An Assessment of the Role of Human Factors in Oil Spills from Vessels

Report to Prince William Sound RCAC

Photo: M/V Selendang Ayu grounding and oil spill, Unalaska, Alaska (Nuka Research, 2005)

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Prepared By:

Elise DeCola and Sierra Fletcher
Nuka Research & Planning Group, LLC.
P.O. Box 175 Seldovia, Alaska 99663
contact@nukaresearch.com

Research & Planning Group, LLC.

About the Authors

This report was prepared by Elise DeCola and Sierra Fletcher of Nuka Research and Planning Group, LLC.

Elise DeCola has published extensively in the field of oil spill prevention and response. She began her career as a policy analyst in the Rhode Island Senate, where she researched and developed legislation to strengthen oil spill prevention requirements for oil-laden vessels following the 1996 *North Cape* oil spill. For the past decade, she has actively participated in oil spill planning projects throughout the US, and has participated in marine transportation risk assessments in New England and Alaska. She has developed and reviewed oil spill contingency plans and emergency operations manuals for production platforms, storage facilities and pipelines in Alaska, the Gulf of Mexico, and West Africa. Ms. DeCola has participated in the design, execution, and critique of dozens of oil spill drills, exercises, equipment trials, and training programs. She holds BS in Environmental Science from the College of William and Mary in Virginia and an MA in Marine Affairs from the University of Rhode Island.

Sierra Fletcher, a Nuka Research project manager, does research, writing, and facilitation work in the environmental and conflict resolution fields. She has worked on projects in the US, Cambodia, Middle East, Afghanistan, India, and Pakistan. Her experience includes designing and facilitating workshop and consensus-building opportunities for both youth and adults; researching and advising on energy and environmental issues; and writing proposals and reports for the projects of US government agencies, multilateral institutions, and private foundations. Ms. Fletcher has a B.A. from Yale University in Anthropology, and a Master's in Law and Diplomacy from the Fletcher School at Tufts University.

The opinions expressed in this PWSRCAC-commissioned report are not necessarily those of PWSRCAC.

Executive Summary

Human factors - either individual errors or organizational failures - have been reported to cause as much as 80% of oil spills and marine accidents. Improvements to oil spill prevention technologies, tanker design, and systems engineering are often cited, along with improved regulatory oversight, as contributors to a general decline in the number of marine oil spills over the last decade. Yet, oil spills and industrial accidents continue to occur. This is due, in part, to the fact that human and organizational errors continue to occur despite, or sometimes because of, improved technologies.

The Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) commissioned this report to consider the role of human factors in oil spills, the relationship between technological improvements and human factors, and complementary prevention measures that may further reduce the risk of oil spills attributed to human or organizational errors. The fundamental research question addressed in this report is: *Where should we focus prevention efforts to reduce oil spills from tankers that are caused by human factors?*

The study of human factors is based on the acknowledgement that human characteristics and behaviors are intrinsically linked with the functioning of the technology people design, build, maintain, and operate. The human-technology relationship works in both directions, though. Not only do humans impact the functioning of our technology, but technology can also influence human decisions and actions. This report considers the complex nature of human-technological interactions in the context of spills from crude oil tankers and considers the potential implications of technological improvements, including the ongoing phase-in of double hulled, redundant tankers, to the overall risk of oil spills from tankers.

This report presents general concepts related to human error, human factors, and accident causality by synthesizing published literature that considers the types of human errors and underlying human factors that commonly cause oil spills or accidents. In an attempt to relate root causes to prevention strategies that target human factors, this report reviews oil spill and marine accident data compilation and analysis practices in the US and internationally. Prevention programs and voluntary practices that target human factors are reviewed, and recommendations presented for linking spill prevention to human factors data and analysis.

Published studies suggest that technological changes and improvements do not necessarily reduce the likelihood of a human-caused spill or accident. In fact, technological improvements may *increase* accident risks due to increased complexity of the system, skills- or knowledge-based lapses in operator abilities, or risk compensation behavior at the individual or organizational level. Increased automation often results in reduced manning levels, which can increase the number and complexity of job tasks assigned to each operator while simultaneously removing or reducing the operator's ability to bypass or override automated systems in an emergency.

While research shows that most crude oil tanker accidents involve the interaction between humans, organizations, and systems or equipment, oil spill and accident prevention measures are often disproportionately focused on the engineering or technological "fixes," since these are the most easily remedied. Technology-based prevention measures such as double hulls and redundant systems can reduce the severity of an oil spill caused by groundings or collisions, but they cannot interrupt the chain of events that may cause the accident to occur in the first place. Therefore, in coming years as double-hulled oil tankers are phased in, human factors will remain a crucial component of oil spill prevention systems in the PWS tanker trade and worldwide.

Human performance breakdowns are rarely the result of a random error, but more likely the result of a poor conscious choice or decision. As such, it is extremely difficult to isolate the specific human factor or factors that cause accidents; yet, this level of specificity is necessary in order to correct the problem. When an accident is attributed to operator error, the first reaction is often to "correct" the problem by adding training or replacing an individual operator or class of operators; however, this will not prevent a problem from recurring. Instead, a systematic analysis is required to determine *why* the operator made the error, in order to intervene at the appropriate point.

Human factors can never be eliminated from the human-constructed marine transportation industry; however, by studying past accidents or spills and drawing lessons from the maritime and other industries in general, we can build an understanding of the dominance of the human-technology interface to guide and enhance oil spill prevention efforts. The research and practical experience described in this report identify several opportunities to improve both our understanding of the contribution of human factors to oil spills from tankers and the implementation of prevention measures that effectively target these human factors. These include:

- Improving and standardizing data collection methods to recognize human factors in accident causality and to access marine insurance claim data;
- Recognizing the relative contributions of individuals, groups, and organizations in assessing human factors;
- Creating a mandatory near miss reporting system for the U.S. maritime industry and analyzing near miss data for lessons learned;
- Promoting and applying best industry practices that have been recognized to reduce accident and spill risks from human factors;

- Incorporating human factors analyses into risk assessments for oil spills from vessels;
- Focusing on crew endurance management and other practices to reduce fatigue;
- Integrating human factors considerations into systems engineering;
- Considering human factors implications in developing and implementing new regulations;
- Promoting a safety culture across the marine oil transportation industry; and
- Measuring the effectiveness of prevention programs and safety initiatives that target human factors.

This report considers the complex and dynamic interaction between human operators and engineered systems and concludes that improved technologies, redundant systems, and enhanced automation generally do not prevent oil spills caused by human error. These systems can prevent a spill from occurring if the inner hull is not punctured, or significantly reduce the impact or severity of an oil spill once it occurs; however, they cannot prevent the human or organizational errors that cause such accidents. Moreover, technological and engineering improvements in the marine sector have been shown, in some cases, to actually increase the risk of an oil spill or accident occurring due to human factors such as fatigue, skill or knowledge deficiencies, or risk compensation.

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1 Introduction

The US oil tanker fleet, including those vessels involved in the Trans-Alaska Pipeline System (TAPS) trade in Prince William Sound (PWS), has undergone major engineering and structural improvements to comply with the double hull and prevention systems requirements of the Oil Pollution Act of 1990 (OPA 90). These improvements have contributed to an overall reduction in spills from vessels in Alaska and worldwide over the last 15 years (Ventikos & Psaraftis, 2004). However, oil spills are not caused by technology alone; often, the people or organizations operating the technology are at fault. An article by the US Coast Guard historian states that human error "has been consistently the major cause of [vessel] casualties in the post-World War II era (Browning, 2004)." Rothblum (2005) points out that regardless of technological improvements, the maritime system is a *people* system, and will thus always be influenced by human error. Therefore, oil spill prevention measures must target human factors to reduce the overall occurrence of marine oil spills.

As naval engineering and spill prevention technologies continue to advance, US and international regulatory bodies and safety organizations have begun to focus more intensely on prevention measures that target human factors. The Coast Guard's "Prevention through People" (PTP) initiative is founded on the premise that human factors are the root cause of most marine casualties and therefore should be the target of safety and prevention programs (USCG, 2004). The International Maritime Organization (IMO) has a mandatory safety management code aimed at promoting a safety culture in the international shipping industry (IMO, 2002). Trade organizations such as the American Waterways Operators (AWO) and the International Federation of Independent Tanker Owners (Intertanko) promote best practices through a variety of outreach programs and voluntary compliance measures.

1.1 Purpose of this Report

The Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) commissioned this report to consider the role of human factors in oil spills, the relationship between technological improvements and human factors, and complementary prevention measures that may further reduce the risk of oil spills attributed to human or organizational errors.

The fundamental research question addressed in this report is: *Where should we focus prevention efforts to reduce oil spills from tankers that are caused by human factors?* After describing human factors in general, this report addresses that question in four parts:

- What do we know about the contribution of human factors to oil spills?
- How can we use oil spill data and analytic tools to understand human factors risks?
- What options exist to prevent/mitigate spills caused by human factors?
- What is the relationship between oil spill prevention technologies (such as double hulls) and human factors?

Section 2 of this report addresses the first question by discussing human factors terminology and synthesizing information from published literature that considers the types of human errors and underlying human factors that commonly cause oil spills or accidents.

Section 3 addresses the second question by presenting a brief discussion of how oil spill and marine accident data is compiled and analyzed in the US and internationally, and considers how improved data management and analytic techniques can be combined to improve our understanding of oil spill risks in the marine industry.

Section 4 discusses prevention measures and interventions that have been used to address the human factors described in Section 2. Emphasis is placed on published reports, and examples are provided from human factors prevention programs at the industry, state, national, and international levels.

Section 5 returns to the question of how technological improvements relate to the overall risk of oil spills caused by human factors. Recommendations are made for improving oil spill prevention in human and organizational systems to keep pace with technological changes in the tanker industry.

1.2 Interactions between Human and Engineered Systems

The study of human factors is based on the acknowledgement that human characteristics and behaviors are intrinsically linked with the functioning of the technology people design, build, maintain, and operate. The human-technology relationship works in both directions, though. Not only do humans impact the functioning of our technology, but technology can also influence human decisions and actions.

As the vessels that transport oil become increasingly reliant on engineered systems and automated technologies, the humans that operate these systems are subjected to new challenges that may actually increase accident risks. And while accident risks with a technological basis can often be remedied through engineering, accidents that involve human-technology interactions are much more difficult to address.

This report considers the complex and dynamic interactions between human operators and organizations and the engineered systems they design, maintain, and operate. This report attempts to synthesize academic theories, published studies, and actual experience from the maritime community to draw conclusions about how human-technological interactions impact the risks of marine accidents, and to transfer those conclusions to the PWS crude oil tanker trade.

1.3 Challenges Encountered in Addressing the Research Questions

PWSRCAC commissioned this report to improve their understanding of oil spill risks from OPA 90 tankers. Earlier drafts of this report sought to quantify the relative contribution of specific human factors to oil spills and marine accidents in order to correlate those causative factors to appropriate prevention measures. However, as described in this report, existing data sources are not sufficient to quantify the specific human factors most likely to cause a tanker spill in PWS. Likewise, human factors-related prevention programs are difficult to assess quantitatively. While studies have been conducted of human factors in maritime accidents from a variety of angles, the complexity of the concept itself makes it ill suited to precise numbers and quantitative analysis. Fortunately, there is a wide body of literature available from the marine industry and other industrial processes that describe and analyze human factors in industrial accidents and oil spills, and these articles inform on many of the questions posed by PWSRCAC. This report considers what we do know from the available literature about human factors, based on the understanding that they are universal, if nuanced, in maritime operations and that lessons learned through accident investigations and human factors studies both within and beyond the marine industry are informative on this topic.

2 What are Human Factors?

2.1 Human Factors and Human Errors: Overview of the Terminology

Various terms are used to describe the complex interaction between technology and the individuals and organizations that design, build, and use technology-based systems. In general, the term "human factor" is used to describe accident causality when cause is attributed to the characteristics or behavior of an individual or organization, rather than structural or mechanical failure or some environmental or other contextual factors that are outside our control. "Human errors," on the other hand, are the mistakes people make—often resulting from these human factors.

Other terms may be used to describe human factors; the IMO, for example, uses "human element" to describe the same basic concept of the human side of the human-technology interface.

Human errors and human factors are often studied separately; therefore, the relationship between them is often overlooked. Gordon (1998) proposes a framework for describing the relationships between underlying human factors and more immediately evident human errors, as shown in Figure 1. Gordon categorizes human factors as individual, group, or organizational, and follows the Rasmussen model (Rasumussen, "Perceptions on the Concept of Human Error," 1993 in Gordon, 1998) of categorizing human errors as skills-based, rule-based, or knowledge-based. 1

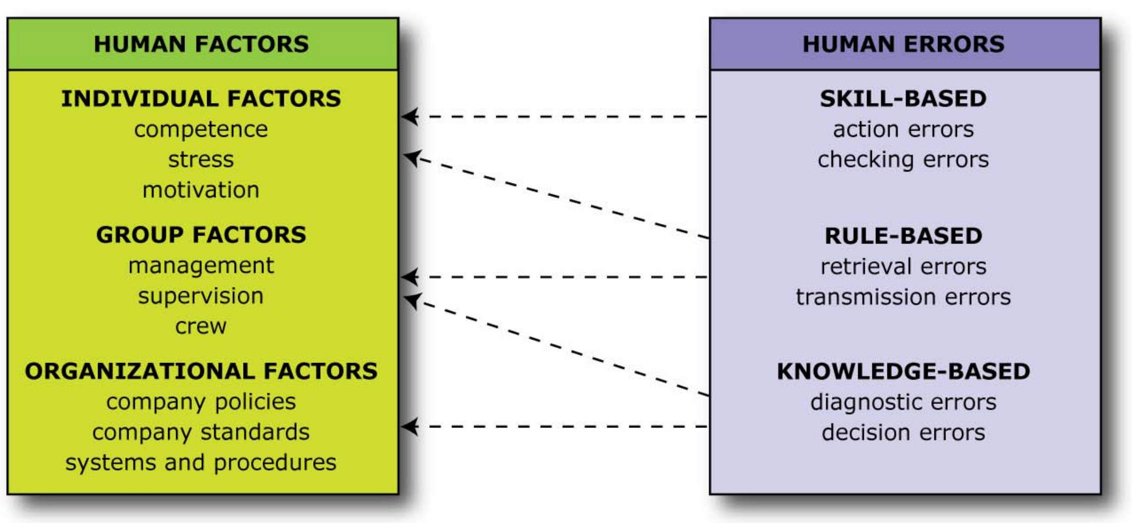

Figure 1. Human factors vs. Human errors (based on Gordon, 1998)

2.2 Types of Human Errors

Human errors are specific acts that either directly (active errors) or indirectly (latent errors) cause an incident. The effects of active errors are usually realized almost immediately, while the consequences of latent errors may lie dormant within the system for a long period of time, until they combine with other factors to compromise the system and lead to an accident (Gordon, 1998).

A skill-based human error might occur when an operator is distracted or preoccupied with another task and allows a mistake to occur. In rule-based or knowledge-based errors, attention may not stray far from the problem, but problem-solving failures may occur due to application of an incorrect rule (rule-based) or lack of familiarity with the problem (knowledge-based). (Gordon, 1998)

The US Coast Guard's (USCG) risk-based decision-making guidelines categorize human error into four categories, which form a matrix: intentional errors, unintentional errors, errors of omission, and errors of commission (Figure 2).

An intentional error is an action committed or omitted deliberately, because of a perception that there is a better or equally effective way to perform the task or step. This can be a shortcut that may not be recognized as a mistake until other conditions arise that result in a noticeable problem. An intentional error may also be committed or omitted because the worker misdiagnosed the system's problem or need. At best, such an action delays the correct response; at worst, it compounds the problem. Intentional errors do not include acts of sabotage. An unintentional error is an act committed or omitted accidentally, with no prior thought; therefore, intentional errors have also been referred to as "routine violations" (Lynch, 2006). An error of omission occurs when an operator fails to perform a step or task. An error of commission occurs when an operator performs a step or task incorrectly (USCG, 2006).

2.3 Types of Human Factors

Gordon (1998) proposes three categories for human factors that contribute to accidents in the offshore oil industry, including tanker operations: individual factors, group factors, and organizational factors (in Figure 1, above). Other researchers focus on individual vs. organizational causes.

Researchers have found that although the majority of immediate causes are attributable to individuals (e.g. operating personnel), the majority of contributing, or underlying, factors can be attributed to the organizational context or group dynamics that influence the individual. Similarly, once an accident sequence has begun, organizational influences may allow the sequence to continue, resulting in an accident. Therefore, the culture, incentives, operating procedures, and policies of organizations have important effects on the safety of marine systems (Hee *et al.,* 1999).

Figure 2. USCG Error Categories (USCG, 2006).

2.4 Organizational Factors

Several studies and case reviews have found that *organizational* factors may be the most critical in considering human factors contributions to oil spills. At the *organizational level,* various factors may contribute to an increase in incidents and accidents, including cost-cutting programs and the level of communication between work-sites (Gordon, 1998).

Pate-Cornell and Murphy (1996) studied organizational factors across several industries and found that operators are generally predictable and well intentioned, and that often "errors" were caused not by lapsed judgment or operator error, but because of their work environment, incentives system, or information availability. Pate-Cornell and Murphy noted a common lack of realization, on the part of managers, regarding the actual implications of company policies.

Pate-Cornell and Murphy (1996) point out those organizational problems are often at the root of human or operator errors. For example, "unofficial" incentives to cut costs or improve efficiency might lead operators to take short cuts that increase accident risks. With the shipping industry often seeking to fill positions quickly, hiring practices and shipboard culture may be such that crew are not fully trained and qualified before being put into a job where their decisions and actions become critical to the safe functioning of the ship system overall (Gordon, 1998).

2.5 Group Factors

At the group level, the relationships among individuals, the members of a vessel crew, for example, or between a supervisor and subordinate, may influence safety. Group factors may overlap with organizational factors, but in the marine oil transportation industry, the dynamics at the group level, such as crews or duty sections, can be extremely important to overall safety (Gordon, 1998).

An important group factor for tanker operations is the atmosphere that exists within operational units, such as a vessel crew. The maritime tradition of "iron men on wooden ships" has been cited as a contributor to risk-taking behavior. Overconfidence or bravado may contribute to actions that violate a company's stated safety policies. Pressure from the organization or company to meet unrealistic demands with the number and qualifications of available personnel may encourage irresponsible or risk-taking behavior as crew stretch to meet demands from supervisors (Pate-Cornell and Murphy, 1996).

Reporting channels are also critical to safety considerations at the group level. Informal communication channels can be as important as or more important than formal ones for encouraging open and proactive communication of safety concerns. Direct communications between operators can be a powerful source of organizational memory and can contribute significantly to accident prevention, especially in regards to maintenance practices. In the marine oil transportation industry, this kind of organizational knowledge is best realized onboard vessels where crew members are retained long-term. With new crewmembers or trainees, it is extremely important that their work be subject to diligent oversight and inspection, as close supervision can have the dual benefits of educating employees while minimizing risks. (Pate-Cornell and Murphy, 1996).

2.5 Individual Human Factors

Although most researchers recognize the importance of the organizational safety culture, the role of the individual operator is critical. The competence, perceptual judgments, stress, motivation, and health risks (such as work over-load) of an individual operator are critical to the chain of events that may cause an accident or oil spill (Gordon, 1998). Two of the most recognized and studied individual factors as related to the maritime industry are described here: inadequate knowledge and fatigue.

2.5.1 Inadequate Knowledge

A National Research Council (NRC) study (1990; cited in Rothblum, 2006) cited inadequate general technical knowledge as the cause of 35% of marine casualties: "Mariners often do not understand how the operation works or under what set of operating conditions it was designed to work effectively." (Rothblum, 2006). In the same study, 78% of mariners ascribed a lack of understanding of the overall system of the ships they work on as a contributing factor to accidents. Moving among different sizes and types of vessels can cause confusion and compromise decision-making abilities if mariners are not familiar with the ship-specific systems (Rothblum, 2006).

When people take actions that increase the risk of failure, it is often because they have encountered a rare event that is not part of their training or general awareness, and they are unaware of how their actions will affect the system or are unaware that they are contributing to accident risk (Pate-Cornell and Murphy, 1996).

> *Mariners are charged with making navigation decisions based on all available information. Too often, we have a tendency to rely on either a favored piece of equipment or our memory. Many casualties result from the failure to consult available information (such as that from a radar or an echo-sounder). In other cases, critical information may be lacking or incorrect, leading to navigation errors (for example, bridge supports often are not marked, or buoys may be off-station). (Rothblum, 2006)*

A 1993 human factors study by the USCG identified the need for automated design approaches that incorporate human factors into the design and use of automated systems, so that operators "will understand the concept of operations and form appropriate mental models during initial learning and routine use." The integration of existing equipment and skills with new systems, such as navigation electronics, was identified as especially important (Mandler and Rothblum, 1993).

While not having adequate information may cause an individual to make an error, the fact that he or she is not adequately trained for his or her position is reflective of an organizational human factor—in this case, an organizational failure (discussed in Section 2.3).

2.5.2 Fatigue

In a recent human factors study, the US Office of Marine Safety, Security and Environmental Protection and the Office of Navigation Safety and Waterway Services found that fatigue was among the top three causes of marine accidents (Gordon, 1998). Rothblum cites studies by the Marine Transportation Research Board in 1976 and the NRC in1990 where fatigue was the primary concern of mariners in both cases (Rothblum, 2006).

In an Australian report that analyzes reporting methodologies and the relationship between sleep, fatigue, and accidents in Incident at Sea Reports, Phillips (2000) found that 86% of the reports analyzed made some reference to sleep, although many of these references described sleep loss as a way of life onboard ships rather than as a direct causal factor. Thirty-nine per cent of the reports considered sleeping or sleepiness as a contributing causal factor. The report noted that accident investigators were able to identify sleep loss as a critical factor in cases where there was a "frank-sleep" episode (e.g. watchstander fell asleep) but had a harder time identifying the more subtle deficiencies in cognition and judgment that resulted from fragmented or deficient sleep. Phillips developed a diagram to describe the relationship between fatigue, sleep and accidents (Figure 3) and recommended additional study to "identify and quantify the manifestations of fatigue other than that of reduced alertness."

2.5.3 Other Individual Factors

Pate-Cornell and Murphy (1996) contend that people are basically rational, but their goals and risk attitude may not always match those of the organization, due to policies that may inadvertently encourage undesirable behavior. People typically act to receive awards and avoid negative consequences, but more weight is generally given to potential negative consequences to themselves, such as being caught and punished, rather than how specific behaviors may contribute to catastrophic accident risks. Production pressures, an organizational factor, may contribute to risk-taking behaviors, because the potential for reward for high production may outweigh the consequences of the worst-case scenario, especially for activities where that risk seems particularly remote.

Another component of individual human factors can be attributed to a lack of preparedness for crises. Operators may be extremely proficient in routine day-to-day operations; however, because crises occur so rarely and are not always well predicted, an operator may be poorly prepared to deal with such an event (Pate-Cornell and Murphy, 1996).

Finally, people have a tendency to ignore information that is inconsistent with their beliefs until it becomes irrefutable. This has been cited as a cause for unrealistic optimism in a variety of industries where accident risks are characterized by uncertainty. Only when faced with inevitable, catastrophic consequences do people acknowledge the potential for disaster, at which point intervention may not be possible (Pate-Cornell and Murphy, 1996).

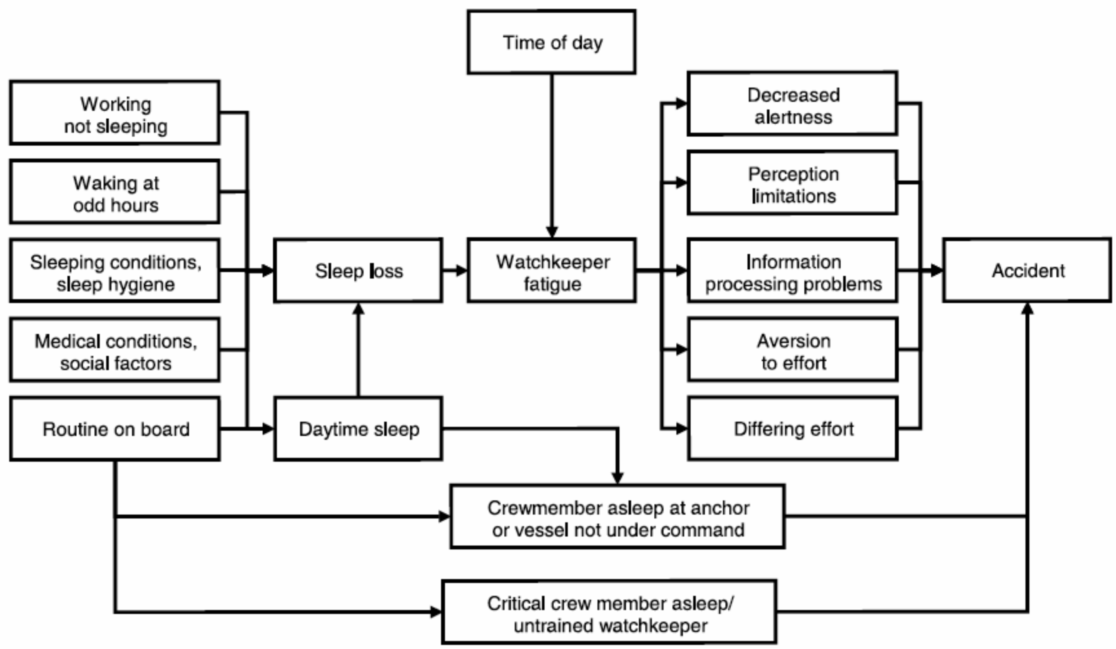

Figure 3: Relationship between sleep loss, fatigue, and accidents (Phillips, 2000)

2.6 Human-Technology Interactions

Human factors at the individual, group, and organizational level all involve, to some extent, the complex interaction between human and engineered systems. Accidents caused by technological failures are more easily remedied than those with human causes, therefore the contribution of human factors to accidents is likely to *increase* as technological improvements and regulatory measures are enacted to address engineering and structural components.

Nivolianitou *et al.* (2004) point out that technical factors are more readily resolved than human factors through technological and regulatory "fixes," leaving human-related errors and breakdowns as the most probable cause of industrial accidents. Hee *et al.* (1999) support this theory, noting that structural or technological failures are generally responsible for less than 20% of accidents involving complex systems, and noting that this is "a tribute to technology." By comparison, more than 80% of accidents can be attributed to the "unanticipated actions of people" leading to undesirable outcomes. Hee *et al.* conclude that human inputs to technological and engineering processes may actually contribute to accident risks from the beginning stages of equipment design:

> *We have come to understand that these unanticipated actions and outcomes can have root sources in design, construction, operation, and maintenance. Unrecognized designed deficiencies can be passed to construction. Construction attempts to work around these deficiencies, or perhaps they are not recognized. In some cases, construction introduces its own flaws and defects. The results are passed on to operations in which further adaptations are developed and new mistakes made.* (Hee *et al.*, 1999)

Pate-Cornell and Murphy (1996) note that technological changes and innovations may sometimes outpace the ability of operators to change and adapt, often due to the fact that operators lack a deep knowledge or understanding of the systems with which they work. As systems and technologies are reconfigured or changed, operators may not be fully aware of the potential implications of their actions on the system. Old operating procedures or habits may have unintended or poorly understood consequences under the new system, but if the operator is not informed or instructed of these changes he may be unaware of them.

Rothblum (2006) notes that the design of technology can have a big impact on how people perform. For example, when a piece of equipment meant to be used outside is designed with data entry keys that are too small and too close together to be operated by a gloved hand, or if a cutoff valve is positioned out of easy reach, these designs will have a detrimental effect on performance. Automation is sometimes designed without sufficient consideration for the information that the user needs to access. Critical information is sometimes either not displayed at all or else displayed in a manner that is not easy to interpret. Such designs can lead to inadequate comprehension of the state of the system and to poor decision making.

Enhanced automation or technological improvements may also lead to reduced manning levels, which in turn places additional pressure on operators to become proficient with even more complex systems. These pressures are exacerbated by the fact that increased automation makes it difficult for operators to override systems, reducing their ability to intervene to prevent a malfunction or accident. Increased automation may decrease the margin for operator error while at the same time reducing the operator’s ability to intervene if an error does occur.

Hee *et al.* (1999) report:

> *Experience with engineered systems indicates that in the main it is neither the environment, nor the structure, nor the hardware, nor the procedures that fail. The failures are firmly rooted in factors involving operating teams, the organizational factors that influence those operating teams, and the interactions between the operating teams and the other system elements.*

A 1993 USCG study found that many human factors issues derive from organizational practices or policies that obstruct the flow of information in the engineering development process or that fail to consider the human costs/benefits of regulatory requirements or work practices. The study concluded that improvements in design process and work structures can reduce human factors problems (Mandler and Rothblum, 1993). The potential for new regulatory requirements to have unintended impacts on accident risks is illustrated by the recent incident involving the car carrier *Cougar Ace*, which capsized while conducting a ballast water exchange offshore of the Aleutian Islands. The vessel was exchanging ballast in the open seas to comply with regulations requiring ballast water exchange beyond the 200-mile exclusive economic zone. While incident investigations in this case are ongoing, maritime industry experts have speculated that the crew may have lacked the knowledge or information regarding the stability issues associated with exchanging ballast in open seas (Corbett, 2006).

3 What is the Role of Human Factors in Oil Spills?

Human factors can never be removed from a tanker or any other industrial operation, but well informed and carefully designed and implemented prevention programs can seek to reduce the number of human errors and mitigate the impact of those that occur. In order to design and evaluate such interventions, we need the best possible understanding of the relative contribution of human factors to oil spills and which factors are most prominent. This section of the report considers available data sources and other analytic tools that may be applied to our understanding of the relative contribution of human factors to oil spills and accidents.

3.1 Review of Existing Data

Since the early 1970s, governments and private groups have collected various data about oil spill incidents, including, sometimes, the cause of the spill. One of the main purposes of such databases is as a source of information about the types of accidents that happen and their consequences, providing material for risk assessment tools and prevention programs. Oil and shipping companies often use internal incident databases as a management tool to identify common mistakes and improve management systems and risk control (Navolionatu *et al.*, 2006). However, these databases are generally not available for public query and therefore the lessons learned may not be applicable on a broader scale.

Public entities and trade organizations also track and analyze data on oil spills and marine accidents, and this data is generally available in the public domain. Information from these databases regarding the chain of events that cause oil spills and other accidents may be used by both regulators and operators to design or select spill prevention programs and risk mitigation measures. However, the value of such data from a risk analysis perspective is often compromised by difficulties in attributing causality.

Review of available databases of oil spills fails to provide a precise percentage of spills—worldwide, nationwide, or in Alaska—caused by human factors. Likewise, it is not possible through database queries to quantify the relative contributions of different types of human factors to tanker spills or marine accidents. The data generally support the conclusion that human factors contribute to a significant portion of marine accidents; however, the data proved difficult to sort and analyze for specific causality. Table 1 summarizes a few publicly available databases with oil spill cause data for Alaska tankers, and describes the capabilities and limitations of each.

Table 1. Overview of Oil Spill Databases Describing Cause

Nature & Source of Data	What does it tell us about the role of human factors in causing oil spills?	Discussion
Alaska Department of Environmental Conservation		
Assigns cause of spills in four categories: accident, human factor, structural/mechanical, and unknown. (ADEC, 2006)	For oil spills of 55 gallons or more from tankers, 1996-2005, human error is attributed to 4 of 58 spills, or just 7%. Adding in "intentional release" brings this up to 12%, with 19% unknown. The greatest number of spills from tankers during this time was attributed to "leak," with "other" coming in after "unknown." It is possible, though unknown from these numbers, that human factors contributed as underlying causes of leaks, or were factors in the unknown cases (ADEC, 2006).	1. Includes all spills over 55 gallons, as per state regulations, not only those from vessels. 2. Only allows for one cause to be attributed, and so does not allow for consideration of chain of events leading to incident itself. 3. High percentage of spills with unknown cause. 4. Does not provide data for just tankers
U.S. Coast Guard: Pollution Incident Compendium		
Marine Information for Safety and Law Enforcement (MISLE) is the latest data management system, as of 2001. Includes data starting in 1973, but cause data is not available past 1992. Spill reporting is mandatory under the Clean Water Act (1972). The US Coast Guard was designated as the recipient agency in 1973 (US Coast Guard, 2003a). No updates available as of this writing.	Inappropriate for analysis of human factors in causing oil spills, as cause data is not included after 1992. Prior to 1992, human factors were not among the cause categories used (container/tank failure, equipment failure, intended discharge, natural seepage, structural failure, unintended discharge, and unknown).	The USCG and NRC acknowledge shortcomings of the data: *Though each spill has a separate cause, and though the large majority of spill are believed to result from human error, this table reflects the limited number of causal choices that have been included in this database* (USCG, 2003b)… *The USCG should ensure that its oil spill database—including information on cause—is capable of facilitating the analysis of trends and the comparison of accidents involving oil spills. This would benefit the development of future regulations aimed at preventing oil spills and would facilitate industry planning* (NRC, 1998).
International Tanker Owners' Pollution Federation (ITOPF) Database (ITOPF, 2004)		
ITOPF has collected spill data since 1973 from publications and member ship owners. Statistics are worldwide, but include *only* "accidental" tanker spills.	Spill cause categories do not give relevant information to address contribution of human factors to the incident. Instead, they describe the incident in categories such as collision, hull failure, loading/discharging, etc. (ITOPF, 2006	Not appropriate for analysis of human factors.

Nature & Source of Data	What does it tell us about the role of human factors in causing oil spills?	Discussion
Pacific States/British Columbia (BC) Oil Spill Task Force, at the Washington Department of Ecology		
Each spill is assigned an "immediate cause" as well as one or more "contributing factors." A data dictionary provides categories and sub-categories for causes, including both Organizational/Management Failure and Human Error (Individual Level). Data managers from each state and BC can attend an Accident Investigation course to further standardize cause investigation methodology. State governments and BC provide the data, which is thus mandatory based on the reporting requirements of each jurisdiction.	In data reported in the 2002, 2003, and 2004 reports, Equipment Failure and Human Error were the top two causes (either immediate cause or contributing factor) of spills by volume. This was true for all states, with the single exception of Oregon in the 2003 report. The data represents non-crude spills more than crude, however, as there have been far more non-crude spills. This may be attributable, in part, to higher risk exposure in the non-crude trade, as there are more non-crude than crude vessels trading in this area. (Cameron, 2004)	1. "Other" and "unknown" categories are high (28% of volume in 2003, 27% in 2002) but coming down. This is attributed to lack of resources for investigation into spills (Cameron, 2004), reiterated as an issue the following year (Cameron, 2005). 2. Provides the most thorough definitions of cause categories of any database with the data definition dictionary (Cameron, 2004). 3. Data set is small, so a single large event in any category can inhibit analysis.

3.2 Challenges of Attributing Causality

Understanding why an oil spill or vessel accident occurred is a complex process shaped by accident reporting, incident investigation, and data collection methodology. In the events or conditions leading up to an oil spill, or the "accident incubation period," (Dien *et al.*, 2004), there are multiple—and perhaps unquantifiable—decisions made and actions taken. From the *immediate cause* of the spill—the broken valve, punctured tank, or cracked hull—an investigator may trace back through the chain of events and identify one or more *contributing factors,* or *root causes*.

The USCG risk-based decision-making guidelines (USCG, 2006) promote the use of a "root cause analysis" to identify the many and varied contributing factors to an accident. More than one root cause may underlie a marine casualty or oil spill. The USCG defines root causes as the most basic of an event that meet two conditions: (1) they can be reasonably identified; and (2) management has the ability to fix or influence them. Root causes typically involve the absence, negligence, or deficiencies of management systems that control human actions and equipment performance. At its simplest definition, root cause analysis seeks to understand *why* an accident occurred (Figure 3).

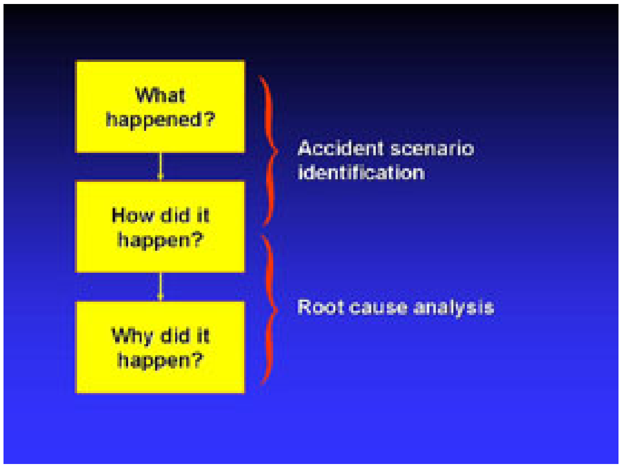

Figure 3. Root Cause Analysis in Accident Investigation (USCG, 2006)

Contributing factors may be linear in nature, resembling a "domino effect," or, more likely, will be a combination of different factors relating to humans, technology, and/or the environment which could be represented in a tree diagram or flow chart (e.g., as described in Ventikos & Psaraftis, 2004). This *multiple causation theory* (Curry *et al.*, 2006) may help deepen our understanding of why oil spills or other industrial incidents happen, but the spill cause data reviewed often attribute only one "cause," as inadequate resources, training, or incentives are available to thoroughly investigate numerous incidents (especially small ones).

3.3 A Next Step in Data Management and Attribution of Causality

The Pacific States/BC Oil Spill Task Force (Task Force) database project takes a step beyond the other databases in incorporating some of the complexities involved in attributing cause. In developing their database, the Task Force found that, "causal information that has been collected often does not delve far enough into the incident to identify the 'root cause'…Unfortunately, too often oil spill data indicate the cause of a spill as a mechanical or equipment failure, instead of addressing the human error (Gregory *et al.,* 1997)." In an attempt to standardize the collection of incident cause data, the Task Force's database uses a "data dictionary" and training in accident investigation for data managers. Each incident is assigned one immediate cause and as many contributing factors as apply. The guidance on individual and organizational human factors from the data dictionary for cause information is included in Table 2. It provides additional examples of human errors at the individual level, and goes the extra step of describing system, or organizational-level errors.

Table 2. Human and organizational factors in causal factor data dictionary developed by Pacific States/British Columbia Oil Spill Task Force for regional oil spill data compilation.

Cause Type	Data Definition in West Coast Database	
Organizational / Management Failure		
	Lack of Procedure/ Policy	Failure to have company procedures or policies.
	Inadequate Procedure/ Policy	Procedures or polices that are conflicting, ineffective, inaccurate, out-of-date, or insufficient
	Inadequate Implementation of Procedure/ Policy	Failure to ensure procedures or policies are followed.
	Lack of Supervision	The absence of proper situational guidance, direction, information or instruction to operating personnel.
	Poor Oversight	Failure of management to effectively oversee subordinates; lack of involvement, inspection, communication, etc.
	Insufficient Personnel	Failure to ensure that all required tasks can be done with adequate personnel of the proper skill level, physical ability, mental ability, experience, or certification.
	Equipment Design	Failure of equipment design (within the control of the responsible party) to provide for safe operations under normal operating conditions.
	Manufacture/ Construction	Failure caused by faulty manufacture or construction (within the control of the responsible party) when operating under normal conditions.
	Installation	Failure caused by faulty equipment installation, when operating under normal conditions.
	Lack of Planned Maintenance Program	Failure to have company planned maintenance program.
Organizational / Management Failure	Inadequate Planned Maintenance Program	Planned maintenance policies and procedures that are conflicting, ineffective, inaccurate, out-of-date, or insufficient.
	Inadequate Implementation of Planned Maintenance Program	Failure to ensure planned maintenance program is followed.
	Inadequate training	Inadequate technical knowledge due to insufficient training.
	Sabotage/intentional violation	Destruction of property or obstruction of normal operations; treacherous action to defeat or hinder; purposeful deviation from procedure.
	Other	Organizational/management failure not listed above.
Human Error		
	Communications	Difficulties in the transfer of information (not language related); failure to understand or comply.

Cause Type	Data Definition in West Coast Database	
(Individual Level)	Language	Difficulties in the transfer of information due to language barriers.
	Drugs/Alcohol	Any form or level of diminished ability (physical or mental) due to the use of drugs or alcohol.
	Inexperience	Inadequate technical knowledge due to a properly trained person not having enough experience to properly perform the task at hand.
	Improper Equipment Use	Using equipment to accomplish tasks other than those for which the equipment was specifically designed.
	Inaccurate computation	Mathematical error.
	Inattention	Loss of attention, not paying attention; the failure to detect, attend to, or be aware of critical or significant information.
	Procedural Error	Unintentional deviation from, or failure to follow an established procedure.
	Fatigue	Weariness or exhaustion from work, other exertion, or sleep disorder that leads to diminished ability (physical or mental).
	Illness	Sickness which causes decrease in physical or mental abilities
	Judgment	Incorrect assessment, estimation, interpretation or opinion.
	Other	Individual human error not listed above.

3.4 Near Miss and "Small" Incident Data

A problem in compiling and analyzing oil spill statistics is that major oil spills from tankers are infrequent occurrences (Gordon, 1998). However, important safety and prevention information can also be derived from small, operational spills or near misses. Kirchsteiger (2004) theorizes that "ordinary and occupational accidents" can be analyzed to derive important information about overall safety and effectiveness of prevention measures at a given facility. Near miss data provides important information not only about the events that may cause an accident, but also about the point at which a specific intervention or series of interventions may prevent the accident from occurring (Kirchsteiger, 2004; Nivolianitou *et al.*, 2006). However, the definition of "near miss" is by nature a subjective one; therefore, in order to develop and implement a near miss reporting system on a broad scale, reporting parties must have some basic agreement on what constitutes a reportable near miss.

In the US, the Federal Aviation Administration (FAA) requires near miss reporting in an effort to understand and mitigate accident risks in commercial aviation. In Germany, the Major-Accident Hazard Commission, which collects data on accidents and incidents in the chemical industry, has an Incident Evaluation subcommittee, which is in charge of collecting and evaluating minor and near miss events to extract safety data. Since 2000, a process has been in place to collect information on those non-notifiable events. Its main elements include: reporting of the incident by the plant operator to an information collecting point of its trust; passing the anonymous report to the "Incident Evaluation" subcommittee; evaluation and classification whether the incident is safety relevant or not; and publishing the relevant information to all interested stake holders in a summary of evaluation results with specific guidance on safety measures to prevent common problems (Uth and Wiese, 2004).

The IMO International Safety Management Code (IMO, 2002), mandatory for all signatories of the Convention for the Safety of Life at Sea, requires near-miss data collection but does not require companies to share this information; therefore, while the information may be available for review within a company, there is no industry-wide data collection or analysis.

3.5 Applying Analytic Tools

Beyond the statistical analysis of past events, numerous other models and methodologies have been developed to analyze the cause of safety breakdowns for the purpose of improving prevention. Several analytic tools have been developed and applied to tanker operations and oil spill prevention, to consider how prevention measures, technological improvements, and regulatory regimes may reduce the risks of oil spills caused by human factors. Several different accident forecasting models and analytical tools have been developed in an attempt to identify root cause errors in human systems and develop preventative measures that intervene at the appropriate level. Again, though, the proper categorization of human and organizational errors is critical to this process (Nivonlianitou *et al.*, 2004)

Within the field of safety engineering and human performance technology, there are literally hundreds of different approaches to understanding the relationship between human and organizational errors and accident prevention; a few approaches are highlighted here.

3.5.1 Professional Performance Analysis System

While the USCG includes both intentional and unintentional elements in its human errors matrix (as described in Section 2.1), Besco (2004) notes that human performance breakdowns are rarely the result of a random error, but more likely the result of a poor conscious choice or decision. As such, adding training or replacing an individual operator or class of operators will not prevent a problem from recurring. Instead, a systematic analysis is required to determine why the operator made the error, in order to intervene at the appropriate point.

The study of human performance has resulted in an entire field of human performance analysis and the professional performance analysis system (PPAS), as founded by Robert Mager (Mager and Pipe 1997), which has been accepted widely and integrated across a range of disciplines. PPAS involves the application of a systematic protocol and algorithm to determine the reasons why humans committed errors or why they failed to perform at an expected level. The PPAS process is based on the principles of behavioral science and looks at five attributes of human performance to identify the factors that can be changed to improve performance in the future (Besco, 2004).

3.5.2 Formal Safety Assessment (FSA)

The IMO has adopted a formal safety assessment (FSA) methodology to analyze data and identify corresponding safety measures that address human error-based causes. The FSA follows from the IMO's event-decision network (EDN), a strategic tool used to support and guide oil spill cleanup decision-making using event/scenario analyses. The EDN uses a tree-like approach to analyze the chain of causes for a particular event, and identifies the human actions that influence error-causing conditions along the way (Ventikos & Psaraftis, 2004). FSA adapts the EDN model and combines it with a human factor analytic technique commonly used in the nuclear industry – human reliability analysis. Human reliability analysis involves the identification and analysis of key tasks, and a subsequent identification, analysis, and sometimes quantification, of human errors as they relate to the key tasks. The FSA methodology then follows a 5-step process to analyze human factors that lead to marine oil spills and identify appropriate interactions:

- FSA Step 1 – Identify hazards and generate a prioritized list of hazards. The approaches used for hazard identification includes both creative and analytical techniques (e.g., expert judgment, human reliability analysis, statistical analysis, etc.). The hazards should be screened and prioritized in order to discard possible scenarios of minor significance using various ranking methods, e.g., risk matrix.

- FSA Step 2 – Conduct risk assessment to identify risk distribution and assess the respective factors that influence risk level. This is achieved by implementing risk contribution trees and by developing regulatory impact diagrams (RIDs) that link the regulatory and policy regime to the event chain.

- FSA Step 3 – Propose efficient and feasible risk control options regarding the level of aggregated risk, frequency, outcome, severity, and uncertainty of pollution accidents. This can be done either by relating how a measure can alleviate risk (risk attributes), or by tracking where in the "initiating event to failure" sequence, risk control can be effected

- FSA Step 4 – Conduct risk-benefit analysis to identify benefits (reductions in fatalities, oil pollution, etc.) and costs (including training, new technologies, etc.) associated with the introduction of risk control options from step 3. The key point of step 4 is the estimation of cost effectiveness for each option in terms of net cost per unit of risk reduction.

- FSA Step 5 – Develop recommendations for the regulatory and decision-making bodies (e.g., IMO) aimed at keeping risk as low as reasonably practicable.

3.5.3 Safety Management Assessment System

In a report that considered the role of human and organizational factors in marine system operations, Hee *et al.* (1999) describe a screening process, Safety Management Assessment System (SMAS), developed to assess human and organizational factors by comparing the safety system with the characteristics of high reliability organizations (discussed in Section 4.1.1). The primary focus of SMAS is to evaluate human and organizational factors in a system, with particular emphasis given to organizational aspects, and to promote a safety culture as part of the assessment process.

SMAS emphasizes the intersection between organizational factors, technology, and individual behavior, with an emphasis on the influence of "operating teams" within the organization. SMAS is distinguished from other approaches because system operators are included in the assessment process, in contrast to other "top down" approaches. Operators are provided with a consequence-free forum to communicate safety information to upper management, without barriers or filtering. SMAS involves a combination of qualitative and quantitative methods under the theory that a combination of approaches is necessary to capture all the factors and complexities important for the future safety of a system. Finally, SMAS is based on the premise that organizational change must come from within. The self-assessment component of SMAS is meant to empower operators and safety managers to incorporate and promote a safety culture at the day-to-day operations level. SMAS is designed to be used by those having direct working responsibility for the safety of the system, and intends to leave behind, through training and the assessment process, an awareness, sensitivity and knowledge base to be used for the continual improvement of their system's safety characteristics.

3.5.4 Other Analytic Tools

Numerous other assessment tools and methodologies exist to help organizations to better understand the root causes of their internal risks for oil spills and accidents. The USCG's Prevention Through People (PTP) program offers several tools and guidance documents, including a risk-based decision-making program, a marine operations risk guide, and a passenger vessel risk guide. All are available on the Internet (USCG, 2004).

3.6 What do Databases and Analytic Models Tell Us?

It is clear through both qualitative and quantitative data sources that human factors are a significant contributor to the cause of marine accidents and oil spills. In reviewing and interpreting oil spill and marine accident databases, it becomes clear that, in addition to the actual contribution of human factors to oil spills, there are numerous data collection and analytical limitations influencing the statistics, including: how the spill reports are made and by whom; extent of analysis of cause; and terminology and parameters available when cause is attributed.

Existing data sets lack standardization regarding human factors causes for accidents and oil spills, and therefore are difficult to query for the purpose of identifying trends in the tanker industry. Grabowski (2005) notes that safety data collected by the USCG do not provide sufficient detail to address trends related to vessel construction, manning, technical systems, maintenance, or general safety procedures. In the marine transportation industry, these problems "make difficult complete analyses of the impact of human error on safety in large-scale systems." (Grabowski, 2005)

Gordon (1998) emphasizes the importance of standardized accident reporting and analysis of human factors causation for meaningful data analysis, and points out that a major challenge facing oil companies in analyzing accident trends to avoid future oil spills is that the available data set of major accidents is very small. Grabowski (2005) supports this conclusion, noting, "The most significant reason for the lack of human factors data as input into maritime risk analysis models is that human factors have not been adequately evaluated in the investigation, analysis, and coding of accidents and incidents." Gordon (1998) recommends that the oil industry combine accident databases with those of other process industries (e.g. nuclear, chemical) to draw on a broader data set. However, this would require standardized accident reporting across industries.

While it is difficult to quantify the types of human and organizational errors that contribute to oil spills, some studies have shown that spill occurrence rates do not necessarily correlate with those activities typically considered to be "high risk." For example, in a study of oil spills in California, researchers found that nearly half of the spills at marine terminals occurred when no transfers were underway, and that many of these were traceable to equipment failures caused by inadequate maintenance and testing procedures (Hee *et al.*, 1993).

Within the oil industry, the Task Force's database is making inroads toward a standardized data reporting system that will have utility in identifying the most prevalent human factors causes for oil spills in the US Pacific states.

These data can then be used to target prevention efforts toward areas of higher risk. Once reliable data regarding root causes are available, prevention strategies can be tailored to address the most serious human factors risks, and future analyses may be able to determine which prevention measures are most effective in preventing human-caused accidents.

Moore *et al.* (1993) emphasize that qualitative analysis of human and organizational errors in tanker accidents may be just as important as quantitative studies.

> *There is no marine accident database that can be relied upon to give accurate quantitative indications of the frequencies of accident contributors; in the case of specific accident scenarios, existing databases frequently give misleading Indications of causes and consequences.*

The need for better human factors data and safety reporting has been recognized by the USCG. A 1993 human factors study recommends that human factors analyses be incorporated into shoreside facility and vessel inspections, casualty investigations, and emergency response procedures (Mandler and Rothblum, 1993). The USCG's PTP program compiles qualitative lessons learned information collected through voluntary submission of stories as well as from incident reports collected by the Nautical Institute's International Marine Accident Reporting Scheme (MARS). The PTP program recommends best industry practices based on this lessons-learned data, which is available on the Internet (USCG, 2004).

4 Mitigating the Human Factors that Cause Marine Accidents and Oil Spills

Since oil spills usually result from multiple contributing factors which may occur or exist far from the actual spill event in time or space, it follows that oil spill prevention efforts must target a similar array of individual, group, and organizational human factors. Double hulled-tankers are one example of a spill prevention measure that is near incident (the double hull does not prevent a collision from happening, but its presence may stop or limit oil from spilling to water.) Human factors-related prevention measures tend to intervene farther away from the potential spill event, focusing instead on promoting a culture of safety, strengthening communications channels, and ensuring adequate training and preparation for both day-to-day and crisis mode operations. Addressing human factors related to day-to-day operations seeks to prevent an accident from happening in the first place, while crisis mode-oriented prevention, such as drills and response exercises, will seek to minimize its severity.

4.1 Establishing a "Safety Culture"

Since organizational errors and failures are cited as important components of human factors, prevention measures that seek to improve both individual and organizational attitudes and policies toward safety are considered an important component of spill prevention. The term "safety culture" has been used to describe an organizational environment that promotes self-regulation by ensuring that each individual within the organization takes responsibility for actions to improve safety and performance. This requires active support and encouragement at all levels of an organization, from the very top management levels down to the equipment operators (Moore and Roberts, 1995).

A major USCG initiative, known as PTP, has been implemented to address human factors in oil spills and accidents and promote a safety culture within companies and across the industry. According to the USCG, PTP is a "people-focused approach to marine safety and environmental protection that systematically addresses the root cause of most accidents: the human element. This approach recognizes that safe and profitable operations require the constant and balanced interaction between the management, the work environment, the behavior of people, and the appropriate technology. PTP itself promotes a cultural change within a company to improve their safety posture (USCG, 2004)."

4.1.1 Importance of Management and Organizational Factors

In a study of safety culture and accidents (not specific to oil spills or marine sector), Lund and Aarø (2003) consider the relative importance of accident prevention measures that influence individual behavior vs. organizational culture and find that improvements to the safety culture at the organizational level lead to more significant reductions in accident occurrence rates and severity. In order to counter the phenomenon of “iron men” discussed in Section 2.4, organizations must be attuned to the attitudes onboard vessels, which can be difficult due to physical distance and separation. Informal reward systems for safe behavior and negative consequences for risk-taking can help to overcome at least part of the “iron men” culture. Social approval or disapproval of peers is a powerful contributor to human behavior; however, it requires significant and ongoing efforts on the part of organizations to effect such an informal rewards system (Pate-Cornell and Murphy, 1996).

A safety culture can be enhanced if management reacts to accidents by considering the organizational policies, both overt and implied, that may have contributed to the operator errors. Similarly, when management sets time or budget constraints, they must consider whether operators may be inadvertently encouraged to cut corners or violate safety policies in order to meet those constraints. Productivity and safety often conflict in the short term; therefore, organizations should offer active incentives that back up stated safety policies (Pate-Cornell and Murphy, 1996).

In the study of organizational safety across industries, researchers have considered high reliability organizations, which are defined as organizations that are involved in dangerous operations, such that failure in the operation results in severe consequences. High reliability organizations have, over long periods of time, had very few accidents. Five attributes have been identified that characterize high reliability organizations: process auditing; appropriate reward systems; high standards of quality; appropriate risk perception; and command and control functions (Hee *et al.,* 1999). These principals generally align with the findings of Pate-Cornell and Murphy (1996) regarding safety cultures.

In order for organizations to improve safety, they must learn from past mistakes. This can be accomplished through several channels, such as describing past accidents in safety bulletins and at safety meetings, and highlighting safety recommendations from past incidents. New employees should be exposed to reports from past incidents, and the company should maintain readily accessible data regarding accident investigation data from past incidents (Gordon, 1998).

4.1.2 Interventions at the Individual and Group Levels

The major human factors that influence accidents within the marine industry at the individual level are fatigue and inadequate knowledge. At the group level, communications among group members and group dynamics tend to influence human errors and influence accident causes. Interventions that target these problems can be challenging to design, implement, and audit.

One challenge in predicting and managing human performance is that, when time or performance constraints are particularly tight, people tend to cut corners in ways that are difficult to predict. Tight production schedules or quotas may lead people to circumvent or improvise safety procedures, or to take high-risk short cuts. In some cases, the people taking these actions are unaware of the potential short or long-term impacts to overall safety.

Individual behavior can be influenced through organizational and group-level safety policies that involve operators in risk assessment processes and that explicitly address cutting corners and other short cuts. Specific directives (e.g. instructions from a supervisor) have been shown to have a more significant effect on human performance than general policies (Pate-Cornell and Murphy, 1996).

To prevent accidents caused by inadequate knowledge, organizations must either ensure that their operators have a sufficient knowledge base to solve problems effectively, or provide sufficient procedural guidance and oversight to prevent errors or lapses in judgment. Pate-Cornell and Murphy (1996) offer that, “The trade-off between productivity and safety can be managed either by extremely competent employees who are given wide latitude, or by less experienced people and strict rules and regulations.” The problem with the latter is that rules and regulations rarely foresee all possible consequences; therefore, it is important to build in sufficient oversight to ensure that operators of complex systems are adhering to the rules and regulations (Lynch, 2006).

Regulatory requirements for manning, qualifications, and licensing are useful to ensure a minimum skill set and knowledge base for individuals filling a particular crew position. In a 1993 human factors study, the USCG found a general need for procedures to ensure adequate training and manning levels on ships. Inadequate knowledge can often be a function of too many job tasks for one crewmember, which is a byproduct of insufficient manning. The USCG recommends regular testing, training, evaluation programs, and “a task-based approach to work requirements for determining manning levels and safe operation.” (Mandler and Rothblum, 1993)

Significant effort has been made to develop programs and policies that address the major individual human factor – fatigue. At its 20th session in November 1997, the IMO Assembly adopted a resolution outlining the human element vision, principles and goals for the organization (IMO, 1997). The resolution included a component that addressed fatigue factors in manning and safety. The fatigue factor initiative aimed at increasing awareness of the complexity of fatigue and encourages all parties involved in ship operations to take these factors into account when making operational decisions (IMO, 1997).

Crew endurance management is a concept promoted through several industry initiatives and USCG programs. Crew endurance management seeks to improve work and rest environments onboard ships to maximize the amount and quality of restorative sleep that crewmembers receive and to integrate other lifestyle factors, such as good diet and nutrition and adequate air quality, which have been found to significantly influence fatigue. However, the major contributor to crew fatigue on vessels is the watchstanding schedule. Typical watches on many US vessels run 6-on, 6-off, which means that two watchstanders alternate every six-hour period. The problem with this schedule is that the 6-off period rarely involves uninterrupted sleep, as crew members have other aggregate duties to address, as well as eating, relaxing, and taking care of personal business. The actual amount of sleep realized by most crewmembers on a 6-on, 6-off schedule may be significantly less than needed (Abernathy and Kelly, 2006).

The USCG's PTP program recommends that 7-7-5-5 or, preferably, 8-8-4-4 watch systems be used to promote better rest patterns for watchstanders. Under these systems, watchstanders have one long (7 or 8 hours) and one short (5 or 4 hours) watch, separated by one long (7 or 8 hours) and one short (5 or 4 hours) rest period, which allows more time for crew members to rest within each 24-hour period. Vessels that have experimented with the 8-8-4-4 system report generally positive feedback from crewmembers and improved alertness among watchstanders (Abernathy and Kelly, 2006).

In the marine industry (and in aviation), group factors are often addressed through crew resource management programs, which address the interactions between crewmembers as they impact safety systems. These programs focus on the interactions among crewmembers on the flight deck or ship's bridge, to improve communications and teamwork.

In aviation industry studies conducted in the 1970s, crew factors found to affect safety performance include the attitudes of the team toward communication and coordination, command responsibility, and recognition of stressor effects. Members of crews with low accident occurrences were found to have a clear understanding not only of their own roles and responsibilities but also those of other team members. Crews with low accident rates tend to promote a climate of openness where junior crewmembers are able to assert their opinions and challenge poor decisions on the part of the captain (Gordon, 1998).

A 1993 USCG human factors study found that communications systems were critical to addressing human factors at the group level. The study recommends that improvements in person-to-person and equipment-to-person communications will reduce confusion and reduce other documented problems on vessels, such as over crowding on radio channels (Mandler and Rothblum, 1993).

Regular and ongoing emergency training is also essential to accident prevention. Likewise, a clear chain of authority is critical during an emergency, and it must be clear to all employees when a switch to crisis mode from day-to-day operations is necessitated (Pate-Cornell and Murphy, 1996).

4.2 Focusing on Human-Technology Interactions

In an analysis of human and organizational error in crude oil tanker operations, Moore *et al.* (1993) found that most accidents involve the interaction between humans, organizations, and systems (equipment). Accidents involving the systems component alone are the most easily remedied; however, when human interactions are involved the remedy becomes more complex.

Curry and McKinney (2006) have developed a matrix to help accident investigators to better understand the human-machine-environment interactions that lead to accidents. They emphasize the importance of human-machine interactions and recommend that engineering systems be designed with consideration for the abilities and limitations of human operators, in order to minimize accident risks.

Human/machine interactions are those that relate to the design of machines or processes with regard to the capabilities and limitations of their human operators. These can include such issues as (Curry and McKinney, 2006):

- Guarding design (size, location, type).
- Information processing/flow/machine design (information presentation style, rate, type, format, etc.).
- Industrial ergonomics (the effects of work on the human body, human strength, body sizes, reach envelopes).
- Operator behavior and performance (reaction time, rate stress, safety consciousness, fatigue, vigilance).
- Warnings and Instructions (comprehensiveness, understandability, formatting, detectability).
- Machine Design and Affordances (Does the design of the machine suggest a particular method of interaction? Is this method compliant with the actual intended operation of the machine?).

In an article about integrating human factors and systems engineering, Johnson (1996) contends that safety engineering sometimes results in "risk compensation," where operators may engage in unsafe practices due to a false sense of safety created by enhanced technologies. Johnson recommends the integration of systems engineering with human factors, to predict the ways that users might compensate for the effects of safety devices. He proposes a model and simulation system that can be used to address these interactions (Johnson, 1996).

In considering the bias toward engineering fixes over human factor interventions, cost factors may come into play, such as the ability to depreciate one-time capital investments in technology/engineering-based fixes. Such cost incentives may impact company decision-making at various levels (Lynch, 2006).

4.3 Managing Risk and Uncertainty

Another factor that comes into play in marine systems is the innate difficulty that human beings have in comprehending and communicating uncertainty. “I don’t know” is often considered an unacceptable response, even when it may be the most true and accurate one. Human beings may tend to make singular, optimistic predictions that can quickly be interpreted as fact, leading to inaccurate risk perceptions. Pate-Cornell and Murphy (1996) recommend that increased acceptance and use of the concepts and language of uncertainty may help people to recognize and deal with incomplete information. Part of having a positive safety culture on board is making it safe for uncertainties to be raised, and creating an environment where everyone shares a realistic understanding of risks and risk management.

In the case of the 1988 Piper Alpha oil platform disaster in the North Sea, where a natural gas condensate release ignited to cause a massive explosion resulting in significant loss of life, investigators found that there was a 'culture of denial' of the serious risks. Management at Occidental Petroleum, which operated the platform, tended to focus on frequent incidents that had the potential to disrupt production rather than focusing on the risk of a catastrophe. Rewards and incentives were given for short-term production figures, which could have encouraged workers to cut corners to get the job finished. There was a high turnover of staff indicating that personnel may not have had the necessary level of understanding of the system, which is of particular importance in the case of the system being pushed to its limit (Gordon, 1998).

Besco emphasizes the importance of leadership and management to overall risk management, noting that organization must be “intolerant of risk denial and supportive of risk detection.” Besco recommends that the corporate culture support wide safety margins, set goals, develop monitoring systems, and follow through with recognition and rewards for all individuals, teams, and organizational entities that display risk-averse performance. Likewise, poor performance or risk-tolerant activities must be recognized and addressed (Besco, 2004).

Pate-Cornell and Murphy (1996) note that risk management systems are often based on insurance considerations, rather than the field conditions that more directly influence risks. They recommend that some of the money allocated to insuring technical systems should be reallocated toward risk management programs that address equipment operators as well as engineering systems. For example, in addition to adding redundancies to a system, the organization should also allow for interruption of operations to facilitate regular safety repairs. Risk mitigation should focus on organizational factors as well as technical issues; however, many operators favor technical and engineering solutions because they are more concrete. Pate-Cornell and Murphy note, "When we pointed out to some oil companies that organizational measures could be more cost-effective than adding steel to a structure, the answer was that structural modifications were a safer way to reduce the risk. This view seems to stem from the belief that people, as opposed to hardware, are unpredictable, and therefore, a major source of risk uncertainty." Technical fixes are therefore viewed as more reliable; however, this is not always the case.

Harrald (1998) notes that, while risk assessments *should* be based on some quantitative analysis of causal factors to oil spills, difficulties in modeling human error can complicate this process considerably. While in some industries, the insurance sector may analyze case file data to make determinations about relative risks, the nature of the marine insurance industry makes it extremely difficult to review claims data, since insurance claim files, once settled, generally revert to the claimant. This prevents any industry-wide analysis of risks based on accident claim data (Coutroubis, 2006).

4.4 ISM Code

The International Safety Management (ISM) Code is an important component of the IMO's human elements initiative, and one that addresses human factors at the individual, group, and organizational level. The ISM Code is intended to improve the safety of international shipping and to reduce pollution from ships by impacting the way shipping companies are managed and operated. The ISM Code is included as an amendment to the International Convention for the Safety of Life at Sea (SOLAS), with mandatory compliance required for all signatories to that convention (Moore and Roberts, 1995).

The ISM Code establishes an international standard for the safe management and operation of ships and for the implementation of a safety management system. To comply with the ISM Code, a company must develop, implement and maintain a safety management system, which includes the following functional requirements:

- A safety and environmental-protection policy;
- Instructions and procedures to ensure safe operation of ships and protection of the environment in compliance with relevant

international and flag State legislation;

- Defined levels of authority and lines of communication between, and amongst, shore and shipboard personnel;
- Procedures for reporting accidents and non-conformities with the provisions of this Code;
- Procedures to prepare for and respond to emergency situations; and
- Procedures for internal audits and management reviews.

The implementation of the ISM Code is often considered one avenue toward cultivating a "safety culture." The ISM Code was patterned on similar management concepts of the International Standards Organization (ISO) quality management standards (ISO 9000). The major difference between the ISO 9000 standard and the ISM Code is that ISO 9000 focuses on quality assurance systems (e.g. commercial practices), while the ISM Code focuses on safety management and pollution prevention (Moore and Roberts, 1995).

The USCG adopted the ISM code into the federal oil spill prevention regulations at 33 CFR 196 for oil tankers operating in U.S. waters. For ships calling at U.S. ports, the audit must be completed by USCG or a USCG-recognized organization such as the American Bureau of Shipping (ABS). Auditors issue a document of compliance to the owner and a safety management certificate to the vessel. USCG inspectors can review the audits for any ship entering a US port and can require an audit for any ship they suspect does not comply with its safety management system.

The ISM code includes requirements for internal tracking of near miss incidents; however, this information is not compiled outside of individual company records therefore lessons learned cannot be derived at the industry-wide level.

4.5 Best Practices and Voluntary Initiatives

Non-regulatory bodies have addressed the human element through various initiatives and recommended standards of practice.

The State of Washington has several voluntary compliance programs focused on human factors in the safe transport of oil through state waters. Both tankers and tank barges can enroll in a "voluntary best achievable protection" program (VBAP), and tanker operators who have demonstrated compliance with even more stringent standards will be recognized by the "exceptional compliance program," or ECOPRO. Companies meeting the standards for these programs are recognized on the State Department of Ecology's website. The voluntary compliance standards include operating procedures, personnel policies, management practices, and marine safety technology. The standards pre-date the ISM Code, and there are now many overlaps with the international standards (Stratton, 2004).

Industry trade groups promote voluntary compliance programs as a means to both improve overall safety and foster positive public relations. Intertanko has numerous publications and programs that address issues such as bunkering, bridge resource management, ballast water management and safe navigation (Intertanko, 2004). The AWO has a Responsible Carriers Program (RCP), which is described by the AWO as “a guide in developing company-specific safety and environmental programs that are tailored to the unique operational environments found in the barge and towing industry (AWO, 2005).”

The Pacific States/British Columbia Task Force has established a project entitled ”Best Industry Management And Operating Practices For Operators Of Large Commercial Vessels And Tank Barges,” which includes both the USCG and the west coast shipping industry, and focuses on developing management and operating standards that promote environmental protection through voluntary compliance with tank vessel chartering policies (Cameron, 2004).”

The effort brought together state and federal regulators with industry representatives and several Task Force Member agencies to discuss such voluntary industry practices to reduce the risk of oil spills. The industry participants agreed to rank a set of “best industry practices” to identify which practices they considered most effective in oil spills both for large tankers and for tank barges. Several human factors were identified by the group as critical to spill prevention, listed below in rank order (most important to least important):

- Watch practices
- Training
- Management systems
- Emergency procedures
- Event reporting policies (including causal analysis)
- Language/communication requirements
- Drug and alcohol testing
- Personnel evaluations

4.6 Evaluating the Effectiveness of Prevention Programs

While this report illustrates the difficulties in measuring cause data in a way that allows for meaningful analysis, it is perhaps even more difficult to assess whether prevention measures are working. Answers may be found by analyzing near miss data, or by looking at overall trends in oil spill causality and measuring those for correlation with various prevention measures.

Accident and near miss data is collected by the Nautical Institute's MARS program, which protects confidentiality to remove the fear of litigation. Information in this database can be queried online (Nautical Institute, 2006), and the USCG uses incident reports from this database to derive lessons learned which are then made available to the industry through the PTP program. Since the reporting system is voluntary, the data collected is not viable for statistical analysis regarding root causes of oil spills. However, if the reporting became compulsory, the data set would be more comprehensive and might be used to draw conclusions regarding which prevention measures are working.

The US Coast Guard Human Factors Plan for Maritime Safety (Mandler and Rothblum, 1993), which was published over a decade ago, provides a road map for the USCG's human factors program (PTP). That report could be used to measure the accomplishments of this program, the ISM code, and other industry initiatives, by considering how and whether these programs have addressed the objectives and critical tasks outlined in the 1993 report.

The Pacific States/BC Task Force Best Industry Practices project takes a self-assessment approach to measuring the effectiveness of prevention measures, by surveying a sample of the industry. The outcome of that study shows that the industry perceives prevention efforts that focus on watch practices, training, and navigation to be the most effective. The project also identifies specific regulatory gaps where the industry perceived the need to focus prevention initiatives. The results of this project can be applied to Alaska, since many of the operators that participated in the project transit Alaskan waters. It is important to remember, however, that this project measured perceived risks, and that a statistical analysis of root cause data might lead to different conclusions regarding risk analysis.

5 Analysis

As much as 80% of oil spills and marine accidents have been attributed to human factors – either individual errors or organizational failures (Hee et al., 1999; Rothblum, 2006). Technological improvements such as double hulls can reduce the severity of an oil spill caused by groundings or collisions, but they cannot interrupt the chain of events that may cause the accident to occur in the first place. And, as new technologies come online, they create the need for new training and job aids to ensure that human operators put the technology to use properly. Therefore, in coming years as double-hulled oil tankers are phased in, human factors will remain a crucial component of oil spill prevention systems in the PWS tanker trade and worldwide.

The study of human factors is based on the acknowledgement that human characteristics and behaviors are intrinsically linked with the functioning of the technology people design, build, maintain, and operate. The human-technology relationship works in both directions, though. Not only do humans impact the functioning of our technology, but technology can also influence human decisions and actions. This report considers the complex nature of human-technological interactions and emphasizes the importance of targeting root causes at the individual and organizational levels in order to prevent oil spills and marine accidents. The essence of this discussion is *risk* – how best to measure and characterize the contribution of human factors to spill risks, and thus how and where to intervene to mitigate those risks.

5.1 Considering the Relationship between Human Factors and Double-Hulled Tankers

The double-hulled oil tanker is arguably the cornerstone of US and international oil spill prevention policy. Double hull requirements were among the most publicly recognized outcomes of OPA 90, although double hull technology is not new, and the prospect of requiring oil tankers to be constructed with double hulls had been discussed for many years before the passage of OPA 90. But as the double hull phase-in schedule moves toward completion (the phase-in deadline for tankers is 2010, for tank barges 2015), it is relevant to consider whether this structural prevention measure might have any appreciable impact on efforts to reduce human-caused oil spills.

Studies from the offshore oil industry and other industrial processes suggest that technological changes and improvements do not necessarily reduce the likelihood of a human-caused spill or accident. In fact, technological improvements may *enhance* accident risks due to increased complexity of the system, skills- or knowledge-based lapses in operator abilities, or risk compensation behavior at the individual or organizational level.

A 1998 NRC study that considers the OPA 90 double hull requirements offers several recommendations that are relevant to the discussion of human factors

(NRC, 1998). These include developing procedures for ballast and cargo transfer to protect vessel stability, and additional crew training programs to ensure proficiency with new technologies. (Note that ballast transfer and vessel stability were factors in the *Cougar Ace* incident described in Section 2.6). The NRC report noted that the implementation of double hull requirements does not erase the need for prevention programs that address human factors.

> *In addition to the vessel design issues identified in OPA 90 and addressed in this report, initiatives such as the USCG Prevention Through People program, which addresses the role of human factors in accident prevention, may further strengthen the ability to prevent the occasional, very large incident or to reduce its severity* (NRC, 1998).

The NRC report also summarized the results of outflow analyses, which attempt to measure the prevention value of double hulls by assessing how oil outflow might be reduced or avoided in an incident involving a double-hulled vessel as compared to a single hull. These outflow analyses showed that four out of every five oil spills attributable to collisions and groundings would be eliminated, and a two-thirds reduction would be realized in the total volume of oil spilled from collisions and groundings. These predictions validate the popular belief that double hulls will have a significant and positive effect on reducing the risk and the severity of oil spills; however, they also show that double hulls are not a perfect prevention measure, thus enforcing the need to continue with human factors prevention programs. In fact, double hulls and "redundant" technologies are only one component of a complex system in which accident risk may actually be exacerbated by technological improvements, due to the impacts of corresponding reductions in manning levels (Hee *et al,* 1999).

Most importantly, the major protection afforded by double hulls occurs in a scenario where a grounding or collision has already occurred, and the double hull serves to prevent oil from spilling or to mitigate the size or severity of the release. Human factors interventions work to prevent accidents and oil spills much earlier in the accident timeline – by preventing the critical failure or series of events that lead to the grounding or collision in the first place.

5.2 Recommendations for Reducing Oil Spills Caused by Human Factors

By their very nature, human factors can never be eliminated from the human-constructed marine transportation industry; however, by studying past accidents or spills and drawing lessons from the maritime and other industries in general, we can build an understanding of the dominance of the human-technology interface to guide and enhance oil spill prevention efforts.

The key to preventing oil spills caused by human factors is to identify the types of individual, group, and organizational failures that most commonly cause spills to occur, and then finding the appropriate intervention to prevent those failures in the future. Many operators undertake such efforts internally, and the IMO, the USCG, and industry trade groups have made significant advances in developing prevention programs that address human factors. However, there is room for improvement, both in terms of prevention initiatives and the metrics used to gauge their effectiveness.

The research and practical experience described in this report points to several opportunities to improve both our understanding of the contribution of human factors to oil spills from tankers and the implementation of prevention measures that effectively target these human factors. These include:

- Improving and standardizing data collection methods to recognize human factors in accident causality and to access marine insurance claim data;
- Recognizing the relative contributions of individuals, groups, and organizations in assessing human factors;
- Creating a mandatory near miss reporting system for the U.S. maritime industry and analyzing near miss data for lessons learned;
- Promoting and applying best industry practices that have been recognized to reduce accident and spill risks from human factors;
- Incorporating human factors analyses into risk assessments for oil spills from vessels;
- Focusing on crew endurance management and other practices to reduce fatigue;
- Integrating human factors considerations into systems engineering;
- Considering human factors implications in developing and implementing new regulations;
- Promoting a safety culture across the marine oil transportation industry; and
- Measuring the effectiveness of prevention programs and safety initiatives that target human factors.

5.2.1 Improve and standardize data collection methods.

From a policy perspective, statistical analyses serve an important function in illuminating trends. The inconsistencies in oil spill cause data recorded by the US Coast Guard, ADEC, and many other agencies and organizations not only complicate statistical analysis, they compromise the usefulness of the data to policymakers. It is critical that spill prevention efforts be appropriately targeted, yet today's publicly accessible oil spill databases are compromised by inconsistencies in accident reporting and investigation. Oil spill cause data tends to underestimate the contribution of organizational factors, and often fails to identify latent errors.

As Gordon (1998) recommends, it may be possible for the oil industry to combine accident databases with those of other process industries (e.g. nuclear, chemical) to draw on a broader data set. However, this would require standardized accident reporting across industries. The process used by the Task Force in the Pacific states and British Columbia provides an excellent model for how to capture and standardize cause data in a spill database. ADEC should be encouraged to follow this protocol, and the USCG should be encouraged to develop a similar approach.

The involvement of the marine insurance industry in discussions of accident risks and human factors might facilitate the review and consideration of a large set of data that is currently not compiled in a central location: claims files from vessel accidents and oil spills. The ability to measure human factor risks would be greatly improved if the marine insurance industry were to consider compiling cause data from claims files and make that data available for review by risk managers.

Finally, the USCG database should be more readily available for search and analysis by the public, as recommended in the 1998 NRC double hull report.

5.2.2 Recognize the relative contributions of humans, groups, and organizations

Gordon (1998) points out that safety programs often focus on preventing active errors, which are more often the immediate causes of accidents, at the expense of latent errors, which can be more difficult to tie to a specific incident. Several studies note a similar problem in addressing human factors at the individual vs. the organizational level (Hee *et al.,* 1999; Pate-Cornell and Murphy, 1996; Gordon, 1998). While organizational factors are generally considered the more important in contributing to accidents and oil spills, individual factors are more readily targeted and more commonly linked to accident causality because they are proximate to the event.

5.2.3 Create near miss reporting requirements in the U.S. marine industry.

At present, near miss reports are filed with the Coast Guard on a voluntary basis. ISM requires that companies maintain internal data on near misses, but these are not collected or analyzed by any outside agency. Near miss reports can be extremely useful in gleaning information regarding spill risks as well as prevention interventions that are effective in mitigating specific risks. The FAA has a near miss reporting system for aircraft that may be a model that could be applied within the maritime industry.

5.2.4 Apply the best industry practices model more broadly.

The best industry practices project in the Pacific states yielded important data regarding industry perceptions of the need for prevention initiatives in specific areas of vessel operations and spill prevention. The program involved only a small sample of the industry, but the conclusions may provide a starting point to consider the need for new policies in Alaska or elsewhere. The BIP program relied on self-assessment by operators, which is a methodology that other human factors researchers have found to be effective in collecting analytic data as well as in promoting an organizational awareness of safety issues (Hee *et al.*, 1999). A similar process could be repeated to target Alaska tanker operators specifically, or other segments of the maritime industry.

It is unclear the extent to which the 1993 Human Factors Plan for Maritime Safety has been referenced in recent years, as the USCG PTP program has evolved and the ISM standards have been implemented. It might be useful for the USCG or an outside entity to check the original objectives and critical tasks in the 1993 report against current accomplishments, to ensure that human factors prevention policies are progressing as envisioned. Similarly, an updated study might help to validate ongoing efforts and illuminate the need for additional programs or policies, within PTP, ISM, or other programs. Such a study should also consider how information collected at the company level could be compiled for analysis at an industry-wide level to illuminate trends in human factors risks and effective mitigation measures.

5.2.5 Include human factors analysis in oil spill risk assessments

Since human and organizational errors are inherent to the causal chain behind most accidents, it seems obvious that any measurement of spill risk must first address the human contribution. However, several authors have noted that a disconnect exists between the way we measure, attribute, and mitigate risks in the context of human-technological interactions. The common misperception that human factors are inherently unpredictable has led them to be discounted or ignored in many risk assessment models.

Risk assessments should consider organizational factors as well as technical issues; however, too often, technical and engineering systems are the focus of risk studies. In order to appropriately target risk mitigation measures at human factors, the relative contribution of human factors to overall risks must be considered. In a report that considers the need for an updated risk assessment for the PWS tanker trade, Grabowski (2005) recommends that a separate human factors analysis should be conducted, “given the importance of human and organizational performance questions in the [PWS tanker and] tug escort system.”

5.2.6 Address crew endurance management and fatigue reduction

Fatigue among vessel crewmembers, and particularly watchstanders, is consistently cited as a major human factor in marine accidents and mishaps. The USCG PTP program has developed recommendations for crew endurance management that advocate changes in watch schedules as one measure to reduce fatigue. However, watchstanding practices are only one component of the fatigue factor. Reductions in manning levels, increases in collateral duties, and unintended consequences of enhanced automation can also contribute to operator fatigue. Additional study is needed to understand and quantify both the causes and manifestations of fatigue.

5.2.7 Integrate human factors analyses with systems engineering

Technological improvements may actually lead to increases in overall accident risk due to a variety of human factors, including risk compensation and skill or knowledge deficiencies. Inadequate knowledge can often be a function of too many job tasks for one crewmember, which is a byproduct of insufficient manning. The integration of systems engineering with human factors analyses has been proposed by several authors as a way to predict how users might compensate for the effects of safety devices. Likewise, engineering system design must consider the abilities and limitations of human operators and must acknowledge the decreased margin for error that can be caused by enhanced automation and reduced manning levels, The USCG recommends a task-based approach to determining manning levels, to ensure that individual operators can safely manage the tasks required to operate a system or technology.

5.2.8 Consider human factors in developing and implementing regulations

Several researchers point out that new regulations can cause stress on the human-technology interactions and lead to unanticipated accidents or mishaps. However, if human factors analyses were incorporated or addressed more thoroughly in developing new regulations, such problems might be avoided. Some of the methodologies discussed in Section 4 for assessing the contribution of human factors to accidents by working directly with operations-level personnel may be transferable to the regulatory development process.

5.2.9 Promote a safety culture

The need for and benefits of a safety culture are obvious. Yet the fact that human factors are cited in as much as 80% of accidents suggests that we are a long way from realizing a complete safety culture in the marine industry. Several general policies and specific actions have been recommended to implement and promote a safety culture. Important elements of a safety culture include:

- Promoting an environment that recognizes and tolerates uncertainty in risk assessment and risk management;
- Promoting an environment where all personnel are comfortable expressing concerns or uncertainties;
- Ensuring that all personnel understand the risk consequences of their actions and job duties;
- Establishing wide safety margins;
- Establishing safety monitoring systems and reporting channels;
- Creating an organizational climate that recognizes individuals, groups, and organizational entities that display risk-averse performance;
- Creating an organizational climate that recognizes and addresses poor performance and risk-tolerant activities;
- Reallocating funds and resources previously spent to insure equipment and engineering systems toward risk management programs that address operators and human-technology interactions; and
- Ensuring proficiency with new technologies through regular testing, training, job aids, supervision, and evaluation of employees.

5.2.10 Measure the Effectiveness of Human Factors Prevention Programs

There are several prevention initiatives already in place at the industry, state, federal and international levels; however, there is very little information available in the published literature to document the effectiveness of such programs. Is PTP working to reduce spills caused by human error? Do companies that follow the ISM standards experience fewer oil spills caused by organizational error? An important component of all of the recommendations cited above is identifying effective prevention measures and implementing them at the individual, organizational, and industry levels.

Analytic techniques and models that consider human performance breakdowns and appropriate interventions emphasize the need to tailor interventions to meet the specific individual or operational factor(s) that cause accidents. For example, while additional training is often the first response to address a human performance breakdown, training may not be the appropriate intervention if the breakdown was actually caused by insufficient oversight or poor communications.

5.3 Conclusions

This report set out to identify where and how to focus prevention efforts to reduce oil spills from tankers that are caused by human factors. Four research questions were presented as a means for framing this discussion.

5.3.1 What do we know about the contribution of human factors to oil spills?

One commonly cited statistic attributes 80% of all marine accidents to human factors causes. An analysis of publicly available databases failed to yield any additional statistics to quantify *specific* human factors contributions to accident causality. However, we know that human factors are a major component of oil spill and accident risk, and as such should be addressed in risk mitigation and prevention measures.

5.3.2 How can we use oil spill data and analytic tools to understand human factors risks?

This report describes a number of different models and analytic tools that can be applied to better understand and quantify the contributions of individual, group, and organizational components of human factors. Improve data keeping practices that account for the complex nature of accident causality is necessary to develop quantitative data sets on human factors. Near miss and "small" incident data can also be compiled and analyzed to learn from past incidents. Because oil spills from tankers, especially major spills, are such infrequent events, other models and analytic tools have been developed to model human contributions to accidents in order to better understand the risks.

5.3.3 What options exist to prevent/mitigate spills caused by human factors?

A number of initiatives at the corporate, industry-wide, and regulatory levels have been applied to prevent or mitigate spills caused by human factors. The majority of these, however, are voluntary practices that are not necessarily subject to oversight or enforcement. Section 5.2 of this report recommends ten specific measures that may be applied to the challenge of reducing accidents and oil spills caused by human factors.

5.3.4 What is the relationship between oil spill prevention technologies (such as double hulls) and human factors?

This report considers the complex and dynamic interaction between human operators and engineered systems and concludes that improved technologies, redundant systems, and enhanced automation generally do not prevent oil spills caused by human error. These systems can prevent a spill from occurring if the inner hull is not punctured, or significantly reduce the impact or severity of an oil spill once it occurs; however, they cannot prevent the human or organizational errors that cause such accidents. Moreover, technological and engineering improvements in the marine sector have been shown, in some cases, to actually increase the risk of an oil spill or accident occurring due to human factors such as fatigue, skill or knowledge deficiencies, or risk compensation.

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7 Acronyms

ABS	American Bureau of Shipping
AWO	American Waterways Operators
BC	British Columbia
EDN	Event-decision network
FAA	Federal Aviation Administration
FSA	Formal safety assessment
IMO	International Maritime Organization
Intertanko	International Federation of Independent Tanker Owners
ISM	International Safety Management
ISO	International Standards Organization
ITOPF	International Tanker Owners' Pollution Federation
MARS	Nautical Institute's International Marine Accident Reporting Scheme
MISLE	Marine Information for Safety and Law Enforcement
NRC	National Research Council
OPA 90	Oil Pollution Act of 1990
PPAS	Professional performance analysis system
PTP	Prevention Through People
PWS	Prince William Sound
PWSRCAC	Prince William Sound Regional Citizen's Advisory Council
RCP	Responsible Carriers Program
RIDs	Regulatory impact diagrams
SMAS	Safety Management Assessment System
SOLAS	International Convention for the Safety of Life at Sea
TAPS	Trans-Alaska Pipeline System
Task Force	The Pacific States/British Columbia Oil Spill Task Force
VBAP	Voluntary Best Achievable Protection program