely related to physical or mental capability of the crew member, which may be a result of all mental and physical tasks the person must perform within a prescribed time. The scheduling of watchstanding coupled with maintenance and repair activities especially affect the individual crew member. Any interference with a person's normal sleeping hours, which results in fatigue and difficulties in sleeping, which again results in fewer hours of sleep. Studies have shown that the effect of the standard three-watch rotation (4 hours watch, 8 hours off) is a disruption of the crew members' circadian rhythms [3]. This disruption of the physiological circadian (approximately 24 hour) rhythm caused by having to be awake and working at unusual hours and sleep during daytime leads to sleep deprivation, which result in degraded performance [57]. Manning is related to the failure to ensure that all required tasks aboard the ship can be performed by adequate personnel of proper skill level, ability, experience, and certification [31].

Formalization

Formalization concerns the existence of well-identified rules, procedures, and standardized methods for routine activities, as well as unusual occurrences. This includes step-by-step written procedures and check-lists. Inadequate formalization concerns procedures that are difficult to read, locate, inconvenient to use, conflicting, inaccurate, inadequate, outdated, or do not provide sufficient detail [15, 57]. Regarding the availability and quality of procedures, the shipboard environment typically suffers from lack of procedures rather than lack of adequate procedures [3].

Coordination of Work

Coordination of work is related to planning, division, integration, and implementation of work related activities among individuals or groups of individuals [15]. The term includes coordination between bridge officers, between the deck and engine room, with pilots, and with the home office. Roles and responsibilities should be clearly defined in order to avoid confusion, and similarly, practices regarding personnel and department work activities should be specified [15]. Coordination of work also includes task design, which refers to designing tasks that match the ability of the people performing the tasks. The task requirements must be specified in a way that are not unreasonable, inefficient, impossible, excessive, or impractical. In addition, tasks should not require extreme levels of complexity, information load, interpretation, or repetitiveness [57]. Examples of inferior requirements include excessive watch duration or frequency, requiring a single person to simultaneously monitor displays spatially separated, or requiring exposure to hazards without proper training, experience, or protective gear [31]. The extent to which decision making and authority are localized to one area or among certain groups of individuals influences the success of the coordination. In emergency situations, for example, extensive centralization may result in time delays because personnel are unable to make quick decisions [15]. In addition, the coordination of work MOF involves problem identification, which concerns the amount of encouragement of personnel by the organization to draw upon knowledge, experience, and current information to identify problems and solutions [15].

Organizational Culture

Organizational culture refers to the personnel's shared perception of the organization. The organizational culture includes traditions, values, customs, practices, goals, and socialization processes that endure over time. The organizational culture distinguishes an organization from others, i.e., it is the "personality" of the organization [15]. It relates to whether personnel take personal responsibility for their actions and the consequences of these actions, as well as the degree of commitment or pride in the organization [15]. The term also refers to the level of understanding, acceptance, or agreement by the personnel regarding the purpose and relevance of company goals [15].

Benefits

Benefits include the level of pay or salary the different personnel receive, as well as other benefits such as insurance and retirement programs, and the overall distribution of the company's financial resources. This term includes actual distribution as well as individual perception of this distribution [15, 57]. In the case that there are large differences in pay among the crew, the crew members receiving the lowest salary or benefits may develop unfavorable feelings towards the higher paid crew members, which results in tensions among the crew. Fair and well-defined policies with respect to salary and benefits are likely to reduce the negative effects of this factor.

Physical Resources

In order to operate the tanker safely and efficiently, the crew must have adequate equipment and resources. Physical resources refers to the management of resources which ensure that people have the tools, equipment, supplies, and facilities to perform the required tasks. This MOF includes the absence, shortage, inappropriateness, and storage of resources, as well as the difficulty in obtaining the resources [31].

Quality of Life

Quality of life refers to the standard of living and the overall happiness of the personnel. It includes the quality and cleanliness of the living quarters and the overall environment, as well as the quality and variation of food and entertainment. It includes inadequate lighting, heating, cooling, or ventilation systems, and the degree of general cleanliness [31]. In addition, excessive noise and vibration, which leads to irritation and fatigue, influences human performance greatly. Cleanliness, which is a psychological factor, affects how the personnel perceive the organization. In the case that the work environment is dirty, it signals that the management is indifferent to work performance [57].

Performance Evaluation

Performance evaluation concerns the degree to which personnel are provided with fair assessments of their work-related behavior [15]. In the case that fair assessments are provided, the personnel will most likely strive to perform well and become more involved in the operation. If no assessment is provided, the personnel may perform at less than optimum levels, because of the perception that their performance will not be noticed or is unimportant. In the case that the assessment provided is unfair, the various individuals will likely struggle for a certain time in order to receive the proper feedback; however, in the absence of this, the individual may eventually give up and rather perform at a substandard level.

Company Programs

Company programs refers to varying programs related to the overall well-being of the crew. It includes alcohol and drug programs, fitness programs, health programs, etc. Alcohol and drug programs are extremely important in order to prevent the consumption of alcoholic beverages and/or use of narcotics on or too close to duty, as well as excessive drinking or drug use over longer periods of time. The mental and physical effects due to alcohol and drug use include extreme drowsiness, false sense of competence, hallucinations, etc. [31, 44]. The fitness and health of the personnel are also important, and therefore well planned and implemented programs are of great significance.

Personnel Selection

Personnel selection concerns the degree to which personnel are properly identified with the requisite knowledge, experiences, skills, and abilities to perform a given job [15]. In addition, the individual differences among the crew members, which may create tension, should be matched as well as practicable. The individual differences are further amplified when multi-national crews are employed, and therefore special measures should be implemented in order to increase the level of understanding with respect to language, culture, etc. Language barriers, cultural differences, and economic backgrounds all influence the way individuals interact and teams function [1].

Personnel Turnover

Personnel turnover concerns the movement of crew members among various vessels, which results in crew members operating a vessel with which they have little or no experience. This is especially a problem among licensed deck officers [44]. (The practice utilizing hiring halls is especially related to high turnover of onboard personnel; however, this practice is not extensively used in the oil tanker industry.)

Training Programs

Training programs relate to the quality of the training sessions in which personnel are provided with the requisite knowledge and skills to perform tasks safely and effectively [15]. In addition to providing required technical and operational knowledge and skill, training programs are often used to influence the employees regarding the desired objectives and goals of the organization. In addition to regular training, drills or emergency simulations are extremely important in maritime operations and should therefore be implemented regularly. By conducting the drills frequently, turnover across the organization does not erase the organizational memory and new responses can be developed for the changing technologies and environments. All parties involved should be included in the drills in order for the parties to work out the relationship amongst themselves, before the event of an emergency. [49].

Supervision

Supervision refers to the level of oversight of activities of the personnel, as well as the degree to which the personnel are provided on-the-job training. The term includes checking to see that a job is performed in a timely and correct manner, providing proper resources, and equal treatment of personnel [31]. The factor of on the-the-job training is especially important with respect to newly hired personnel. Regardless of their level of education and experience, it takes some time before new personnel are familiar with the vessel and the organizational environment.

Time Urgency

Time urgency concerns the situation in which personnel perceive schedule pressures while completing tasks [15]. In order to be cost-effective, the operation will always be associated with a certain degree of time urgency. However, there are varying levels at which the management pressures the crew to complete the voyages as fast as possible. In the case that voyage-time becomes more important than safety and pollution prevention, this factor greatly influences the personnel's ability to perform at an optimum level.

Organizational Learning

Organizational learning refers to the degree to which the organization uses personnel sufficiently, as well as knowledge gained from past experience, both from the company itself or the industry, to improve future performance [15]. For instance, in the case that a company utilizes accident investigations to determine which factors may lead to accidents and implements the necessary changes, the company uses past experience to reduce risk in the future.

Communication

The term communication concerns the lines of communication established by the organization. It includes external, inter-departmental, and intra-departmental communication. External communication refers to problems in the exchange of information, both formal and informal, between the tanker, its parent organization, and external organizations [15]. Inter-departmental communication refers to problems in exchange of information, both formal and informal, between the different departments or units within the tanker company [15]. Intra-departmental communication refers to problems in the exchange of information, both formal and informal, within a given department or unit of the tanker [15], i.e., the bridge team and the engine room team.

7.3 Ranking of PSFs and MOFs

As discussed in Chapter 5, the PSFs and the MOFs may be ranked according to their relative importance with respect to specific HEPs associated with the relevant tasks. The PSFs that influence the performance of an individual in executing the specific task identified in the grounding model and the MOFs, impacting the various PSFs, are identified and analyzed in Section 7.4. In order to analyze the impact of these factors' on HEPs, PSFs and MOFs are ranked according to their relative importance or degree of influence. The rankings are obtained by pairwise comparisons performed by individuals familiar with the operations of vessels and the AHP method. (The group of experts includes naval officers with cumulatively 30-45 years of experience.) The questionnaires utilized for the pairwise comparisons are located in Appendix V. Once the pairwise comparisons are performed, Expert Choice is utilized to calculate the relative importance of the PSFs and MOFs, and a value function can be determined relating MOFs to the probability of tanker grounding.

7.3.1 Pairwise Comparison

In order to simplify the pairwise comparison of the PSFs with respect to the HEPs and the MOFs with respect to the PSFs, it is assumed that the MOFs influencing a specific PSF are the same regardless of which HEP the PSF influences. Therefore, it is only necessary to do pairwise comparison of the MOFs for each PSF once. The pairwise comparison scale, shown in Table 7-1, is utilized when comparing the relative importance of two factors.

Table 7-1: Pairwise Comparison Scale

Verbal Judgment of Importance	Numerical Ratings
Extremely important	9
Very important to extremely important	8
Very important	7
Important to very important	6
Important	5
Moderately important to important	4
Moderately important	3
Equally to moderately important	2
Equally important	1

In order to compare the factors, a baseline condition/state and a target condition/state are utilized. The baseline is characterized as a worst case scenario, within reasonable limits, for each of the factors. The target is defined as a best case scenario, within reasonable limits. That is, when comparing two PSFs with respect to a task, the relative importance of the PSFs is determined with respect to the potential improvement from the worst case to the best case scenario. In this way, the importance of the improvement of one PSF from the worst case to the best case scenario is ranked with respect to the importance of the improvement of the other PSF from the worst case to the best case scenario.

Similarly, the importance of the improvement of one MOF from the worst case to the best case scenario is ranked with respect to the importance of the improvement of the other MOF from the worst case to the best case scenario. In order to determine the worst case scenario for each factor, the operation of a substandard management company operating under a substandard flag is used as a guideline, while the determination of the best case scenario is based on the operations of an excellent management company operating under a traditional flag.

7.4 Linking HEPs, PSFs, and MOFs

The following sections discuss the root causes characterized as HEPs determined to have the largest impact on the probability of tanker grounding. For each of the HEPs, the related PSFs and MOFs are identified, and the MOFs determined to have the largest influence on human performance are discussed.

7.4.1 Failure to Initiate and Carry Out Planning Correctly

The human error characterized as failure to initiate and carry out planning correctly, consists of four different tasks; failure to check publications and notices without error, failure to properly enter the changes on the charts, failure to determine safe waypoints, and failure to lay down a safe track. Although the individual HEPs associated with these tasks are different, the PSFs and MOFs influencing the navigator are assumed to be the similar for all these tasks. Therefore it is only necessary to perform the pairwise comparison once for the four tasks.

Prior to departure and arrival, the bridge team must ensure that navigational charts reflect the most current and accurate information, which involves checking various publications and notices [3]. The actions involved in checking periodicals for changes in the charts are assumed to be similar to the actions in nuclear power plant operations involving following procedures with no check-off provisions [57]. The changes must be entered in the charts, which is assumed to be similar to following procedures with check-off provisions [57], because the mariner usually develops a list of changes to make. The task of determining waypoints for the passage involves studying the charts to determine the track of the vessel. It is assumed that determining the waypoints are similar to that of writing down a procedural item [57]. The task of laying down the track involves plotting the waypoints and highlighting any hazards to navigation. The process requires precise use of dividers and simple mathematical calculations, analogous to a reactor technician's use of a micrometer [3]. The actions involved in plotting the track are therefore assumed to be analogous to those involved in following procedures with simple arithmetic [57].

The factors which influence the task of initiating and carrying out planning correctly are shown in Figure 7-1. The PSFs are the factors immediately underneath the HEP, while the MOFs associated with the PSFs are listed directly underneath the respective PSF. The task of carrying out the planning of the vessel's track is normally performed under a limited amount of stress, i.e., the situation may be characterized as relatively relaxed. However, the process can be tedious and time-consuming [3], and a risk of deferring the task exists.

Based on the pairwise comparisons and the ranking of the influence factors, it was found that the PSF most important in determining the performance of the crew when initiating and carrying out planning is

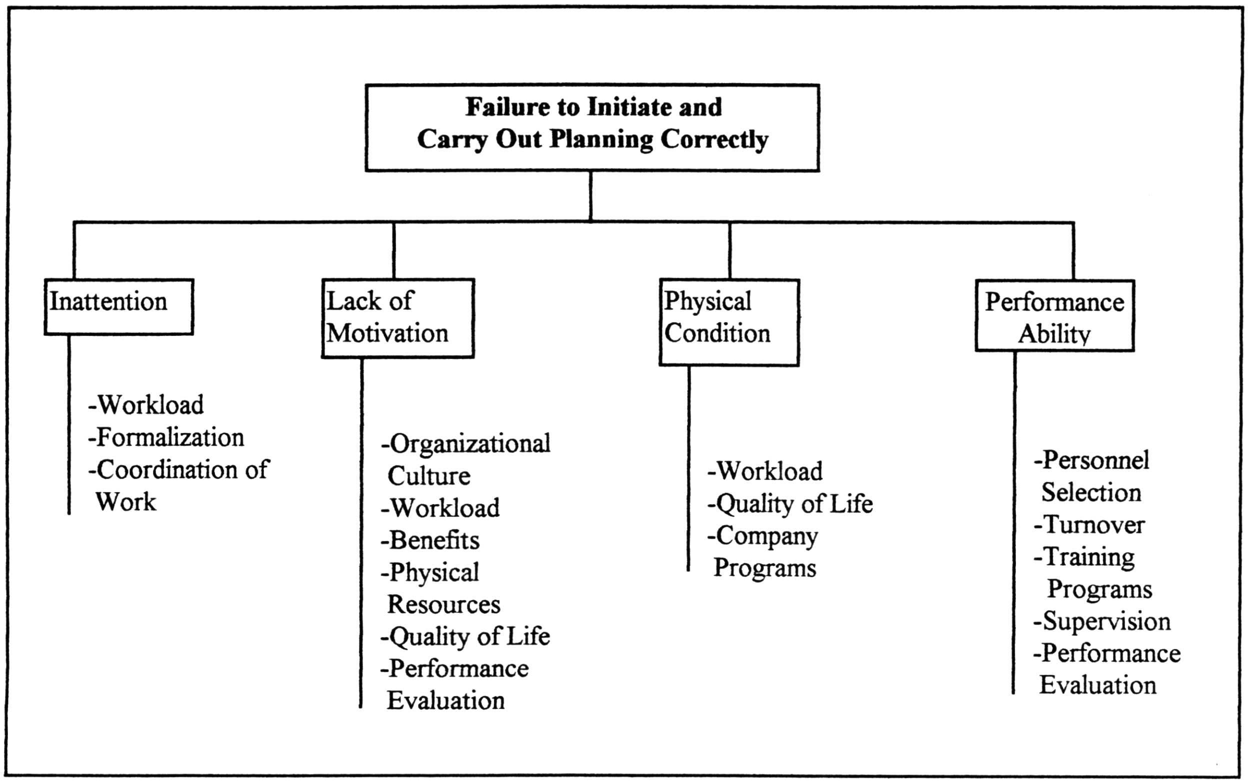

Figure 7-1: Factors Influencing the Task of Initiate and Carry Out Planning

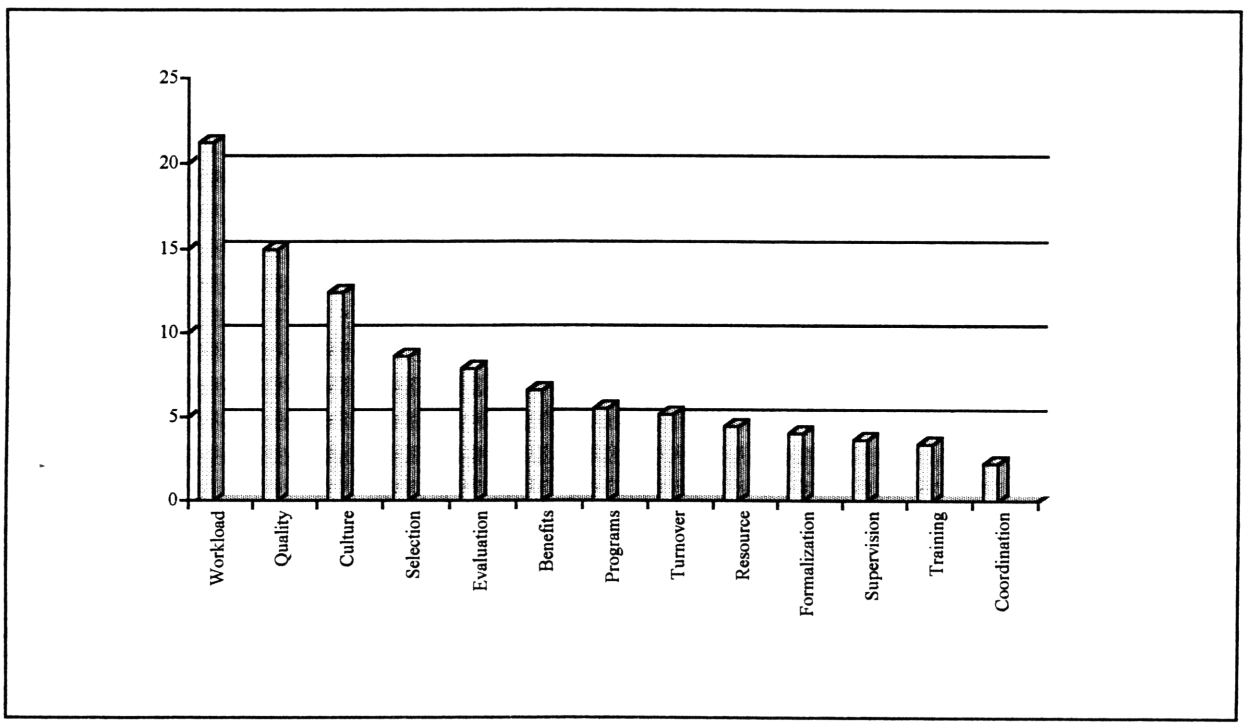

Figure 7-2: Percent Importance of MOFs - Initiating and Carrying Out Planning

the level of motivation, followed by performance ability, physical condition, and level of attention. The MOF impacting performance to the greatest extent is workload. Figure 7-2 illustrates the degree of influence the different aspects of management and the organization have on this HEP. (The abbreviations used for the MOFs are defined in Appendix VI.)

7.4.2 Failure of Captain to Detect and Correct Errors

The approval process assumes that the captain is involved and takes a hands-on approach in verifying the validity of the plan [3]. The actions involved in the captain approving the plan are assumed to be analogous to those involved in a checker's failure to detect errors [57], i.e., hands-on checking.

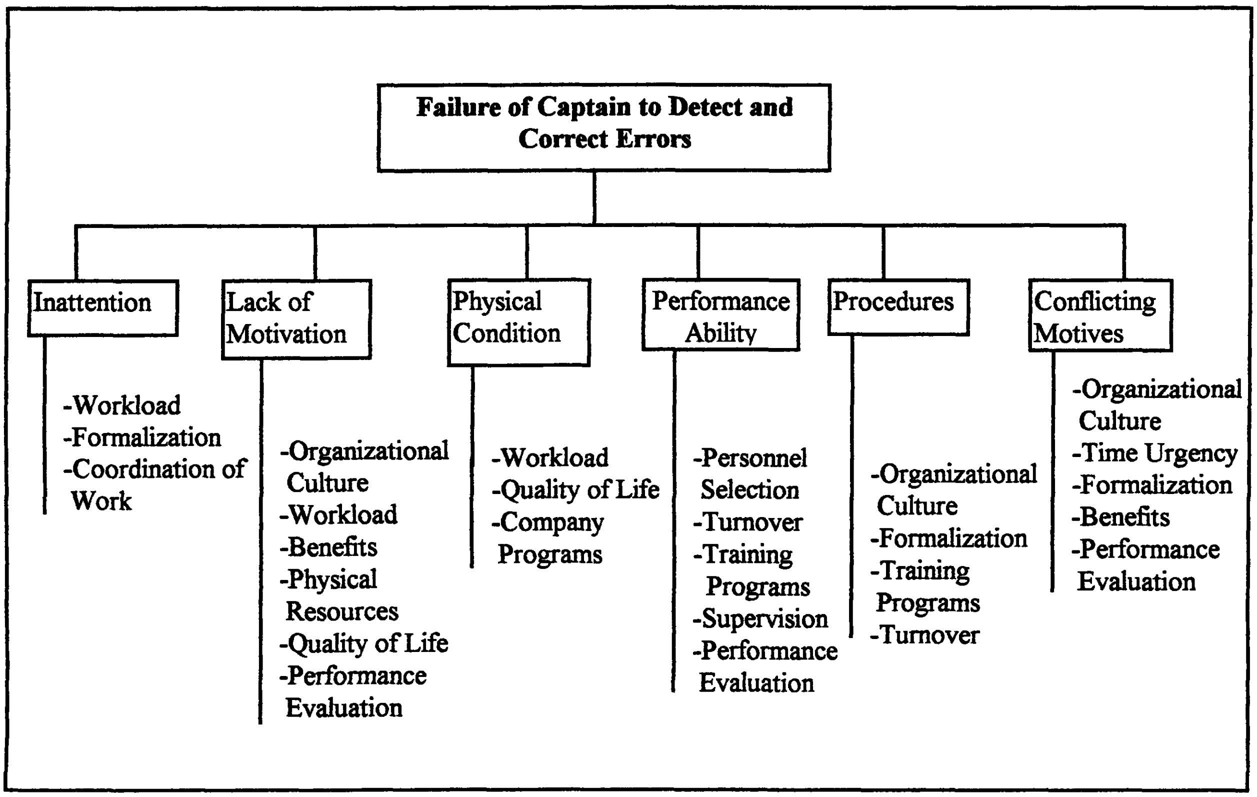

Figure 7-3: Factors Influencing the Captain's Ability to Detect and Correct Errors

The factors influencing the captain's ability to detect and correct errors are shown in Figure 7-3. The captain will most likely have adequate training and experience to perform his/her tasks; however, in the case that the captain is new to the company or the vessel, this is not necessarily true. The captain has the ultimate responsibility for the operation of the vessel, and therefore also the safety of the crew as well as responsibility for preventing an oil spill.

Similar to the task of initiating and carrying out planning, the PSF most important for determining the level of performance of the captain is the level of motivation. Following this PSF are the level of attention, the captain's knowledge of company procedures and standards, the possibility of conflicting motives, the captain's ability to perform, and physical condition. The MOF having the largest impact on the task of detecting and correcting errors is the workload. The different MOFs impacts on the captain are shown in Figure 7-4.

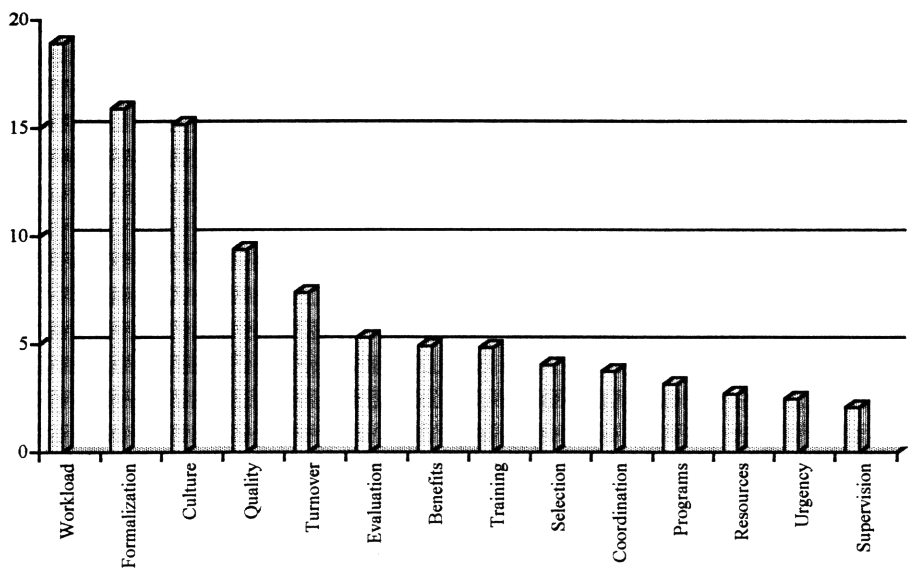

Figure 7-4: Percent Importance of MOFs - Detect and Correct Errors

7.4.3 Failure to Correctly Read Ranges Off Radar

The process of taking a fix typically involves taking at least two radar ranges. The navigator must read the ranges off the radar, which is presented in a digital format [3]. Hence, the actions involved in reading the radar ranges are assumed to be analogous to those involved in reading quantitative information from a digital display [57].

The PSFs and MOFs influencing the individual reading ranges off the radar are shown in Figure 7-5. As previously discussed, the architectural features of the bridge are important because people tend to avoid unnecessary effort, which may result in attempting to read the radar from a distance. Based on the ranking of the specified PSFs, the level of motivation was again found to have the most influence on performance, followed by ability to perform the task, physical condition, level of attention, and architectural features. The MOF influencing the individual reading ranges the most is workload; all the MOFs are shown in Figure 7-6.

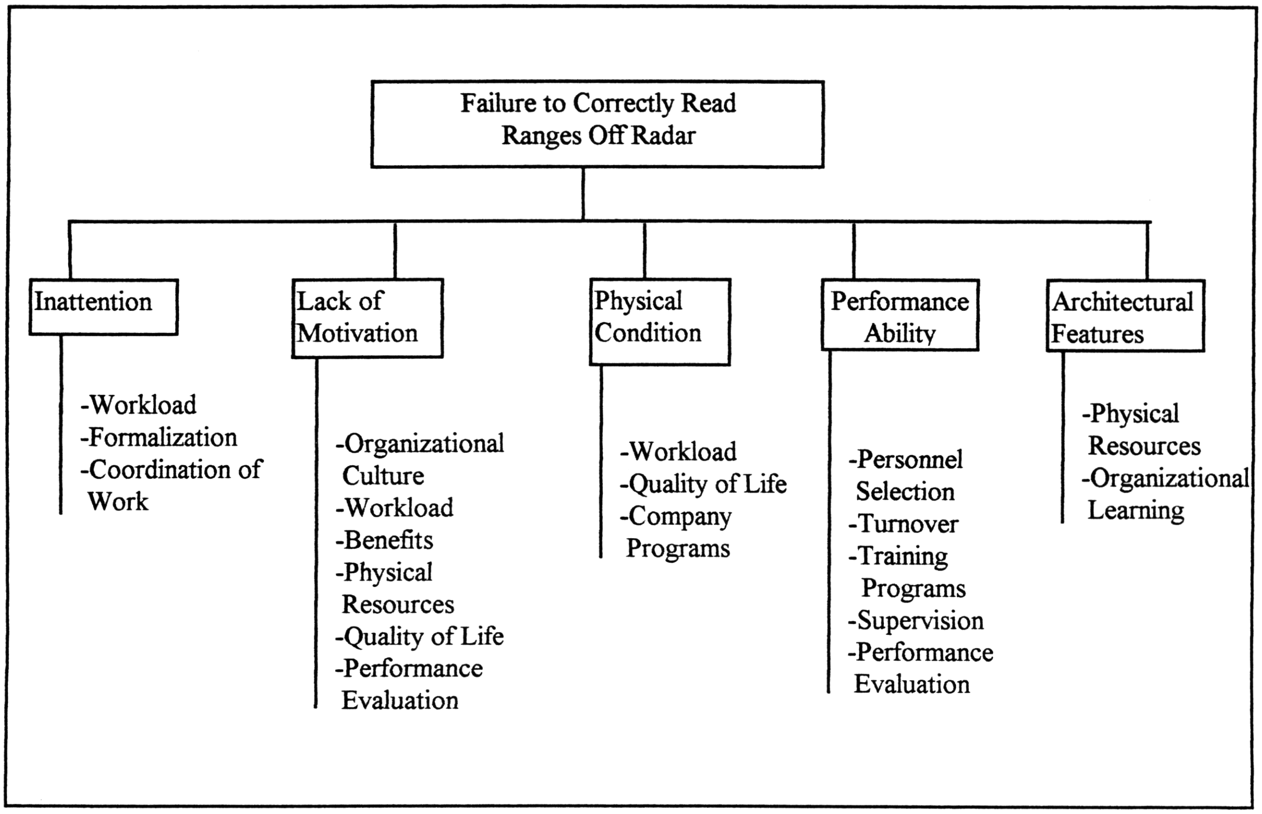

Figure 7-5: Factors Influencing the Task of Reading Ranges Off the Radar

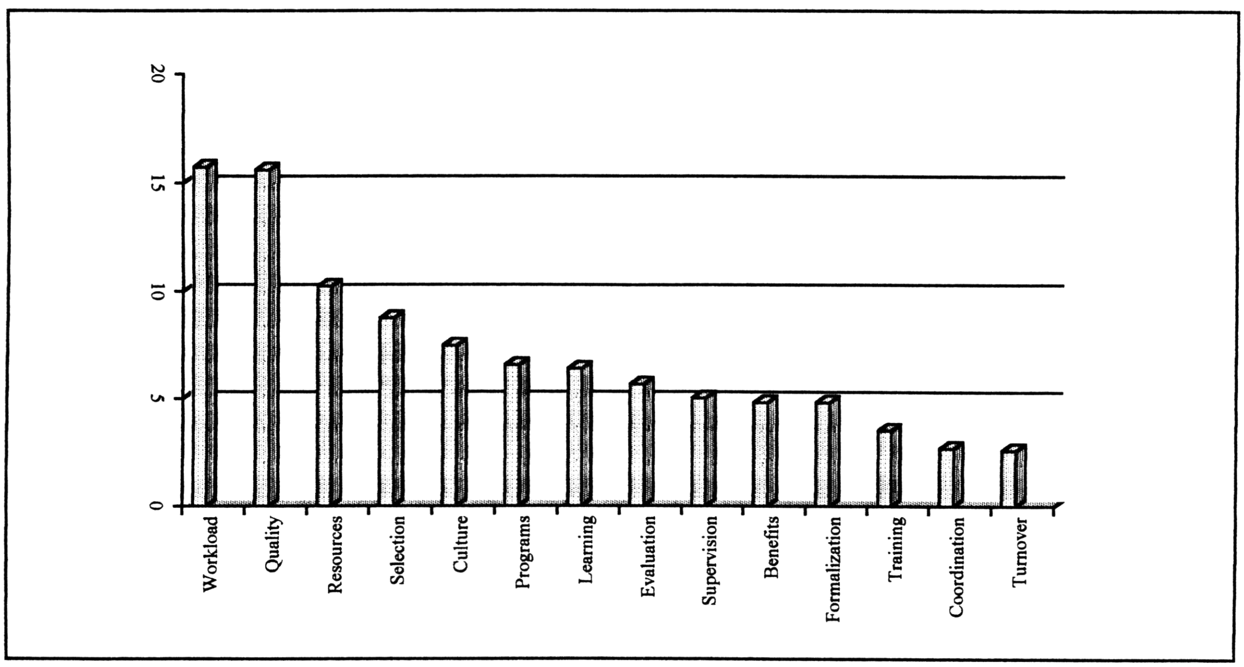

Figure 7-6: Percent Importance of MOFs - Reading Ranges Off the Radar

7.4.4 Failure to Correctly Plot Ranges on Chart

The second part of the process of taking a fix involves plotting the ranges correctly on the chart. The recording of the information obtained involves more than just writing down the information; some skill is required in using the dividers to plot the ranges to the correct scale [3]. The actions involved in plotting the ranges are assumed to be similar to those involving error of commission in recording readings [57].

The factors influencing the task of correctly plotting the ranges on the navigational chart are shown in Figure 7-7. Two PSFs, the level of motivation and ability to perform, were found to be equally important PSFs. Following these two factors are level of attention and physical condition. The levels of impact by the various MOFs are shown in Figure 7-8.

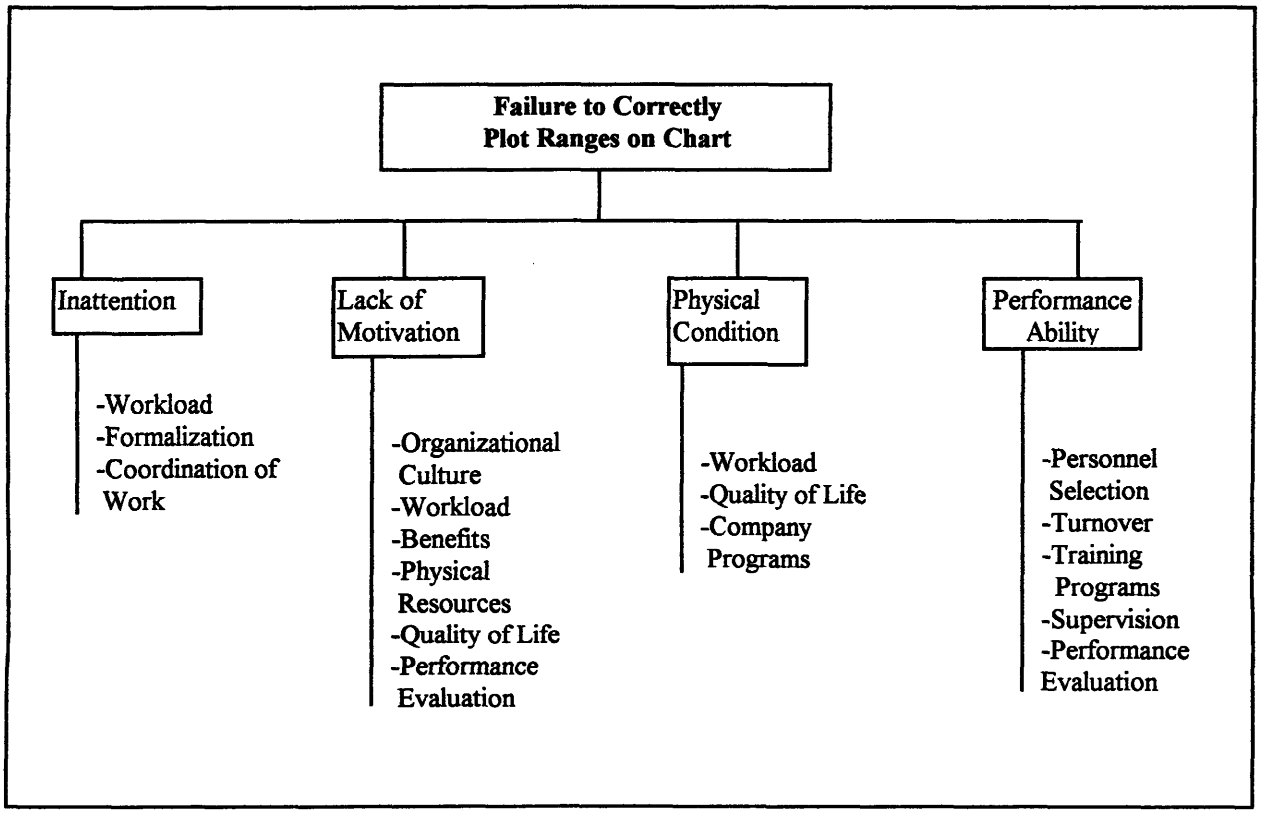

Figure 7-7: Factors Influencing the Task of Plotting the Ranges on the Chart

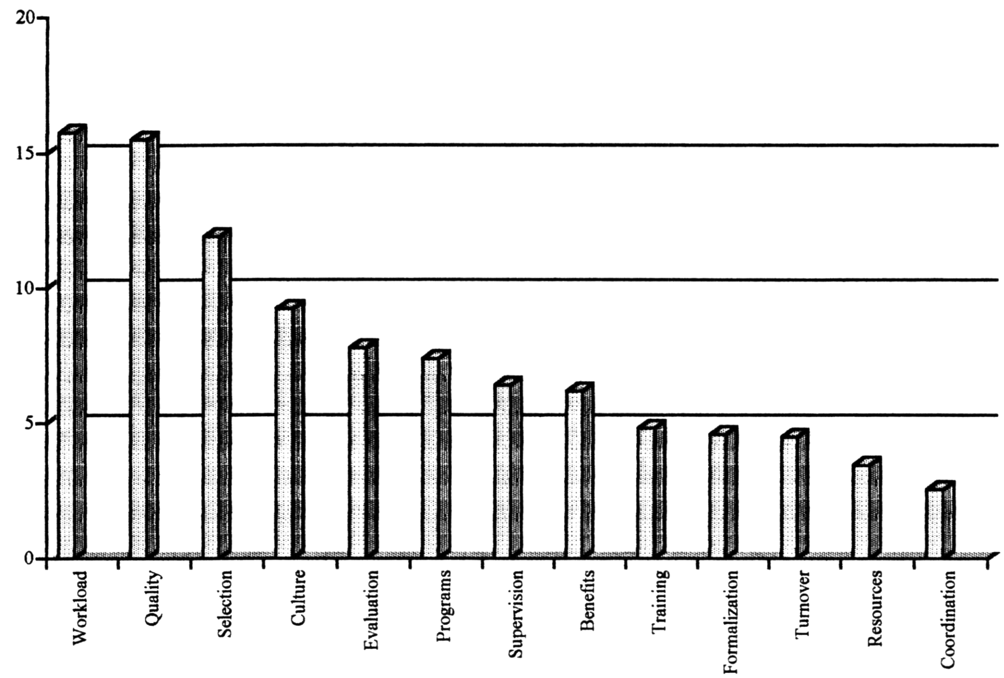

Figure 7-8: Percent Importance of MOFs - Plotting Ranges on the Chart

7.4.5 Failure to Detect Difference Error

Once the fix is plotted, the navigator must assess whether or not the vessel is following the desired track. The actions involved in detecting a difference error between the actual course track and the planned track are assumed to be similar to those involved in the task of checking readings with limits [57], where the navigator checks the plotted fix to ensure that it is within tolerable limits within the planned track.

The PSFs and MOFs influencing whether or not a difference error is detected are shown in Figure 7-9. The PSFs found to have the largest influence on this task are the level of perception and the level of attention, both of approximately equal importance. Level of perception was previously defined as the degree to which the existence of a problem is properly realized or diagnosed, while level of attention was defined as the level of vigilance regarding tasks assigned. These PSFs are followed by level of motivation, ability to perform, and physical condition. The levels of impact of the various MOFs on the task are shown in Figure 7-10.

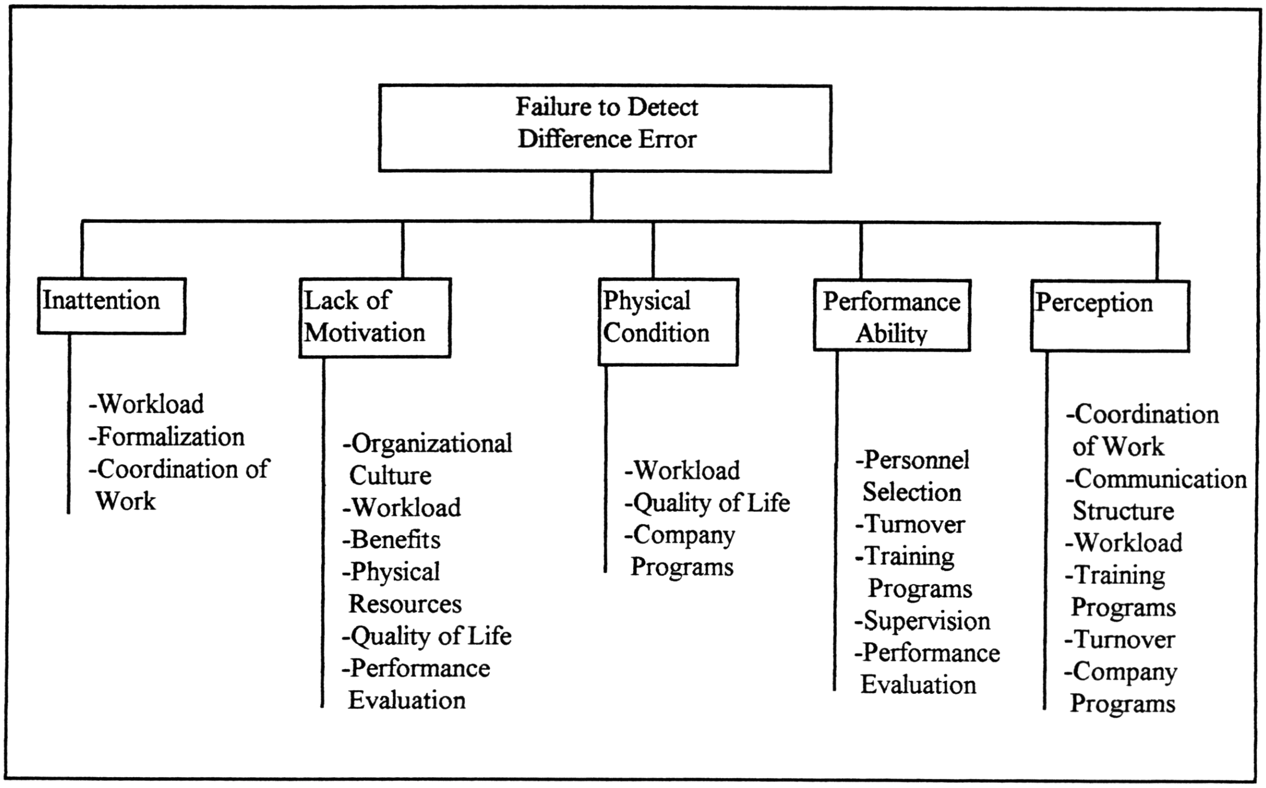

Figure 7-9: Factors Influencing the Task of Detecting the Difference Error

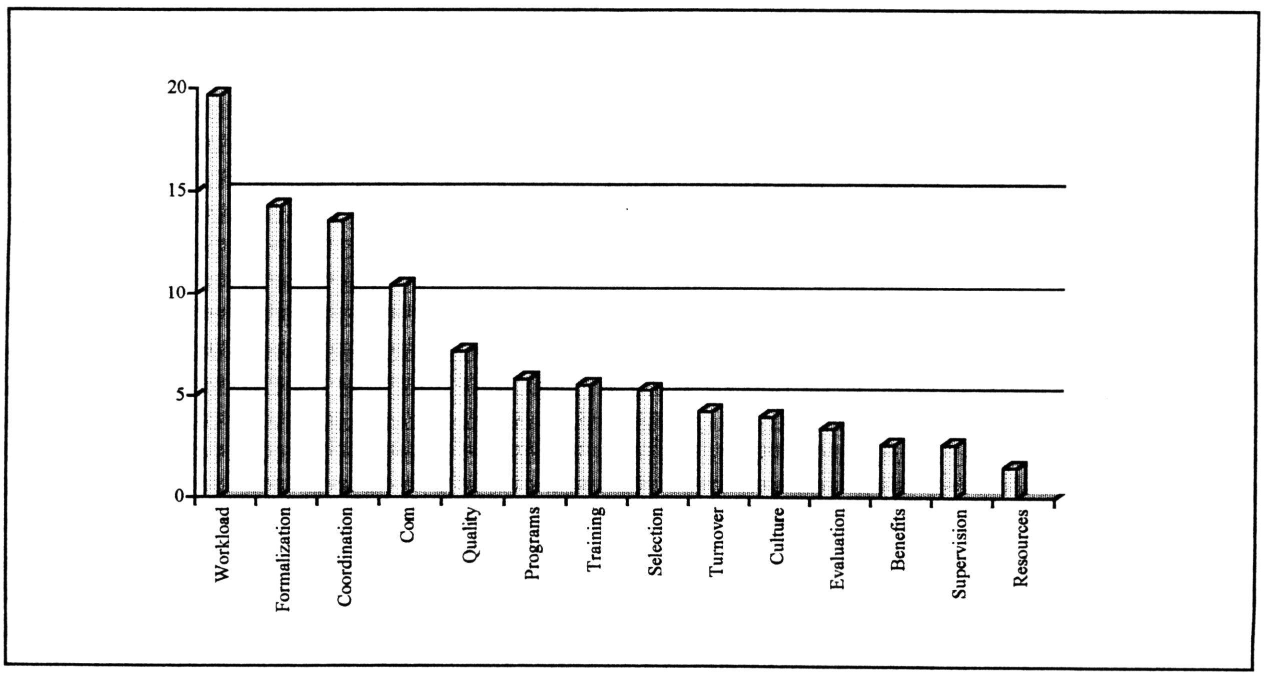

Figure 7-10: Percent Importance of MOFs - Detecting Difference Error

7.4.6 Failure to Order Required Course Change

Given the existence of a difference error, the conning officer must order the correct course change. This can be as simple as a rudder order, however, the standard order involves both a rudder angle order and a final course to steady on [3]. The possible errors involved in ordering a course change are assumed to be nonpassive task errors of commission [57].

The PSFs and MOFs influencing the task of ordering a course change are shown in Figure 7-11. The PSF found to be the most important for ordering a course change correctly is the level of perception. Following this PSF are communication or exchange of information, ability to perform, and physical condition. The MOF most important to the task is communication, i.e., established lines of communication. The various MOFs influencing the task are shown in Figure 7-12.

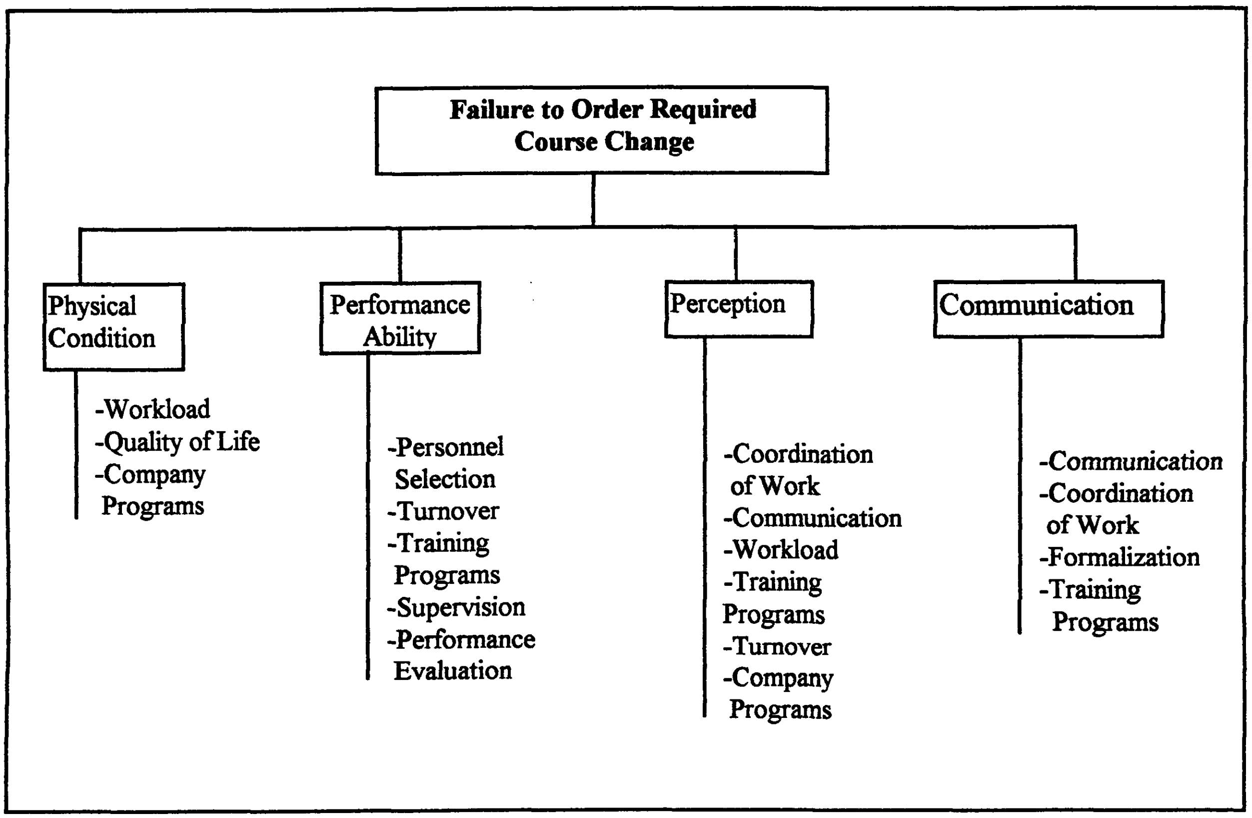

Figure 7-11: Factors Influencing the Task of Ordering the Required Course Change

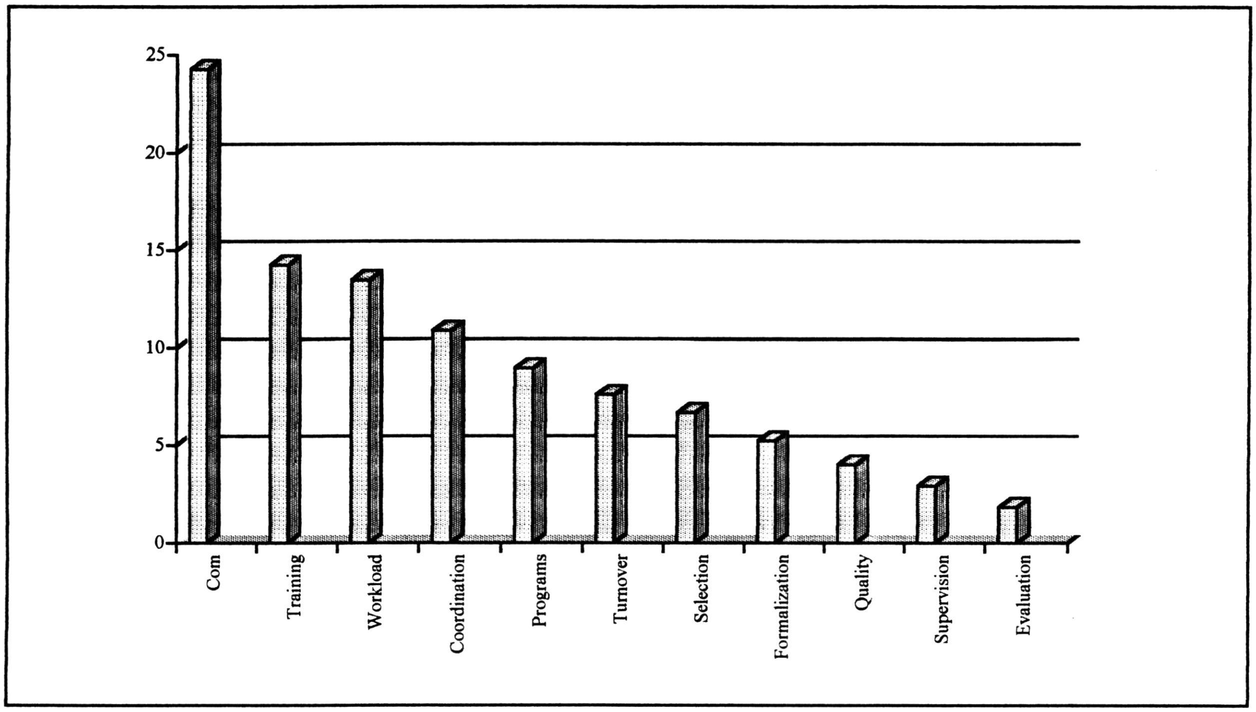

Figure 7-12: Percent Importance of MOFs - Ordering Required Course Changes

7.4.7 Failure to Respond to Ordered Course Change

Once the order to change course is given, the helm must respond to the order. This involves turning the wheel while watching the rudder angle indicator and the gyro repeater until the ordered course is achieved [3]. The actions involved in the helmsman responding to the order are assumed to be a type of failure to recall two items, or instructions, given orally [57].

The factors important to the successful performance of this task are shown in Figure 7-13. The relative impacts of the five PSFs, in descending order, are communication/exchange of information, physical condition, level of attention, level of perception, and ability to perform. Similar to the task of ordering the course change, the most influential MOF for this task is the established lines of communication. The different impacts of the MOFs are shown in Figure 7-14.

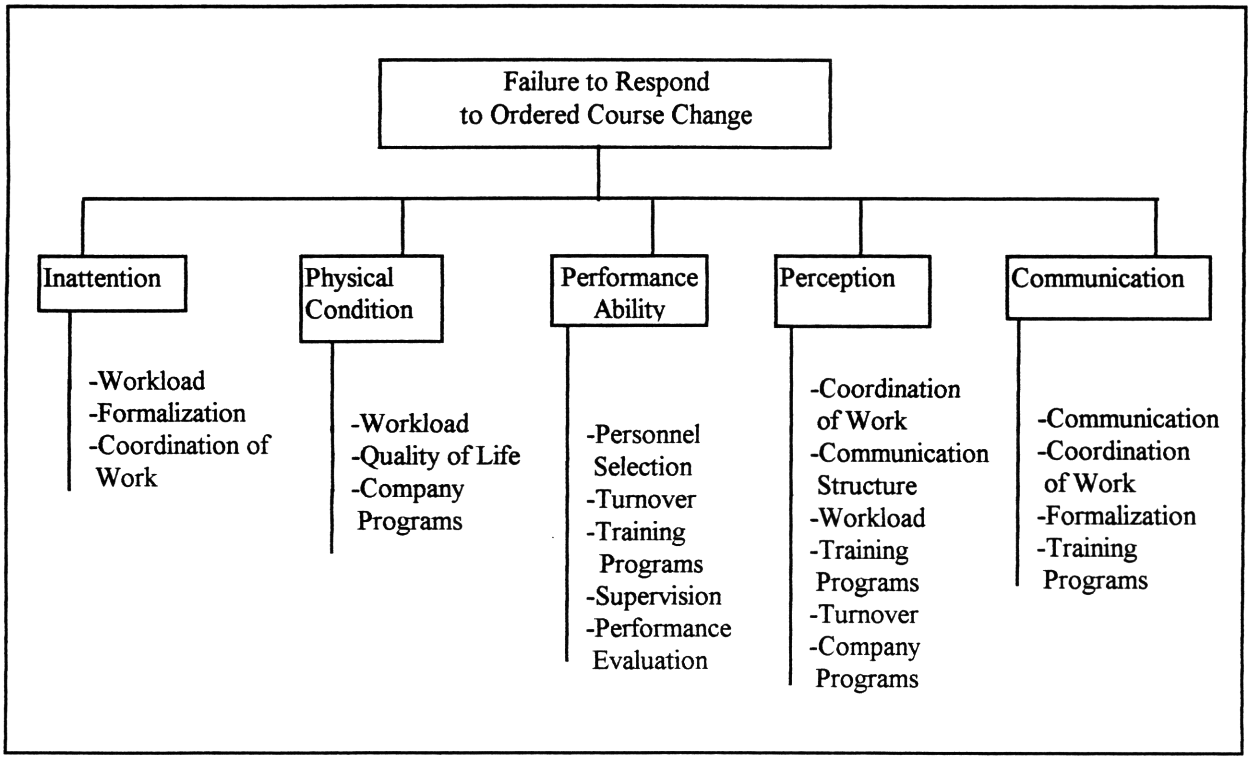

Figure 7-13: Factors Influencing the Task of Responding to Ordered Course Change

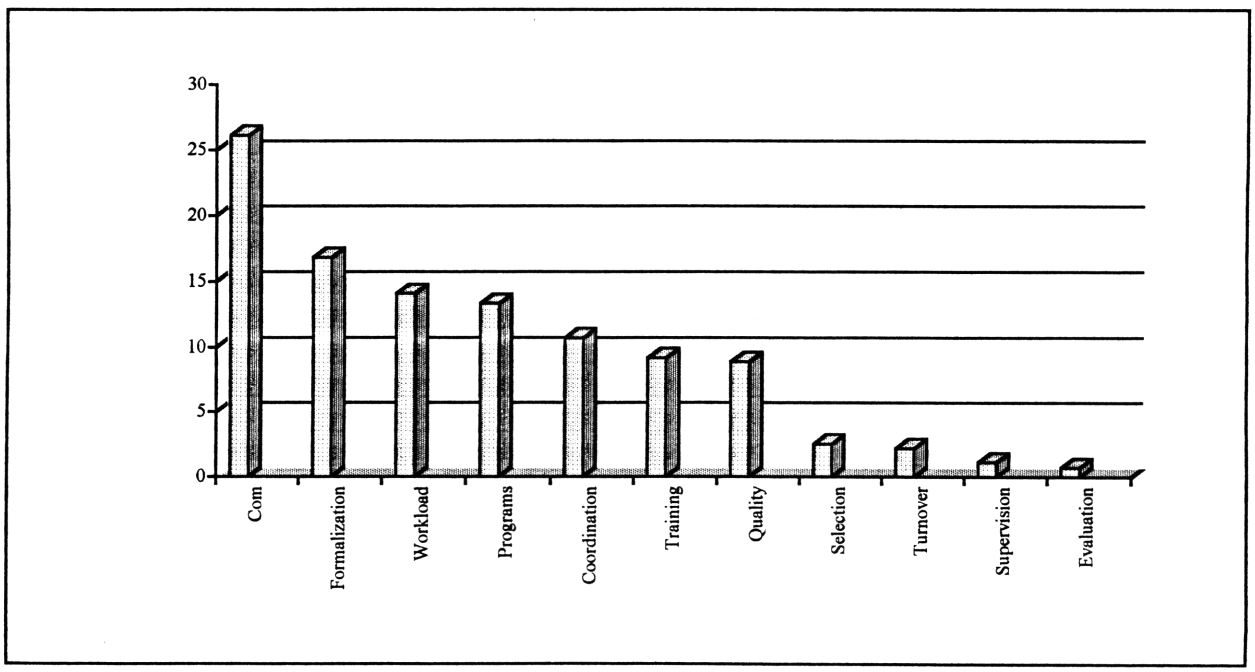

Figure 7-14: Percent Importance of MOFs - Responding to Ordered Course Change

7.4.8 Failure to Drop Anchor in an Emergency Situation

In the event that propulsion or steering abilities are lost, dropping the anchor may prevent the vessel from drifting into too shallow water. The situation that requires dropping the anchor is very stressful. The actions that are involved in the situation in which the anchor is considered are assumed to be similar to those defined for a diagnosis following an abnormal event in the nuclear power industry [57].

The factors influencing the individuals considering whether or not to drop the anchor are shown in Figure 7-15. The PSF found to have the largest impact is the factors related to conflicting motives. In the case that the captain and crew are uncertain about which objectives or goals are most important for the organization, confusion and indecision are likely results. Following the PSF related to conflicting motives are exchange of information, level of perception, level of awareness of roles and responsibilities, ability to perform, and physical condition. The behavior of the decision-maker is in this situation also affected by the natural environment. In the case of storm or strong winds and currents, the situation is dramatically more stressful. However, the natural environment, which is a PSF, is not influenced by MOFs, and therefore this PSF is indifferent to changes in the management or the organization. However, by utilizing the PSFs that are influenced by MOFs, the most important factor was found to be the established lines of communication. All the MOFs influencing the mariner in this situation are shown in Figure 7-16.

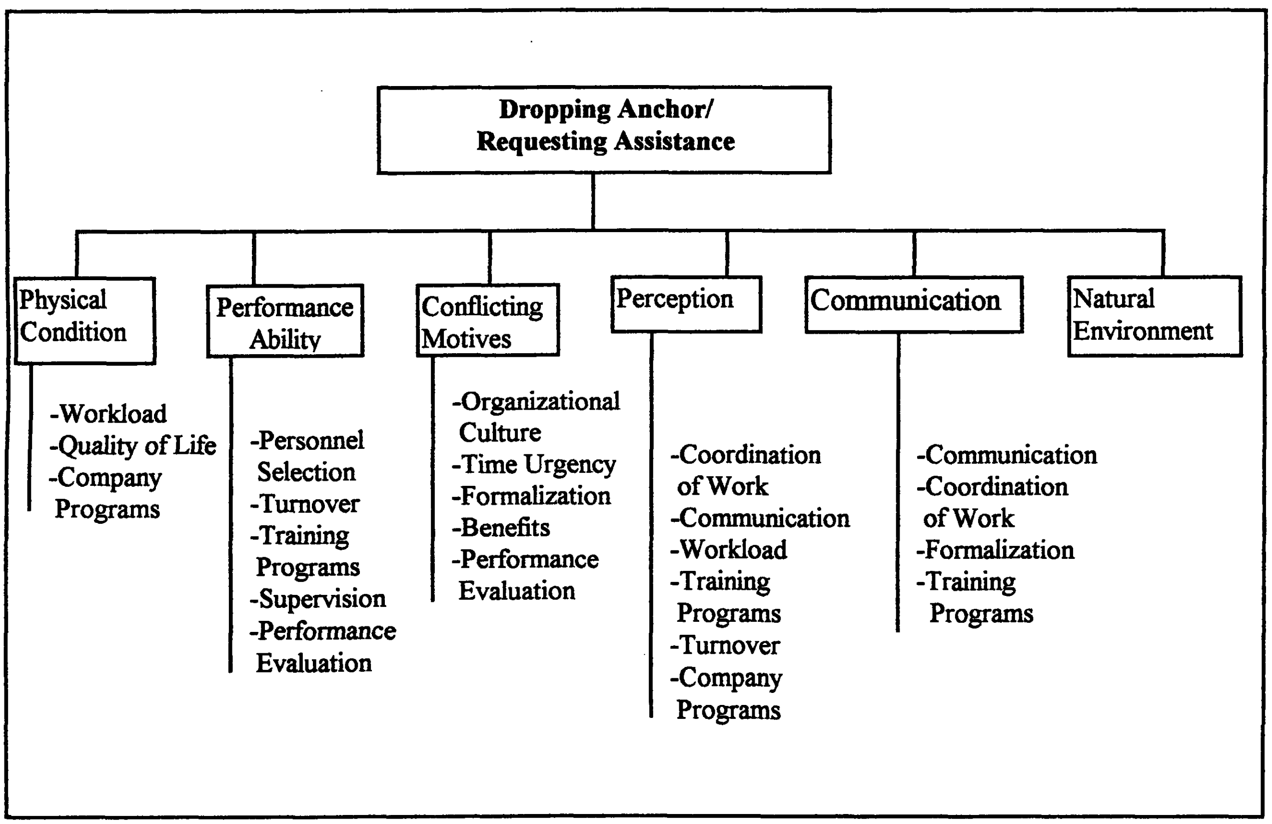

Figure 7-15: Factors Influencing the Task of Deciding to Drop Anchor/Request Assistance

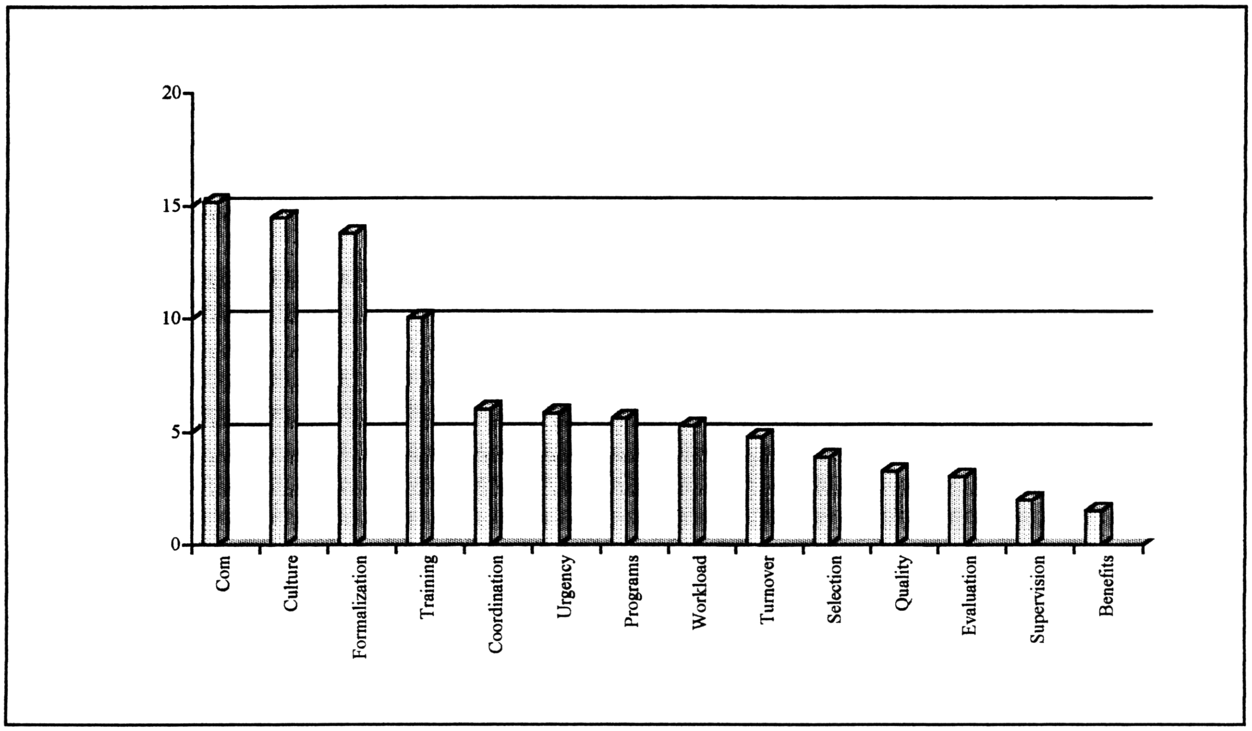

Figure 7-16: Percent Importance of MOFs - Considering Dropping the Anchor

7.4.9 Failure to Request Assistance in an Emergency Situation

In the case that all else fails, assistance is necessary in order to prevent a casualty to occur. As previously discussed, the failure to request assistance represents one of the largest contributions to an assistance failure [3]. Once the bridge crew recognizes that assistance is required, the stress level is extremely high. Similar to the situation in which the anchor is considered, the situation in which assistance is considered is assumed to be analogous to that considered a diagnosis, following an abnormal event, in the nuclear power industry [57].

The factors influencing the decision-maker in this situation are equal to those identified for the situation in which dropping the anchor is considered, which are shown in Figure 7-15. The PSFs, with respect to relative degree of importance, are level of perception, conflicting motives, exchange of information, level of awareness of roles and responsibilities, ability to perform, physical condition, and the natural environment. The MOF having the largest impact on the individual deciding whether to request assistance or not, is the established lines of communication. All the MOFs influencing the individual mariner are shown in Figure 7-17.

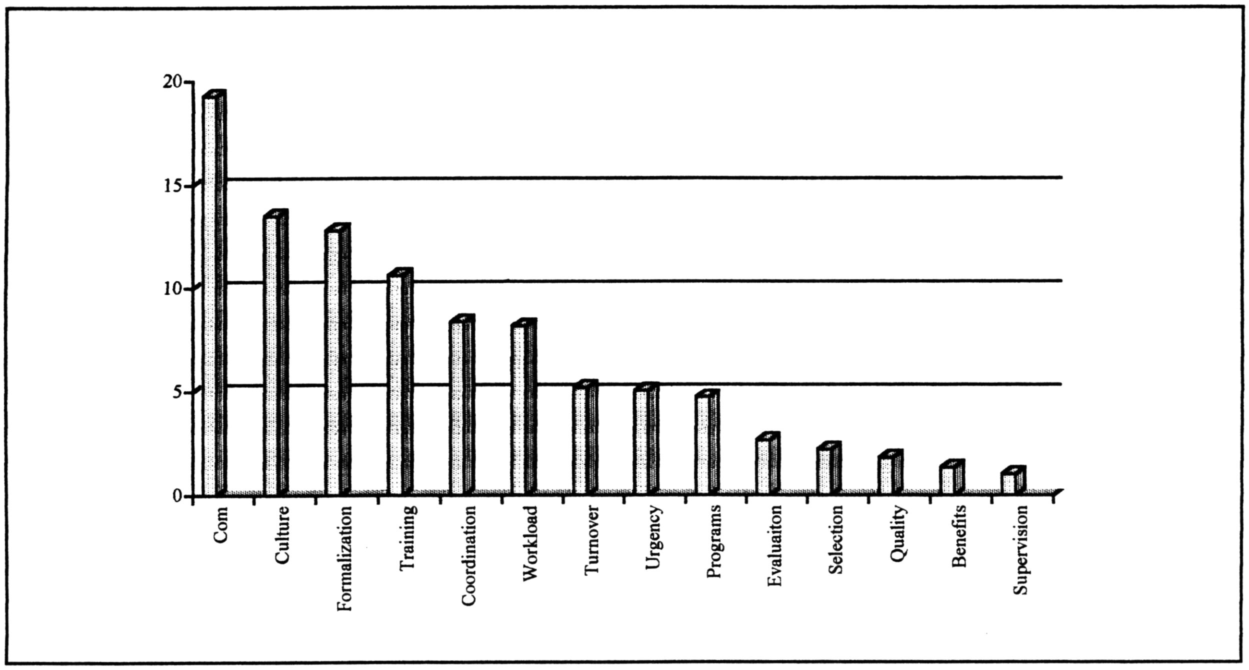

Figure 7-17: Percent Importance of MOFs - Considering Requesting Assistance

7.5 Summary of Factors with Greatest Impact

Human performance is greatly influenced by the various PSFs, which serve as intermediate variables for the MOFs influencing performance. By utilizing AHP, the MOFs of most importance with respect to the various tasks performed by personnel operating a tanker have been identified. The PSFs having the greatest impact on each of the different HEPs, identified in the grounding analysis in Chapter 6, are listed in Table 7-2, together with the MOFs having the largest influence on the different HEPs.

Table 7-2: PSFs and MOFs with Greatest Impact on the Identified HEPs

HEP	PSF	MOFs
Failure to Initiate and Carry Out Planning Correctly	Level of Motivation	Workload
Failure of Captain to Detect and Correct Errors	Level of Motivation	Workload
Failure to Correctly Read Ranges Off Radar	Level of Motivation	Workload
Failure to Correctly Plot Ranges on Chart	Level of Motivation	Workload
Failure to Detect Difference Error	Level of Perception Level of Attention	Workload
Failure to Order Required Course Change	Level of Perception	Communication
Failure to Respond to Ordered Course Change	Exchange of Information	Communication
Failure to Drop Anchor in Emergency Situation	Conflicting Motives	Communication
Failure to Request Assistance in Emergency Situation	Level of Perception	Communication

8 Incorporating MOFs Into the Grounding Model

In order to determine quantitatively which aspects of management and organizations have the largest impact on grounding, the results presented in Chapter 7 must be incorporated into the grounding model presented in Chapter 6. By having estimates of the degree to which the different MOFs impacts the various HEPs, i.e., the rankings of the MOFs, it is possible to calculate the degree to which these factors impact the probability of grounding. (As discussed in Section 5.4.2, the rankings are determined by normalizing the eigenvectors associated with the eigenvalues of the ratio matrices resulting from the pairwise comparisons.) Each HEP varies with respect to how great a role it plays in determining the grounding probability, and therefore the MOF which seems to be most important, from only analyzing the HEPs, may not necessarily be the factor that has the largest influence.

8.1 Modification of HEPs

In Table 6-1 and Table 6-2, the mean HEP values were presented with their associated uncertainty ranges. The HEPs, together with the uncertainty ranges, are utilized to determine the impact of the MOFs on the probability of grounding. In Chapter 7, the degree of influence that each MOF has on specific HEPs was determined as a percentage of all the MOFs influencing that specific HEP. As the different MOFs influencing the HEP vary, the HEPs will vary accordingly. By utilizing the uncertainty ranges, the amount of variation in each HEP as a result of changes in the various MOFs is determined.

8.1.1 Uncertainty Bounds

The estimates of the mean HEP values are accompanied by uncertainty. This uncertainty is related to imperfect knowledge, stochasticity, and variability in situations. That is, it includes the random variability in individuals, presumed uncertainty of the analysis, and variations in PSFs. The PSFs are, as previously discussed, intermediate variables between the HEPs and the MOFs, and therefore the uncertainty bounds are utilized in order to obtain an estimate of the degree to which the MOFs influences the HEPs. The uncertainty bounds include approximately 90 percent of the true HEP for a given task of activity [57]. The uncertainty bounds are estimates of the spread of the HEPs associated with a lognormal distribution, i.e., the bounds are symmetrical on a logarithmic scale about the nominal HEP [57].

8.1.2 Ratings of Organizations

Once the percentages of each MOFs' influence on the different HEPs are estimated, the influence the different management and organizations have on the MOFs must be incorporated. This is accomplished by the following value function:

$$HEP = HEP_{low} + \Delta HEP \cdot [(0.01 \cdot P_{MOF1}) \cdot R_{MOF1} + (0.01 \cdot P_{MOF2}) \cdot R_{MOF2} + (0.01 \cdot P_{MOFX}) \cdot R_{MOFX}]$$

ΔHEP = Uncertainty Range
P_{MOFx} = Percent Importance of MOF_x
R_{MOFx} = Rating of MOFx with Respect to Specific Company

The ratings of a company with respect to the different MOFs are incorporated as R's in the equation. That is, for each MOF the company is rated with respect to adequacy. The chart utilized when rating a company is included in Appendix VII, and the ratings with respect to each HEP are demonstrated in Appendix VIII. For simplicity, as well as due to the fact that the uncertainty bounds are symmetric on a logarithmic scale which complicates the calculations, the ratings are limited to inadequate, adequate, and excellent. A value of 1 is used for a rating of inadequate, while a value of 0 is used for a rating of excellent. For a rating of adequate, the value depends on the uncertainty range, and is determined separately for each HEP, as illustrated in Appendix VIII.

8.2 Modification of the Probability of Grounding

As already mentioned, the influence of the MOFs on the probability of grounding may be estimated through their influence on the HEP values. By incorporating the modified HEP values into the equation for the probability of grounding, the probability reflects the conditions of a specific management company operating a tanker. In addition, by performing sensitivity analysis, the MOFs influencing the probability of grounding to the largest extent are determined.

In order to incorporate the MOFs into the grounding probability equation, the modified HEP values, including the percentage MOF values and the company ranking values, are substituted for the mean HEPs. In this manner, the probability of grounding increases in the case that a MOF, having an impact on HEPs important to the determination of the probability of grounding, is rated unfavorably. Similarly, the same MOF will decrease the probability of grounding if rated favorably.

In addition to the MOFs identified, human behavior, and therefore the probability of grounding, is influenced by various degrees of stress. Stress results in physical or psychological tension [57], which influences the performance of the crew. Stress is implicitly included in the analysis. If stress needs to be included more explicitly, it is easily incorporated in the analysis as discussed in Section 2.2.

8.3 Results of Modified Grounding Model

The MOFs determined to have the largest influences on the probability of grounding are workload, organizational culture, quality of life, and formalization. Workload, which considers the number of work hours, breaks, and overall amount of work, affects the physical and mental capabilities of the crew, and therefore affects their performance to a great extent. Organizational culture is related to the crew's perception of the organization. Quality of life refers to the standard of living, working environment, and the overall well-being of the crew. Formalization considers the quality of procedures and standardized methods.

The MOFs which have the largest impact on the powered grounding portion of the probability of grounding are the same as those important to the total probability of grounding. This is due to the fact that powered grounding represents the largest contribution to the probability of grounding. The MOFs which have the largest impact on the drift grounding portion of the probability of grounding are established lines of communication, organizational culture, formalization, and training programs. Established lines of communication refers to the extent to which well-identified paths for communication, or exchange of information, exist. Organizational culture refers to, as described above, the perception of the organization, while formalization refers to the quality of standard task procedures. Training programs refer to the quantity and quality of crew training. The factors determined to have the largest impact on grounding are summarized in Table 8-1.

Table 8-1: MOFs Having the Largest Impact on Tanker Grounding

TOTAL GROUNDING	Powered Grounding	Drift Grounding
Workload Organizational Culture Quality of Life Formalization	Workload Organizational Culture Quality of Life Formalization	Communication Organizational Culture Formalization Training Programs

It is interesting to examine the resulting probability of grounding over the full range of MOF ratings. In Appendix IX, it is shown that the probability of grounding, for a company for which all MOFs are rated excellent, is $6.79 \cdot 10^{-6}$. This represents a great improvement compared to a company rated inadequate, which has a probability of grounding of $1.51 \cdot 10^{-3}$. Similarly, it is an improvement compared to a company rated adequate, which has a probability of grounding of $1.04 \cdot 10^{-4}$.

8.4 Sensitivity Analysis

Sensitivity analyses are performed in order to determine the variation in the probability of grounding as a result of varying the MOF ratings. Table 8-2 shows the percentage reduction in the probability of total, powered, and drift grounding, as each MOF is improved from inadequate to excellent, keeping the other MOF variables as inadequate. Table 8-3 shows the percentage increase in the probability of total, powered, and drift grounding as each MOF is improved from adequate to excellent, keeping the other MOFs as adequate.

Table 8-2: Percent Decrease in the Probability of Grounding Due to Improvements in Each MOF from Inadequate to Excellent

MOFs	Total Grounding	Powered Grounding	Drift Grounding
Benefits	9.76	10.16	2.79
Communication	2.02	0.36	31.28
Coordination of Work	6.06	5.63	13.75
Organizational Culture	23.88	23.76	25.89
Performance Evaluation	11.26	11.58	5.55
Formalization	18.71	18.37	24.66
Organizational Learning	0.01	0.01	~ 0
Company Programs	7.93	7.81	10.01
Quality of Life	20.08	20.93	5.00
Physical Resources	6.00	6.34	~ 0
Personnel Selection	10.84	11.12	5.99
Supervision	5.00	5.11	2.94
Training Programs	8.24	7.60	19.46
Turnover	11.25	11.34	9.65
Time Urgency	2.81	2.37	10.54
Workload	32.27	33.37	12.89

Table 8-3: Percent Decrease in the Probability of Grounding Due to Improvements in Each MOF from Adequate to Excellent

MOFs	Total Grounding	Powered Grounding	Drift Grounding
Benefits	7.68	7.99	2.21
Communication	1.60	0.27	25.17
Coordination of Work	4.85	4.51	10.94
Organizational Culture	19.23	19.14	20.76
Performance Evaluation	8.84	9.09	4.39
Formalization	18.34	15.08	19.76
Organizational Learning	0.01	0.01	~ 0
Company Programs	6.18	6.08	7.95
Quality of Life	15.81	16.49	3.95
Physical Resources	4.69	4.95	~ 0
Personnel Selection	8.42	8.63	4.75
Supervision	3.89	3.98	2.33
Training Programs	6.59	6.08	15.54
Turnover	9.02	9.09	7.66
Time Urgency	2.32	1.98	8.37
Workload	25.93	26.82	10.25

8.5 Comparison with Factors Emphasized by the ISM Code

The MOFs emphasized by the ISM Code, discussed in Section 4.3, are summarized in Table 8-4, together with the MOFs found to have the largest impact on the probability of grounding. The MOFs emphasized by the ISM Code are listed in an arbitrarily order, while the factors resulting from the grounding analysis are listed in order of importance.

Table 8-4: Factors Emphasized by ISM Code vs. Factors Resulting from Grounding Analysis

ISM Code	Grounding Analysis
Safety Culture	Workload
Organizational Culture	Organizational Culture
Organizational Learning	Quality of Life
Formalization	Formalization
Coordination of Work	Performance Evaluation
Communication	Turnover
Personnel Selection	Personnel Selection
Training Programs	Benefits
	Training Programs

As seen from Table 8-4, the factors that match are culture, formalization, personnel selection, and training programs. The ISM Code addresses both organizational culture and safety culture. In the grounding analysis, safety culture is assumed to influence all other variables, and therefore is removed from the analysis. However, due to the assumption that safety culture has an impact on all the MOFs, its importance is clearly seen. Organizational culture, which clearly represents a match, was determined to be the second largest influence on the probability of grounding. Similarly, formalization, which concerns the quality of procedures and standards, personnel selection, and training programs are of importance both in the ISM Code and to the probability of grounding.

The MOFs representing important factors to the grounding analysis that do not match the factors emphasized by the ISM Code are workload, quality of life, performance evaluation, turnover, and benefits. Workload, determined to have the greatest impact on the probability of grounding, is not specifically addressed in the ISM Code. This might be due to the fact that safety culture has a large influence on this factor and also that this factor is addressed in other regulations, e.g., the STCW Convention. Similarly, quality of life, performance evaluation, turnover, and benefits are not explicitly emphasized by the ISM Code. The reason for this might be that these factors are addressed in regulations more specifically related to issues concerning crew members. However, another reason might be that these factors are not satisfactorily considered in the ISM Code, and therefore these factors require further investigation.

Factors emphasized by the ISM Code that were determined to be of lesser importance in the grounding analysis are organizational learning, coordination of work, and communication. Organizational learning, which certainly would seem to be of great importance, needs to be investigated further with respect to the probability of grounding. It is a possibility that this factor influences a larger number of PSFs, and therefore HEPs, than what was considered in the grounding analysis. Coordination of work and communication were found to be of importance to the probability of drift grounding. However, due to the fact that drift grounding represents a fairly small portion of the total probability of grounding, these factors are less important to the probability of grounding.

The ISM Code is valid for a variety of types of vessels, including passenger ships and mobile offshore platforms, and therefore the issues emphasized by the ISM Code may differ slightly from those specific to oil tankers. However, the majority of the MOFs determined to be of importance for one type of vessel should apply to most of other types of vessels. This because the tasks involved in passage planning, piloting, and emergency situations are very similar.

Relative importance with respect to the different management and organizational aspects of ship operators is not explicitly stated in the ISM Code. Therefore, the code does not provide any guidelines as to which areas should be emphasized to the greatest extent. In order to be certified, a company must meet certain requirements; however, in the case that the company decides to exceed the requirements, the ISM Code does not provide any assistance in determining which MOF would result in the most benefit, due to an improvement. The model developed for tanker grounding provides new insight, and it represents an important framework for developing investment and operational strategies.

9 Conclusion

The operation of oil tankers represents a risk to the environment due to the severe consequences of oil spills. Tankers are the largest contributor by vessel type to worldwide spill volume. One of the largest causes of accidents involving oil tankers is the event of grounding. The probability of grounding is largely influenced by the performance of the individuals responsible for the operation of the tanker. Therefore, in order to reduce the risk of grounding, the factors having an impact on the performance of humans must be addressed.

As discussed, individuals are influenced by both internal and external factors. The various PSFs determine whether an individual's performance is highly reliable, reliable, or unreliable. The PSFs serve as intermediate variables between the HEPs for various tasks and the different MOFs. By determining the relative influence of the MOFs on the PSFs, estimates of the impact of the different MOFs on human performance are obtained.

The MOFs determined to have the greatest impact on the probability of grounding are workload, organizational culture, quality of life, and formalization. Workload refers to the amount of overall work that must be done by the crew, organizational culture concerns the overall perception of the organization by the crew, quality of life refers to the standard of the living and working environment, while formalization refers to the extent to which well-identified procedures and standards are developed. The factors found to have the largest influence on powered grounding are the same as those for total grounding. The MOFs most important to drift grounding are established lines of communication, organizational culture, formalization, and training programs. Safety culture is assumed to influence all other MOFs, and therefore this factor is naturally one of the factors with greatest impact on the probability of grounding.

The primary purpose of this analysis was to develop and demonstrate the methodology enabling the inclusion of MOFs into risk analyses, and therefore the results are limited. In order to improve the results related to the impacts of management and organizations, a greater number of experts should perform the pairwise comparison. Even though the process of performing pairwise comparison is tedious and time-consuming, and requires some familiarity with the AHP method, it is an important method for estimating relative importance. By receiving feedback from the experts doing the comparisons, the framework and the questionnaires may be improved. The improved questionnaires may then be redistributed to experts for additional and improved pairwise comparison.

Areas of improvement of the grounding analysis include further development of the drift grounding portion of the grounding fault tree. A more detailed study utilizing event trees may result in more accurate estimates compared to the estimates utilized for this analysis. In addition to developing the analysis with respect to grounding, the analysis should be extended to the event of collision involving oil tankers.

The framework developed, or an improved version of this framework, may be used to determine which aspects of a company need the greatest emphasis. It may be utilized to develop and maintain philosophies related to design and operation, and function as a tool for developing investment strategies. In addition, the results may be utilized and integrated into the formulation of legislation and regulation.

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APPENDICES

Appendix I

NUREG 1278 Performance Shaping Factors [57]

External	Situation al Characteristics	Architectural features Quality of Environment Work hours/Breaks Availability/Adequacy of equipment Manning parameters Shift rotations Actions by supervisors Rewards, recognition, benefits
	Job and Task Instructions	Procedures required Written or oral communication Cautions and warnings Work methods
	Task and Equipment Characteristics	Perceptual requirements Speed, strength, precision requirements Control-Display relationship Anticipatory requirements Interpretation required Decision-making Complexity Narrowness of task Frequency and repetitiveness Task criticality Long and short term memory Calculation requirements Feedback Dynamic vs. step-by-step activities Team structure and communication Man-machine interface factors
Stressors	Psychological Stressors	Suddenness of onset Duration of stress Task speed and load High jeopardy risk Threats of failure Monotony Long, uneventful vigilance periods Conflicts of motives about job performance Reinforcement absent of negative Sensory deprivations Distractions Inconsistent cueing
	Physiological Stressors	Duration of stress Fatigue Pain or discomfort Hunger or thirst Temperature extremes Oxygen insufficiency Vibration Movement constriction Lack of physical exercise Disruption of circadian rhythm

Internal	Organismic Factors	Training/Experience Proficiency Personality/Intelligence variables Motivation/Attitude Knowledge of required performance standards Emotional states Physical condition Attitudes based on outside influences Group identification

Appendix II

Definitions of Organizational Factors [59]

Decision Making	
Centralization	The extent to which decision making and authority are localized to one area or among certain groups.
Goal Prioritization	The extent to which personnel understand, accept, and agree with the purpose and relevance of company goals.
Organizational Learning	The extent to which personnel and organization use knowledge gained from past experience, from the particular company or the industry, to improve future performance.
Problem Identification	The extent to which organizations encourage personnel to draw upon knowledge, experience, and current information to identify problem.
Resource Allocation	The extent to which the company distributes financial resources, including actual distribution well as individual perception of this distribution.
Communication	
External	The existence of problems in exchange of information, both formal and informal, between the tanker, its parent organization, and external organizations.
Inter-Departmental	The existence of problems in exchange of information, both formal and informal, between the different departments or units within the tanker company.
Intra-Departmental	The existence of problems in the exchange of information, both formal and informal, within a given department or unit of the plant.
Human Resource Allocation	
Performance Evaluation	The degree to which personnel are provided fair assessments of their work-related behavior.
Personnel Selection	The degree to which personnel are identified with the requisite knowledge, experiences, skills, and abilities to perform a given job.
Technical Knowledge	The depth and breadth of requisite understanding to which personnel have regarding design and systems, including phenomena and events that bear on safety.
Training	The degree to which personnel are provided with the requisite knowledge and skills to perform tasks safely and effectively.
Administrative Knowledge	
Coordination of Work	The existence of problems with planning, integration, and implementation of work activities among individuals or groups.
Formalization	The existence of well-identified rules, procedures, and standardized methods for routine activities as well as unusual occurrences.
Organizational Knowledge	The understanding of personnel regarding the interactions of organizational subsystems and the way in which work is actually accomplished.
Roles-Responsibility	The degree to which personnel and department work activities are clearly defined and carried out.

Culture	
Organizational Culture	The personnel's shared perception of the organization. Includes traditions, values, customs, practices, goals, and socialization processes that endure over time and that distinguishes an organization from others. (The "personality" of the organization.)
Ownership	The degree to which personnel take personal responsibility for actions and the consequences of these actions. The existence of a commitment to pride in the organization.
Safety Culture	The characteristics of the work environment, such as the norms, rules, and common understandings, that influence personnel's perception of the importance the organization places on safety. Includes the degree to which a critical, questioning attitude directed toward improvement exists.
Time Urgency	The degree to which plant personnel perceive schedule pressures while completing tasks.

Appendix III

Calculations for the Probability of Grounding

Powered Grounding

Passage Planning

$$P_{ProducingFaultyPlan} = 1-[P_{PublicationsAffectPlan}\cdot(1-P_{CheckPub})\cdot(1-P_{Plot})\cdot(1-P_{Waypoints})\cdot(1-P_{LayTrack}) + (1-P_{PublicationsAffectPlan})\cdot(1-P_{Waypoints})\cdot(1-P_{LayTrack})]$$
$$= 1-[0.1\cdot(1-0.003)\cdot(1-0.001)\cdot(1-0.003)\cdot(1-0.01) + (1-0.1)\cdot(1-0.003)\cdot(1-0.01)]$$
$$= 1.336\cdot 10^{-2}$$

$$P_{ErrorsMadeInPlanning} = P_{ProducingFaultyPlan}\cdot P_{RecognizeFaultyTrack}\cdot P_{CaptainVerify}$$
$$= 1.336\cdot 10^{-2}\cdot 0.002\cdot 0.01$$
$$=2.673\cdot 10^{-7}$$

$$P_{PlannedTrackUnsafe} = (P_{IncorrectPlanningInformation} + P_{ErrorMadeInPlanning}\cdot P_{IntersectHazard})\cdot P_{NotDiscovered}$$
$$= (4.58\cdot 10^{-4} + 2.673\cdot 10^{-7}\cdot 0.5)\cdot 0.01$$
$$= 4.581\cdot 10^{-6}$$

Piloting

$$P_{FixNotCorrect} = (P_{Sensor} + P_{Measurement} + P_{PlotFix})\cdot P_{Captain}$$
$$= (9.5\cdot 10^{-4} + 0.001 + 0.001)\cdot 0.01$$
$$= 2.95\cdot 10^{-5}$$

$$P_{DifferenceErrorNotDetectedByMeasurement} = (P_{MateFailsToDetect}\cdot P_{CaptainFailsToDetect}) + P_{FixNotCorrect}$$
$$= (0.001\cdot 0.01) + 2.95\cdot 10^{-5}$$
$$= 3.95\cdot 10^{-5}$$

$$P_{DifferenceErrorNotDetectedVisually} = P_{Indication} + P_{Visibility} + (P_{Lookout}\cdot P_{Mate}\cdot P_{Captain})$$
$$= 0.5 + 0.25 + (0.001)^3$$
$$= 0.750$$

$$P_{DifferenceErrorNotDetected} = P_{DifferenceErrorNotDetectedByMeasurement}\cdot P_{DifferenceErrorNotDetectedVisually}$$
$$= 3.95\cdot 10^{-5}\cdot 0.750$$
$$= 2.963\cdot 10^{-5}$$

$$P_{InsufficientAction} = P_{CaptainFailsToCorrect}\cdot (P_{Order} + P_{Response})$$
$$= 0.01\cdot (0.003+0.003)$$
$$= 6.0\cdot 10^{-5}$$

$$P_{PilotingError} = P_{DifferenceErrorNotDetected} + P_{InsufficientAction}$$
$$= 2.963 \cdot 10^{-5} + 6.0 \cdot 10^{-5}$$
$$= 8.963 \cdot 10^{-5}$$

$$E_{PilotingErrorRate} = 8.963 \cdot 10^{-5} \cdot \lambda_{AverageFixRate}$$
$$= 8.963 \cdot 10^{-5} \cdot (1/3)$$
$$= 2.988 \cdot 10^{-5} \text{ errors/min}$$

$$P_{CourseDeviatesFromPlan\text{-}StraightTrack} = P_{OutsideChannel} \cdot P_{ErrorWhenOutsideChannel}$$
$$= 0.023 \cdot (1 - e^{-EPilotingErrorRate \cdot T(OutOfChannel)})$$
$$= 0.023 \cdot (1 - e^{-(0.00002988 \cdot 7.108)})$$
$$= 4.884 \cdot 10^{-6}$$

$$P_{NoFix\text{-}LeftTurn} = e^{-\lambda AverageFixRate \cdot T(UntilOutsideChannel\text{-}LeftTurn)}$$
$$= e^{-(1/3) \cdot (8.089/60)}$$
$$= 0.956$$

$$P_{NoFix\text{-}RightTurn} = e^{-\lambda AverageFixRate \cdot T(UntilOutsideChannel\text{-}RightTurn)}$$
$$= e^{-(1/3) \cdot (24.267/60)}$$
$$= 0.874$$

$$P_{CourseDeviatesFromPlan\text{-}Turn} = 1 - [1 - P_{FailToTurn} \cdot P_{CaptainFailsToDetectFailure} \cdot P_{NoFix\text{-}LeftTurn}]^{NumberOfLeftTurns} \cdot [1 - P_{FailToTurn} \cdot P_{CaptainFailsToDetectFailure} \cdot P_{NoFix\text{-}RightTurn}]^{NumberOfRightTurns}$$
$$= 1 - [1 - 0.001 \cdot 0.01 \cdot 0.956]^{10} \cdot [1 - 0.001 \cdot 0.01 \cdot 0.874]^{10}$$
$$= 1.830 \cdot 10^{-4}$$

$$P_{CourseDeviatesFromSafeDesiredTrack} = (P_{CourseDeviatesFromPlan\text{-}StraightTrack} + P_{CourseDeviatesFromPlan\text{-}Turn}) \cdot P_{IntersectsHazard}$$
$$= (4.884 \cdot 10^{-6} + 1.830 \cdot 10^{-4}) \cdot 0.5$$
$$= 9.394 \cdot 10^{-5}$$

$$P_{PoweredGrounding} = P_{PlannedTrackUnsafe} + P_{CourseDeviatesFromSafeDesiredTrack}$$
$$= 4.581 \cdot 10^{-6} + 9.394 \cdot 10^{-5}$$
$$= 9.852 \cdot 10^{-5}$$

Drift Grounding

$$P_{AdverseEnvironmentalConditions} = 0.25$$

$$P_{LostWay} = 1 - e^{-TotalTransitTime \cdot \lambda Drift}$$
$$= 1 - e^{-TotalTransitTime \cdot AccidentQuotient \cdot VesselSpeed}$$
$$= 1 - e^{-5.214 \cdot 0.0000045 \cdot 13.8094} \quad \text{; VesselSpeed = 12 knot = 13.8094 mph}$$
$$= 3.240 \cdot 10^{-4}$$

$$P_{AnchorFailure} = 0.25$$

$$P_{AssistanceFailure} = 0.25$$

$$
\begin{aligned}
P_{DriftGrounding} &= P_{AdverseEnvironmentalConditions} \cdot P_{LostWay} \cdot P_{AnchorFailure} \cdot P_{AssistanceFailure} \\
&= 0.25 \cdot 3.240 \cdot 10^{-4} \cdot 0.25 \cdot 0.25 \\
&= 5.063 \cdot 10^{-6}
\end{aligned}
$$

Total Probability of Grounding

$$
\begin{aligned}
P_{Grounding} &= P_{PoweredGrounding} + P_{DriftGrounding} \\
&= 9.852 \cdot 10^{-5} + 5.063 \cdot 10^{-6} \\
&= 1.0358 \cdot 10^{-4}
\end{aligned}
$$

Appendix IV

Additional Definitions of PSFs and MOFs

The following PSFs and MOFs, even though important in some cases, are considered to have less of an impact on the specific human errors/tasks identified in the grounding analysis. In the case that some of the PSFs or MOFs identified here are found to be important to the grounding analysis, these factors may be added to the pairwise comparison.

Definitions of PSFs

Emotions
Emotions refer to a state of agitation or disturbance which may reduce the normal ability to perform the required task. This may be caused by interpersonal conflicts or personal problems such as death or illness in the family, relationship problems, etc. [31].

Panic
The term panic refers to a sudden overpowering fear which may result in degraded performance. This fear may be caused by an emergency situation, weather conditions, etc. [31].

Anxiety
Anxiety refers to a state of uneasiness and distress about future uncertainties. This state may be caused by an emergency situation, a situation in which the individual faces the possibility of losing the job, etc. [31].

Lack of Self-Discipline
Lack of self-discipline refers to an inadequate ability of an individual to control personal conduct. Examples of this include loss of temper, or other types of unprofessional conduct [31].

Injury
Injury refers the physical damage to the body in which the pain causes loss of physical and mental abilities [31]. Examples of this include head injury, injured fingers, severe burns, etc.

Physical Illness
Physical illness refers to sickness which decreases the normal ability to perform. Examples of physical illness include colds and flu, hallucinations due to fever, headaches, seasickness, exposure to toxic substances, etc. [31].

Mental Impairment
Mental impairment involves diminished mental ability which reduces the ability to perform the mental part of a task [31].

Mental Illness
Mental illness concerns psychotic behavior, depression, hallucinations, or other forms of abnormal behavior [31].

Deliberate Misaction
Deliberate misaction includes purposely taking incorrect action or failing to take correct action. Examples of deliberate misaction include dereliction of duty, refusal to obey commands, etc. [31].

Poor Operations
Poor operations refer to the situation in which individuals or group of individuals degrade the shipboard environment in such a way that the performance of some tasks is difficult. Examples of this include ship maneuvers which result in balance and restraint difficulties, or personnel performing tasks which interfere with those performing other tasks [31].

Poor Maintenance
Poor maintenance concerns the failure to keep any part of ship or equipment in the condition it was design to function within a design's operation period [31]. This includes inadequate replacement parts and tools to perform proper maintenance.

Low Morale
Low morale relates to the problem with groups of individuals as shown by reduced willingness, confidence, or discipline to perform assigned duties. Low morale may be due to interpersonal conflicts amongst the crew, officers with poor interpersonal skills, lack of a strong corporate or shipboard safety culture, or excessively long hours of duty [31].

Definitions of MOFs

Discipline
Discipline refers to the failure to ensure that personnel submit to authority, regulations, and procedures. This includes tolerating unqualified personnel, not enforcing regulations and procedures, or tolerating inappropriate insubordination [31].

Organizational Knowledge
Organizational knowledge applies to the lack of understanding regarding the interactions of organizational subsystems and the way in which work is actually accomplished [15].

Appendix V

Questionnaires Utilized for Pairwise Comparisons

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Motivati
2	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical
3	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
4	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical
5	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
6	Physical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability

Abbreviation	Definition
Goal	Failure to Initiate and Carry Out Planning Correctly
Inattent	Inattention
Motivati	Lack of Motivation
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Formaliz
2	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Coordina
3	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Coordina

Abbreviation	Definition
Goal	Inattention
Workload	Workload (Work hours/breaks, manning, etc.)
Formaliz	Formalization
Coordina	Coordination of Work

Lack of Motivation

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Workload
2	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Benefits
3	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Resource
4	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Quality
5	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
6	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Benefits
7	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Resource
8	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Quality
9	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
10	Benefits	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Resource
11	Benefits	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Quality
12	Benefits	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
13	Resource	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Quality
14	Resource	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
15	Quality	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati

Abbreviation	Definition
Goal	Lack of Motivation
Culture	Organizational Culture
Workload	Workload (Work hours/breaks, manning, etc.)
Benefits	Benefits such as salary, insurance and retirement plans, etc.
Resource	Physical Resources
Quality	Quality of Life (Living quarters, food, entertainment, etc.)
Evaluati	Performance Evaluation

Poor Physical Condition

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Quality
2	Workload	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Programs
3	Quality	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Programs

Abbreviation	Definition
Goal	Poor Physical Condition
Workload	Workload (Work hours/breaks, manning, etc.)
Quality	Quality of Life (Living quarters, food, entertainment, etc.)
Programs	Company Programs (Alcohol/drug, fitness, health, etc.)

Poor Performance Ability

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Turnover
2	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
3	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Supervis
4	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
5	Turnover	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
6	Turnover	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Supervis
7	Turnover	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
8	Training	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Supervis
9	Training	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
10	Supervis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati

Abbreviation	Definition
Goal	Poor Performance Ability
Selectio	Personnel Selection
Turnover	Personnel Turnover
Training	Training Process
Supervis	Supervision
Evaluati	Performance Evaluation

Failure of Captain to Detect and Correct Errors

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motivati
2	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Physical
3	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
4	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Proced
5	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives
6	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Physical
7	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
8	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Proced
9	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives
10	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
11	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Proced
12	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives
13	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Proced
14	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives
15	Proced	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives

Abbreviation	Definition
Goal	Failure of Captain to Detect and Correct Errors
Inattent	Inattention
Motivati	Lack of Motivation
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)
Proced	Inadequate Knowledge of Procedures, Standards, and Regulations
Motives	Conflicting Motives Regarding Performance

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Culture	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Formaliz
2	Culture	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training
3	Culture	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover
4	Formaliz	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training
5	Formaliz	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover
6	Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover

Abbreviation	Definition
Goal	Inadequate Knowledge of Procedures, Standards, and Regulations
Culture	Organizational Culture
Formaliz	Formalization
Training	Training Process
Turnover	Personnel Turnover

Conflicting Motives Regarding Performance

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Urgency
2	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Formaliz
3	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Benefits
4	Culture	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
5	Urgency	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Formaliz
6	Urgency	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Benefits
7	Urgency	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
8	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Benefits
9	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
10	Benefits	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati

Abbreviation	**Definition**
Goal	Conflicting Motives Regarding Performance
Culture	Organizational Culture
Urgency	Time Urgency
Formaliz	Formalization
Benefits	Benefits such as salary, insurance and retirement plans, etc.
Evaluati	Performance Evaluation

Failure to Correctly Read Ranges Off Radar

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motivati
2	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Physical
3	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
4	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Architec
5	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Physical
6	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
7	Motivati	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Architec
8	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
9	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Architec
10	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Architec

Abbreviation	**Definition**
Goal	Failure to Correctly Read Ranges Off Radar
Inattent	Inattention
Motivati	Lack of Motivation
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)
Architec	Poor Architectural Features

Poor Architectural Features

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Resource	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Learning

Abbreviation	Definition
Goal	Poor Architectural Features
Resource	Physical Resources
Learning	Organizational Learning

Failure to Correctly Plot Ranges on Chart

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Motivati
2	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical
3	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
4	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical
5	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
6	Physical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability

Abbreviation	Definition
Goal	Failure to Correctly Plot Ranges on Chart
Inattent	Inattention
Motivati	Lack of Motivation
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)

Failure to Detect Difference Error

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Motivati
2	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical
3	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
4	Inattent	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Percept
5	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical
6	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
7	Motivati	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Percept
8	Physical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ability
9	Physical	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Percept
10	Ability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Percept

Abbreviation	Definition
Goal	Failure to Detect Difference Error
Inattent	Inattention
Motivati	Lack of Motivation
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)
Percept	Lack of Perception or Inadequate Situational Awareness

Lack of Perception or Inadequate Situational Awareness

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Coordina	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Com
2	Coordina	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Workload
3	Coordina	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training
4	Coordina	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover
5	Coordina	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Programs
6	Com	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Workload
7	Com	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training
8	Com	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover
9	Com	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Programs
10	Workload	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training
11	Workload	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover
12	Workload	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Programs
13	Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Turnover
14	Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Programs
15	Turnover	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Programs

Abbreviation	Definition
Goal	Lack of Perception or Inadequate Situational Awareness
Coordina	Coordination of Work
Com	Established Lines of Communication
Workload	Workload (Work hours/breaks, manning, etc.)
Training	Training Process
Turnover	Personnel Turnover
Programs	Company Programs (Alcohol/drug, fitness, health, etc.)

Failure to Order Required Course Change

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
2	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
3	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
4	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
5	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
6	Percept	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic

Abbreviation	Definition
Goal	Failure to Order Required Course Change
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)
Percept	Lack of Perception or Inadequate Situational Awareness
Communic	Inadequate Exchange of Information

Communication - Inadequate Exchange of Information

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Com	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Coordina
2	Com	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Formaliz
3	Com	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
4	Coordina	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Formaliz
5	Coordina	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
6	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training

Abbreviation	Definition
Goal	Communication - Inadequate Exchange of Information
Com	Established Lines of Communication
Coordina	Coordination of work
Formaliz	Formalization
Training	Training Process

Failure to Respond to Ordered Course Change

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Physical
2	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
3	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
4	Inattent	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
5	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
6	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
7	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
8	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
9	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
10	Percept	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic

Abbreviation	**Definition**
Goal	Failure to Respond to Ordered Course Change
Inattent	Inattention
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)
Percept	Lack of Perception or Inadequate Situational Awareness
Communic	Inadequate Exchange of Information

Failure to Drop Anchor in Emergency Situation

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Ability
2	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives
3	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
4	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
5	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Responsi
6	Physical	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Environm
7	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Motives
8	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
9	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
10	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Responsi
11	Ability	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Environm
12	Motives	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Percept
13	Motives	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
14	Motives	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Responsi
15	Motives	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Environm
16	Percept	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Communic
17	Percept	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Responsi
18	Percept	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Environm
19	Communic	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Responsi
20	Communic	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Environm
21	Responsi	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Environm

Abbreviation	Definition
Goal	Failure to Drop Anchor in Emergency Situation
Physical	Poor Physical Condition (Fatigue, poor fitness, etc.)
Ability	Poor Performance Ability (Training, experience, and aptitude)
Motives	Conflicting Motives Regarding Performance
Percept	Lack of Perception or Inadequate Situational Awareness
Communic	Inadequate Exchange of Information
Responsi	Unawareness of Responsibilities
Environm	Hazardous Natural Environment (Weather, shallow water, etc.)

Unawareness of Responsibilities

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Coordina	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Formaliz
2	Coordina	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Com
3	Coordina	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
4	Coordina	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Turnover
5	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Com
6	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
7	Formaliz	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Turnover
8	Com	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
9	Com	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Turnover
10	Training	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Turnover

Abbreviation	**Definition**
Goal	Unawareness of Responsibilities
Coordina	Coordination of Work
Formaliz	Formalization
Com	Established Lines of Communication
Training	Training Process
Turnover	Personnel Turnover

Failure to Request Assistance in Emergency Situation

Node: 20000

Compare the relative IMPORTANCE with respect to: Ability < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Turnover
2	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
3	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Supervis
4	Selectio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
5	Turnover	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Training
6	Turnover	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Supervis
7	Turnover	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
8	Training	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Supervis
9	Training	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati
10	Supervis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Evaluati

Abbreviation	Definition
Goal	Failure to Request Assistance in Emergency Situation
Ability	Poor Performance Ability (Training, experience, and aptitude)
Selectio	Personnel Selection
Turnover	Personnel Turnover
Training	Training Process
Supervis	Supervision
Evaluati	Performance Evaluation

Appendix VI

Abbreviations used for the MOFs

Abbreviation	**Definition**
Benefits	Benefits
Com	Communication
Coordination	Coordination of Work
Culture	Organizational Culture
Evaluation	Performance Evaluation
Formalization	Formalization
Learning	Organizational Learning
Programs	Company Programs
Resources	Physical Resources
Selection	Personnel Selection
Supervision	Supervision
Training	Training Programs
Turnover	Turnover
Urgency	Time Urgency
Workload	Workload
Quality	Quality of Life

Appendix VII

Company Rating

Rate each factor with respect to the company by crossing off in the appropriate box

		Inadequate	Adequate	Excellent
MOF1:	Benefits			
MOF2:	Communication			
MOF3:	Coordination			
MOF4:	Culture			
MOF5:	Evaluation			
MOF6:	Formalization			
MOF7:	Learning			
MOF8:	Programs			
MOF9:	Quality			
MOF10:	Resources			
MOF11:	Selection			
MOF12:	Supervision			
MOF13:	Training			
MOF14:	Turnover			
MOF15:	Urgency			
MOF16:	Workload			

Appendix VIII

Assigning of Rating Values

In the case that a factor is rated inadequate, the value of 1 should be assigned.
In the case that a factor is rated excellent, the value of 0 should be assigned.
In the case that a factor is rated adequate, the value specified for each HEP should be assigned.

HEP1: Procedures with no check-off provisions

Inadequate = 1, Adequate = 0.250, Excellent = 0

Uncertainty: 0.008

	Ranking	Rating value	Weight (RankingxRatingValue)
MOF1	0.0660		0
MOF3	0.0223		0
MOF4	0.1243		0
MOF5	0.0787		0
MOF6	0.0400		0
MOF8	0.0550		0
MOF9	0.1497		0
MOF10	0.0443		0
MOF11	0.0860		0
MOF12	0.0363		0
MOF13	0.0337		0
MOF14	0.0517		0
MOF16	0.2120		0
Modified HEP1:		0.0010	

HEP2: Procedures with check-off provisions

Inadequate = 1, Adequate = 0.259, Excellent = 0

Uncertainty: 0.0027

	Ranking	Rating value	Weight (RankingxRatingValue)
MOF1	0.0660		0
MOF3	0.0223		0
MOF4	0.1243		0
MOF5	0.0787		0
MOF6	0.0400		0
MOF8	0.0550		0
MOF9	0.1497		0
MOF10	0.0443		0
MOF11	0.0860		0
MOF12	0.0363		0
MOF13	0.0337		0
MOF14	0.0517		0
MOF16	0.2120		0
Modified HEP2:		0.0003	

HEP3:	Writing procedural item		
Inadequate = 1, Adequate = 0.167, Excellent = 0			
Uncertainty:	0.0144		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0660		0
MOF3	0.0223		0
MOF4	0.1243		0
MOF5	0.0787		0
MOF6	0.0400		0
MOF8	0.0550		0
MOF9	0.1497		0
MOF10	0.0443		0
MOF11	0.0860		0
MOF12	0.0363		0
MOF13	0.0337		0
MOF14	0.0517		0
MOF16	0.2120		0
Modified HEP3:		0.0006	

HEP4:	Writing procedural item with arithmetic		
Inadequate = 1, Adequate = 0.259, Excellent = 0			
Uncertainty:	0.027		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0660		0
MOF3	0.0223		0
MOF4	0.1243		0
MOF5	0.0787		0
MOF6	0.0400		0
MOF8	0.0550		0
MOF9	0.1497		0
MOF10	0.0443		0
MOF11	0.0860		0
MOF12	0.0363		0
MOF13	0.0337		0
MOF14	0.0517		0
MOF16	0.2120		0
Modified HEP4:		0.0030	

HEP5:	Check chart recorder with limits		
Inadequate = 1, Adequate = 0.245, Excellent = 0			
Uncertainty:	0.0053		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0490		0
MOF3	0.0373		0
MOF4	0.1517		0
MOF5	0.0530		0
MOF6	0.1590		0
MOF8	0.0313		0
MOF9	0.0940		0
MOF10	0.0270		0
MOF11	0.0403		0
MOF12	0.0207		0
MOF13	0.0483		0
MOF14	0.0740		0
MOF15	0.0247		0
MOF16	0.1890		0
Modified HEP5:		0.0007	

HEP6:	Hands-on type checking		
Inadequate = 1, Adequate = 0.167, Excellent = 0			
Uncertainty:	0.048		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0490		0
MOF3	0.0373		0
MOF4	0.1517		0
MOF5	0.0530		0
MOF6	0.1590		0
MOF8	0.0313		0
MOF9	0.0940		0
MOF10	0.0270		0
MOF11	0.0403		0
MOF12	0.0207		0
MOF13	0.0483		0
MOF14	0.0740		0
MOF15	0.0247		0
MOF16	0.1890		0
Modified HEP6:		0.0020	

HEP7:	Reading a digital display		
Inadequate = 1, Adequate = 0.259, Excellent = 0			
Uncertainty:	0.0027		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0483		0
MOF3	0.0270		0
MOF4	0.0750		0
MOF5	0.0567		0
MOF6	0.0483		0
MOF7	0.0640		0
MOF8	0.0657		0
MOF9	0.1560		0
MOF10	0.1027		0
MOF11	0.0877		0
MOF12	0.0503		0
MOF13	0.0353		0
MOF14	0.0260		0
MOF16	0.1573		0
Modified HEP7:		0.0003	

HEP8:	Record readings		
Inadequate = 1, Adequate = 0.259, Excellent = 0			
Uncertainty:	0.0027		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0617		0
MOF3	0.0253		0
MOF4	0.0923		0
MOF5	0.0777		0
MOF6	0.0457		0
MOF8	0.0737		0
MOF9	0.1550		0
MOF10	0.0343		0
MOF11	0.1193		0
MOF12	0.0640		0
MOF13	0.0480		0
MOF14	0.0447		0
MOF16	0.1577		0
Modified HEP8:		0.0003	

HEP9:	**Check reading with limits**		
Inadequate = 1, Adequate = 0.259, Excellent = 0			
Uncertainty:	0.0027		**Weight**
	Ranking	**Rating value**	**(RankingxRatingValue)**
MOF1	0.0257		0
MOF2	0.1047		0
MOF3	0.1357		0
MOF4	0.0397		0
MOF5	0.0337		0
MOF6	0.1427		0
MOF8	0.0583		0
MOF9	0.0720		0
MOF10	0.0147		0
MOF11	0.0530		0
MOF12	0.0257		0
MOF13	0.0553		0
MOF14	0.0423		0
MOF16	0.1967		0
Modified HEP9:		0.0003	

HEP10:	**Nonpassive task error of commission**		
Inadequate = 1, Adequate = 0.25, Excellent = 0			
Uncertainty:	0.008		**Weight**
	Ranking	**Rating value**	**(RankingxRatingValue)**
MOF2	0.2427		0
MOF3	0.1087		0
MOF5	0.0183		0
MOF6	0.0523		0
MOF8	0.0893		0
MOF9	0.0400		0
MOF11	0.0667		0
MOF12	0.0293		0
MOF13	0.1427		0
MOF14	0.0757		0
MOF16	0.1350		0
Modified HEP10:		0.0010	

HEP11:	Recalling two instructions given orally		
Inadequate = 1, Adequate = 0.25, Excellent = 0			
Uncertainty:	0.008		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF2	0.2047		0
MOF3	0.1070		0
MOF5	0.0070		0
MOF6	0.1683		0
MOF8	0.1333		0
MOF9	0.0890		0
MOF11	0.0253		0
MOF12	0.0113		0
MOF13	0.0920		0
MOF14	0.0220		0
MOF16	0.1407		0
Modified HEP11:		0.0010	

HEP12:	Diagnosis - Dropping anchor		
Inadequate = 1, Adequate = 0.2105, Excellent = 0			
Uncertainty:	0.95		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.01586		0.00
MOF2	0.1604		0.00
MOF3	0.0634		0.00
MOF4	0.1530		0.00
MOF5	0.0320		0.00
MOF6	0.1456		0.00
MOF8	0.0592		0.00
MOF9	0.0346		0.00
MOF11	0.0412		0.00
MOF12	0.0208		0.00
MOF13	0.1061		0.00
MOF14	0.0504		0.00
MOF15	0.0616		0.00
MOF16	0.0557		0.00
Modified HEP12:		0.0500	

Note: The ranking values are changed in order to remove the factor regarding the natural environment from the equation

HEP13: Diagnosis - Requesting assistance			
Inadequate = 1, Adequate = 0.2105, Excellent = 0			
Uncertainty:	0.95		Weight
	Ranking	Rating value	(RankingxRatingValue)
MOF1	0.0138		0
MOF2	0.1992		0
MOF3	0.0865		0
MOF4	0.1399		0
MOF5	0.0272		0
MOF6	0.1323		0
MOF8	0.0489		0
MOF9	0.0186		0
MOF11	0.0227		0
MOF12	0.0103		0
MOF13	0.1099		0
MOF14	0.0538		0
MOF15	0.0524		0
MOF16	0.0845		0
Modified MOF13:		0.0500	

Note: The ranking values are changed in order to remove the factor regarding the natural environment from the equation

Appendix IX

Probability of Grounding - Company for which all MOFs are rated excellent

P(ProducingFaultyPlan):	0.0037277
P(ErrorsMadeInPlanning):	5.2188E-09
P(PlannedTrackUnsafe):	9.1601E-07
P(FixNotCorrect):	3.10000E-06
P(DifferenceErrorNotDetectedByMeasurement):	0.0000037
P(DifferenceErrorNotDetectedVisually):	0.75
P(DifferenceErrorNotDetected):	2.775E-06
P(InsufficientAction):	0.000004
P(PilotingError):	6.775E-06
E(PilotingErrorRate):	2.2583E-06
P(CourseDeviatesFromPlan-StraightTrack):	3.6452E-07
P(NoFix-LeftTurn):	0.95605591
P(NoFix-RightTurn):	0.87387611
P(CourseDeviatesFromPlanInTurn):	1.098E-05
P(CourseDeviatesFromSafeDesiredTrack):	5.672E-06
P(AdverseEnvironmentalConditions):	0.25
P(LostWay):	0.000324
P(AnchorFailure):	0.0500
P(AssistanceFailure):	0.0500
P(PoweredGrounding):	**6.5880E-06**
P(DriftGrounding):	**2.0250E-07**
P(Grounding):	**0.00000679**

Sensitivity Analysis

Percent change compared to company for which all MOFs are rated:

	Powered	Drift	Grounding
Inadequate	-99.54	-99.75	-99.55
Adequate -	-93.29	-96.00	-93.44
Excellent -	0.00	0.00	0.00