2002

Improving Incident Investigation through Inclusion of Human Factors

Anita Rothblum
U.S. Coast Guard

David Wheal
U.K. Department for Transport

Stuart Withington
U.K. Department for Transport

Scott A. Shappell
FAA Civil Aeromedical Institute

Douglas A. Wiegmann
University of Illinois at Urbana-Champaign

See next page for additional authors

Authors

Anita Rothblum, David Wheal, Stuart Withington, Scott A. Shappell, Douglas A. Wiegmann, William Boehm, and Marc Chaderjian

WORKING GROUP 1

2ND INTERNATIONAL WORKSHOP ON HUMAN FACTORS IN OFFSHORE OPERATIONS (HFW2002)

HUMAN FACTORS IN INCIDENT INVESTIGATION AND ANALYSIS

Dr. Anita M. Rothblum
U.S. Coast Guard Research & Development Center
Groton, CT 06340

Capt. David Wheal and Mr. Stuart Withington
Marine Accident Investigation Branch
U.K. Department for Transport
Southampton SO15 2DZ

Dr. Scott A. Shappell
FAA Civil Aeromedical Institute
Oklahoma City, OK 73125

Dr. Douglas A. Wiegmann
University of Illinois at Urbana-Champaign
Institute of Aviation
Savoy, IL 61874

Mr. William Boehm
Stolt-Nielsen Transportation Group
Houston, TX 77015

Dr. Marc Chaderjian
California State Lands Commission
Marine Facilities Division
Long Beach, CA 90802

April 8 – 10, 2002
Houston, Texas

ABSTRACT

Studies of offshore and maritime incidents (accidents and near-misses) show that 80% or more involve human error. By investigating incidents, we can identify safety problems and take corrective actions to prevent future such events. While many offshore and maritime companies have incident investigation programs in place, most fall short in identifying and dealing with human errors. This paper discusses how to incorporate human factors into an incident investigation program. Topics include data collection and analysis and how to determine the types of safety interventions appropriate to safeguard against the identified risks. Examples are provided from three organizations that have established their own human factors investigation programs.

DISCLAIMER

ACKNOWLEDGEMENTS

The authors wish to thank their organizations for granting the permission both to contribute their time to the development of this paper and to share their organization's data and lessons learned so that others may profit from our experiences. Thanks to Rodger Holdsworth and Christy Franklyn of Risk, Reliability and Safety Engineering for providing guidance and reviews of this paper and for supplying information, references, and a figure used herein. Thanks to Gerry Miller (G.E. Miller and Associates) for the clarifying discussion of his Triangle of Effectiveness, help with locating references, and for his editing suggestions. Rachael Gordon contributed material on error detection and recovery, as well as information about her Human Factors Investigation Tool (HFIT). Jan Erik Vinnem shared a presentation on Norway's offshore near-miss database. This paper benefited from lively discussions at the April workshop and from amplifying information contributed by Scott Bergeron (McDermott), Melissa Roberts (ChevronTexaco), Sally Caruana (BOMEL Ltd.), and Cyril Arney (ExxonMobil). Thanks also to the following people who kindly took the time to critique a draft of this document: Capt. Dan Maurino (International Civil Aviation Organization), Trond S. Eskedal (Norwegian Petroleum Directorate), Jeffery Thomas (ExxonMobil), and James Reason (University of Manchester).

TABLE OF CONTENTS

TABLE OF FIGURES

PAGE

HUMAN FACTORS IN INCIDENT INVESTIGATION AND ANALYSIS

1.0 INTRODUCTION

Traditionally, incident investigation has focused on hardware issues, such as material failures and equipment malfunctions. In the last fifteen years or so, it has become increasingly evident that human factors, rather than hardware factors, are responsible for most of the precursors to incidents. While many offshore and maritime companies have incident investigation programs in place, most consider human contributions to incidents only in a superficial way, if at all. The purpose of this paper is to help offshore and maritime companies incorporate human factors into their incident investigation programs so that they can identify human causes of incidents and determine effective safety interventions to prevent such incidents in the future.

1.1 Why Study Incidents?

An "accident" is defined as "an unplanned event or sequence of events that results in undesirable consequences" (Center for Chemical Process Safety, 1992, p.327). Accidents represent the proverbial "tip of the iceberg". It has been estimated that for every accident, there are about *600 near-misses*[1] (Det Norske Veritas, 1995; Ferguson & Landsburg, 1998; Bea, Holdsworth, & Smith, 1997). Essentially, a near-miss is an accident that almost happened. Near-misses and accidents have the same causes, so studying near-misses can help us understand safety problems and make corrective changes *before* an accident takes place. In addition, since near-misses do not result in full-blown casualties, studying near-misses can help us learn how to develop early-warning systems to detect when conditions have become "non-normal" and also show us what steps were taken that *avoided the accident.*

Incident[2] investigation and analysis – that is, the study of accidents and near-misses – is squarely in line with the intent of the *International Safety Management (ISM) Code.* ISM requires that a company provide for a safe work environment and safe practices in maritime operations and establish safeguards against all identified risks. Incident investigation helps the company to identify its risks and to understand the underlying causes of incidents. This in turn helps the company develop safe work practices.

---

[1] A "near-miss" is defined as "an extraordinary event that could reasonably have resulted in a negative consequence under slightly different circumstances, but actually did not" (Center for Chemical Process Safety, 1992, p. 329).

[2] An "incident" is defined as including "all accidents and all near-miss events that did or could cause injury, or loss of or damage to property or the environment" (Center for Chemical Process Safety, 1992, p. 1).

This paper will help you to learn about human error and how it contributes to virtually every incident. This paper will also show you how to establish a human factors incident investigation program in your company and how to analyze the data collected so that you can learn from incidents and identify how to improve your policies and work practices to achieve a higher level of safety. Examples are provided from three different organizations that have established their own human factors investigation programs, sharing “lessons learned” and how the program has benefited them.

1.2 Background from the 1996 International Workshop on Human Factors in Offshore Operations

Studies of accidents and other incidents on offshore platforms have indicated that the vast majority of these accidents involve human error. In fact, about 80% do, and a further 80% of these occur during operations (Bea, Holdsworth, & Smith, 1997). The need to understand and control these human errors led to the assemblage of the 1996 International Workshop on Human Factors in Offshore Operations. The 1996 Workshop took a broad look at how Human Factors – often called Human and Organizational Factors to underscore the fact that most of these errors occur *not* within the span of control of the frontline operator, but are caused instead by decisions, policies, and operating procedures handed down by higher levels of the organization – affect every aspect of the offshore industry, from the design and fabrication of offshore production facilities, to field operations and maintenance, to management systems for improving safety and productivity. That Workshop laid the groundwork for the current workshop, which is delving into more detail on a number of human factors issues, including incident investigation and analysis.

The 1996 Workshop provided some good background material on human error (Bea, Holdsworth, & Smith, 1997; Card, 1997; Wenk, 1997), and even provided some tools that can be employed for incident investigation (Bea, 1997; Howard, et al., 1997; Kirwan, 1997; Moore, et al., 1997; Scient, Gordon, et al., 1997); these papers are heartily commended to the interested reader. The present paper goes into more detail on these topics and focuses the discussions on: the understanding of how human errors arise and contribute to incidents; a specific set of tools for representing the events and causes of an incident; dissecting out the different levels of human error; analyzing incident data; and using the human error model to select the most effective safety interventions. In short, this paper attempts to provide the reader with a “soup to nuts” examination of how to build a successful human factors incident investigation program.

1.3 The Typical Offshore Incident System and How Human Factors Data Can Enrich It

Thanks, in part, to OSHA and EPA regulations on Process Safety and Risk Management (e.g., 29 CFR 1910.119 and 40 CFR Part 68) and to the International Safety Management Code, many offshore and maritime companies already have an incident investigation program in place. These programs often follow well-grounded investigative practices, providing investigation team members with training in the basics of incident investigation, gathering and documenting evidence, and interviewing techniques. Many of these companies also keep an incident database and may do frequency and trending analysis. In short, they have many of the elements of a good incident investigation program already in place. However, where most of these programs fall short is in the areas of identifying human factors causes and determining how best to correct these problems.

While a number of companies attempt to consider "operator errors" during incident investigations, these operator errors represent only the tip of the human factors iceberg. As described in more detail in Section 2, most human factors causes originate further up the organizational chain, taking the form of poor management decisions, inadequate staffing, inadequate training, poor workplace design, etc. Simply identifying the "mistake" an operator made, and not "drilling down" to identify the underlying, organizational causes of that mistake, will not help to prevent reoccurrences of the incident. Because most offshore incident investigation programs do not have a thorough process for identifying the many types of human error, and the various levels of the organizations from which such errors originate, they lack the tools with which to make effective, human error-reducing, and thus incident-reducing, changes.

The remainder of this paper will provide the tools to understand, investigate for, and productively solve human error causes of incidents:

- Section 2 will describe what human error is and how it causes incidents; it will also discuss some of the most pervasive types of human error in the maritime and offshore industries.
- Section 3 outlines the keys to building a successful human factors incident investigation and analysis program. It will describe in detail the concept of an organization's "layers of system defenses" against catastrophic events, and how a weakening of these system defenses can result in incidents.
- Section 4 presents the Human Factors Analysis and Classification System (HFACS) – a simple to understand and use system for categorizing the types of human errors at each layer of system defense. HFACS has been used successfully in military and other industrial applications, and is compatible with maritime and offshore needs.
- Section 5 walks you through the analysis of an incident. It introduces Events and Causal Factors Charting, a method which first determines the events which occurred in the evolving incident (similar to a timeline analysis), and then considers the contributing causes to each event. The combination of Events and Causal Factors Charting, followed by an HFACS analysis of the causes, provides a powerful tools for ferreting out the underlying human error contributions to an incident.
- Data analysis is the topic of Section 6. Several different approaches are introduced, allowing companies to go well beyond the simple frequency and trend analysis in common usage today. Proactive, thoughtful data analysis is key to a company's awareness of safety issues and their probable underlying causes.
- Finding effective safety solutions is discussed in Section 7. This section takes you from the results of your HFACS and data analyses, through focused information-gathering on safety problems, to crafting effective interventions. The "triangle of effectiveness" is a

tool that will help you to find the most effective human factors interventions and safety solutions.

- Section 8 presents the "lessons learned" and "success stories" from three organizations now involved in human factors incident investigation and analysis. Their experiences can give you a head start with your own program.
- Section 9 wraps up the paper with a summary of the most important points discussed.
- The Appendices provide you with sample human factors-related questions to ask during an investigation, additional examples of human factors incident investigation classification schemes, database elements to capture the non-human factors relevant to an investigation, and specific data elements that can help to identify and understand three of the most prevalent types of human error in maritime/offshore accidents: fatigue, inadequate communications, and limitations in skill and knowledge.

When a focus on human error is incorporated into your existing incident investigation, analysis, and intervention program (as in Fig. 1), it can produce great benefits for your company, including fewer incidents, fewer lost-time accidents, improved employee morale, greater productivity, and an overall improvement to the bottom line.

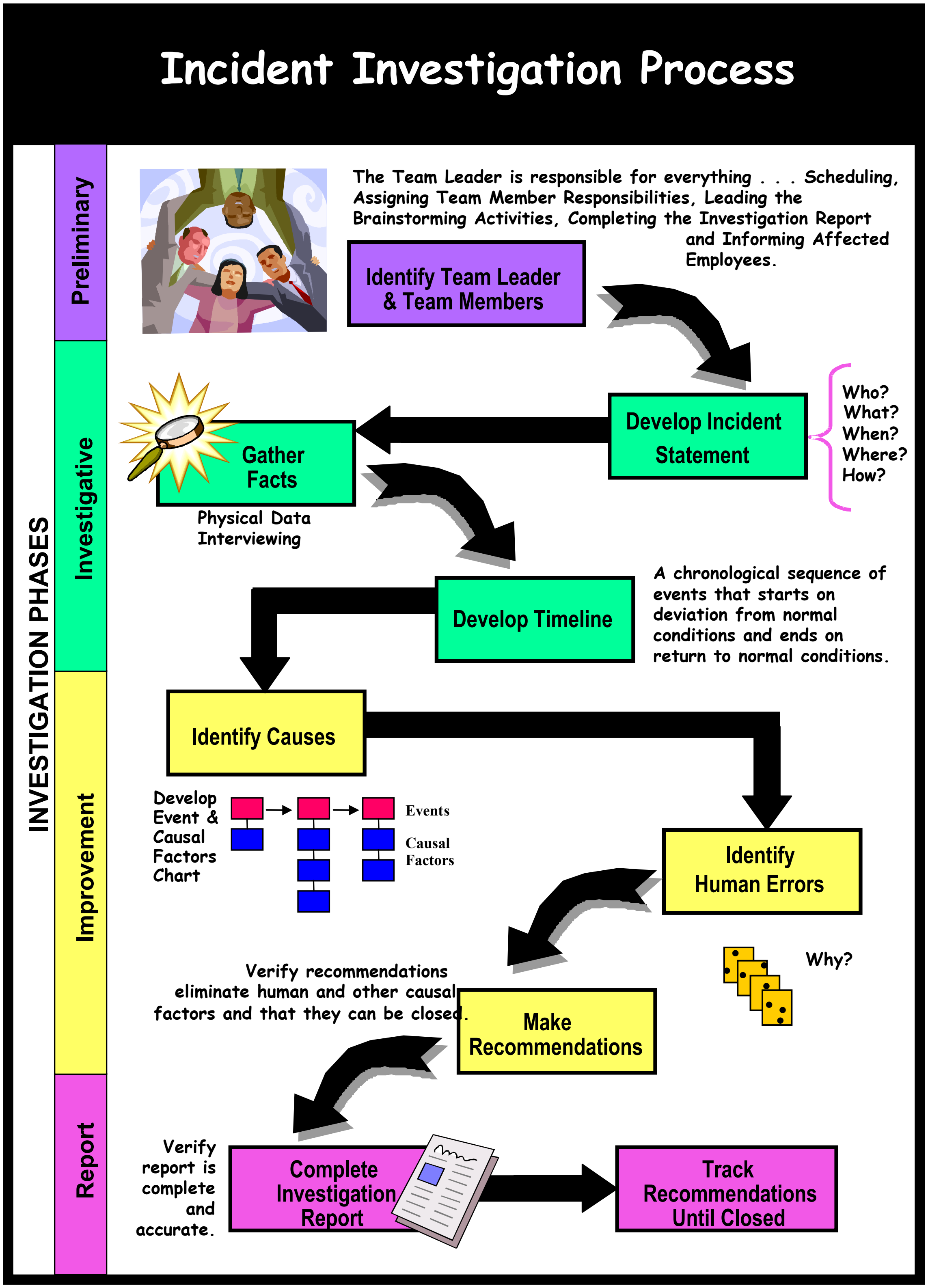


Figure 1. Incident Investigation Process.
(modified from Franklyn, 2000)

2.0 HUMAN ERROR[3]

Over the last 40 years or so, the shipping industry has focused on improving the structure of ships and platforms and improving the reliability of equipment systems in order to reduce casualties and increase efficiency and productivity. Today's maritime and offshore systems are technologically advanced and highly reliable. Yet, the maritime casualty rate is still high. The reason for this is because ship/offshore structure and system reliability are a relatively small part of the safety equation. The maritime system is a *people* system, and human errors figure prominently in casualty situations. About 75-96% of marine casualties are caused, at least in part, by some form of human error. Studies have shown that human error contributes to:

- 84-88% of tanker accidents (Transportation Safety Board of Canada, 1994)
- 79% of towing vessel groundings (Cormier, 1994)
- 89-96% of collisions (Bryant, 1991; U.K. P&I Club, 1992)
- 75% of allisions (Bryant, 1991)
- 75% of fires and explosions (Bryant, 1991)

Therefore, if we want to make greater strides towards reducing marine casualties, we must begin to focus on the types of human errors that cause casualties.

One way to identify the types of human errors relevant to the maritime and offshore industries is to study incidents and determine how they happen. Chairman Jim Hall of the National Transportation Safety Board (NTSB) has said that accidents can be viewed as very successful events. What Chairman Hall means by "successful" is that it is actually difficult to create an accident (thank goodness!). Accidents are not usually caused by a single failure or mistake, but by the confluence of a whole series, or chain, of errors. In looking at how accidents happen, it is usually possible to trace the development of an accident through a number of discrete events.

A Dutch study of 100 marine casualties (Wagenaar & Groeneweg, 1987) found that the number of causes per accident ranged from 7 to 58, with a median of 23[4]. Minor things go wrong or little mistakes are made which, in and of themselves, may seem innocuous. However, sometimes when these seemingly minor events converge, the result is a casualty. In the study, human error was found to contribute to 96 of the 100 accidents. In 93 of the accidents, multiple human errors were made, usually by two or more people, each of whom made about two errors apiece. But here is the most important point: *every human error* that was made was determined to be a *necessary condition* for the accident. That means that if just one of those human errors had *not* occurred, the chain of events would have been broken, and *the accident would not have happened*. Therefore, if we can find ways to prevent some of these human errors, or at least increase the probability that such errors will be noticed and corrected, we can achieve greater marine safety and fewer casualties.

---

[3] This section is taken from Rothblum (2000).

[4] This means that half the accidents had 7-23 causes and the other half of the accidents had 23-58 causes.

2.1 Types of Human Error

What do we mean by "human error"? Human error is sometimes described as being one of the following: an incorrect decision, an improperly performed action, or an improper lack of action (inaction). Probably a better way to explain human error is to provide examples from two real marine casualties.

The first example is the collision of the *M/V SANTA CRUZ II* and the USCG Cutter *CUYAHOGA*, which occurred on a clear, calm night on the Chesapeake Bay (Perrow, 1984). Both vessels saw each other visually and on radar. So what could possibly go wrong? Well, the *CUYAHOGA* turned in front of the *SANTA CRUZ II*. In the collision that ensued, 11 Coast Guardsmen lost their lives. What could have caused such a tragedy? Equipment malfunctions? Severe currents? A buoy off-station? No, the sole cause was human error.

There were two primary errors that were made. The first was on the part of the *CUYAHOGA*'s captain: he misinterpreted the configuration of the running lights on the *SANTA CRUZ II*, and thus misperceived its size and heading. When he ordered that fateful turn, he thought he was well clear of the other vessel. The second error was on the part of the crew: they realized what was happening, but failed to inform or question the captain. They figured the captain's perception of the situation was the same as their own, and that the captain must have had a good reason to order the turn. So they just stood there and let it happen. Another type of human error that may have contributed to the casualty was insufficient manning (notice that this is not an error on the part of the captain or crew; rather, it is an error on the part of a "management" decision-maker who determined the cutter's minimum crew size). The vessel was undermanned, and the crew was overworked. Fatigue and excessive workload may have contributed to the captain's perceptual error and the crew's unresponsiveness.

The second example is the grounding of the *TORREY CANYON* (Perrow, 1984). Again we have clear, calm weather--this time it was a daylight transit of the English Channel. While proceeding through the Scilly Islands, the ship ran aground, spilling 100,000 tons of oil.

At least four different human errors contributed to this incident. The first was economic pressure, that is, the pressure to keep to schedule (pressure exerted on the master by management). The *TORREY CANYON* was loaded with cargo and headed for its deep-water terminal in Wales. The shipping agent had contacted the captain to warn him of decreasing tides at Milford Haven, the entrance to the terminal. The captain knew that if he didn't make the next high tide, he might have to wait as much as five days before the water depth would be sufficient for the ship to enter.

This pressure to keep to schedule was exacerbated by a second factor: the captain's vanity about his ship's appearance. He needed to transfer cargo in order to even out the ship's draft. He could have performed the transfer while underway, but that would have increased the probability that he might spill a little oil on the decks and come into port with a "sloppy" ship. So instead, he opted to rush to get past the Scillies and into Milford Haven in order to make the transfer, thus increasing the pressure to make good time.

The third human error in this chain was another poor decision by the master. He decided, in order to save time, to go *through* the Scilly Islands, instead of *around* them as originally planned. He made this decision even though he did not have a copy of the *Channel Pilot* for that area, and even though he was not very familiar with the area.

The final human error was an equipment design error (made by the equipment manufacturer). The steering selector switch was in the wrong position: it had been left on autopilot. Unfortunately, the design of the steering selector unit did not give any indication of its setting at the helm. So when the captain ordered a turn into the western channel through the Scillies, the helmsman dutifully turned the wheel, but nothing happened. By the time they figured out the problem and got the steering selector back on "manual", it was too late to make the turn, and the *TORREY CANYON* ran aground.

As these two examples show, there are many different kinds of human error. It is important to recognize that "human error" encompasses much more than what is commonly called "operator error". In order to understand what causes human error, we need to consider how humans work within the maritime system.

2.2 The Maritime System: People, Technology, Environment, and Organizational Factors

As was stated earlier, the maritime system is a *people* system (Fig. 2). People interact with technology, the environment, and organizational factors. Sometimes the weak link is with the people themselves; but more often the weak link is the way that technological, environmental, or organizational factors influence the way people perform. Let's look at each of these factors.

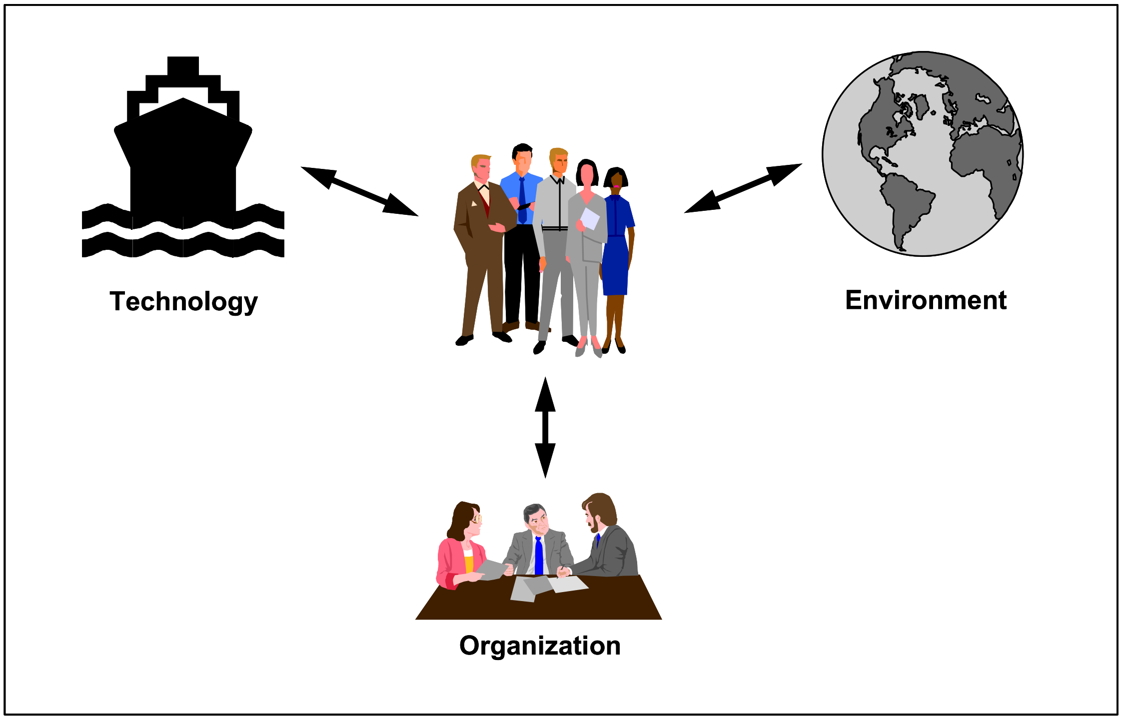


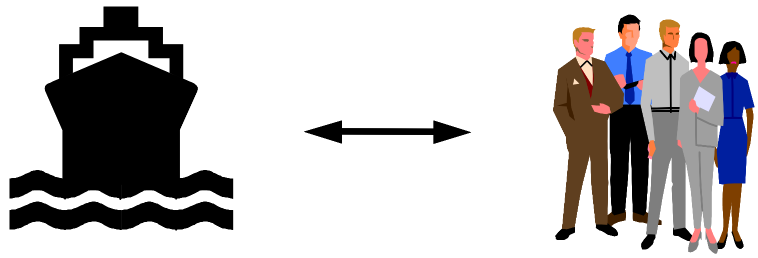
Figure 2. The Maritime System Is A *People* System

First, the people. In the maritime system this could include the ship's crew, pilots, dock workers, Vessel Traffic Service operators, and others. The performance of these people will be dependent on many traits, both innate and learned (Fig. 3). As human beings, we all have certain abilities and limitations. For example, human beings are great at pattern discrimination and recognition. There isn't a machine in the world that can interpret a radar screen as well as a trained human being can. On the other hand, we are fairly limited in our memory capacity and in our ability to calculate numbers quickly and accurately--machines can do a much better job. In addition to these inborn characteristics, human performance is also influenced by the knowledge and skills we have acquired, as well as by internal regulators such as motivation and alertness.

- **Knowledge**
- **Skills**
- **Abilities**
- **Memory**
- **Motivation**
- **Alertness**

Figure 3. The Maritime System: People

The design of technology can have a big impact on how people perform (Fig. 4). For example, people come in certain sizes and have limited strength. So when a piece of equipment meant to be used outdoors 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 often designed without much thought to the information that the user needs to access. Critical information is sometimes either not displayed at all or else displayed in a manner which is not easy to interpret. Such designs can lead to inadequate comprehension of the state of the system and to poor decision making.



- **Anthropometry**
- **Equipment layout**
- **Information display**
- **Maintenance**

- **Reach, strength, agility**
- **Perception & comprehension**
- **Decision-making**
- **Safety & performance**

Figure 4. The Maritime System: Effect of Technology on People

The environment affects performance, too (Fig. 5). By “environment” we are including not only weather and other aspects of the physical work environment (such as lighting, noise, and temperature), but also the regulatory and economic climates. The physical work environment directly affects one’s ability to perform. For example, the human body performs best within a fairly restricted temperature range. Performance will be degraded at temperatures outside that range, and fail altogether in extreme temperatures. High sea states and ship vibrations can affect locomotion and manual dexterity, as well as cause stress and fatigue. Tight economic conditions can increase the probability of risk-taking (e.g., making schedule at all costs).

Finally, organizational factors, both crew organization and company policies, affect human performance (Fig. 6). Crew size and training decisions directly affect crew workload and their capabilities to perform safely and effectively. A strict hierarchical command structure can inhibit effective teamwork, whereas free, interactive communications can enhance it. Work schedules which do not provide the individual with regular and sufficient sleep time produce fatigue. Company policies with respect to meeting schedules and working safely will directly influence the degree of risk-taking behavior and operational safety.

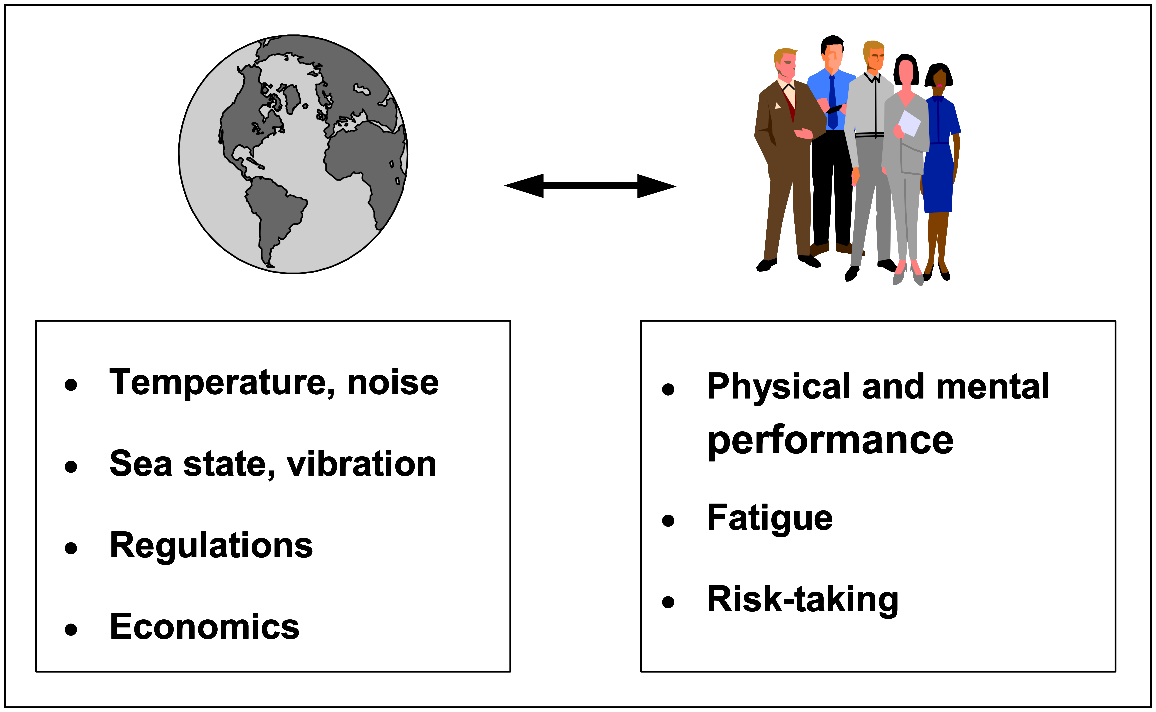


Figure 5. The Maritime System: Effect of Environment on People

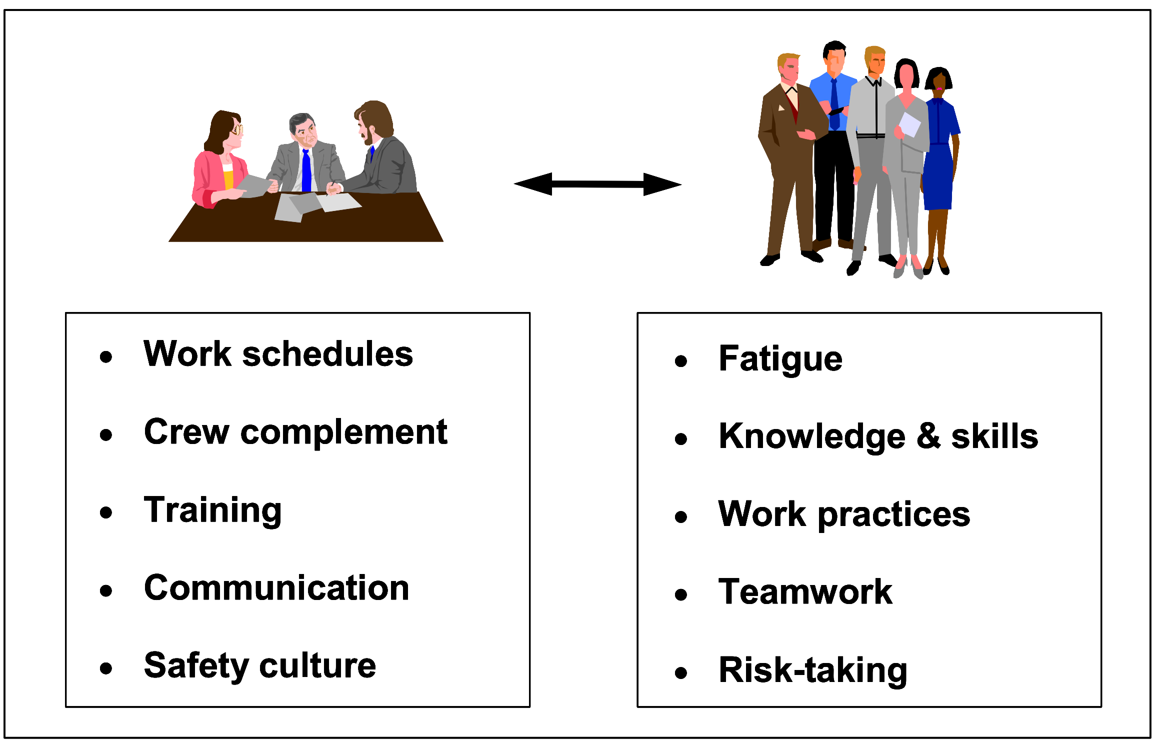


Figure 6. The Maritime System: Effect of Organization on People

As you can see, while human errors are all too often blamed on "inattention" or "mistakes" on the part of the operator, more often than not they are symptomatic of deeper and more complicated problems in the total maritime system. Human errors are generally caused by technologies, environments, and organizations which are incompatible in some way with optimal human performance. These incompatible factors "set up" the human operator to make mistakes. So what is to be done to solve this problem? Traditionally, management has tried either to cajole or threaten its personnel into not making errors, as though proper motivation could somehow overcome poorly designed management and equipment systems and inborn human limitations. In other words, the human has been expected to adapt to the system. *This does not work*. Instead, what needs to be done is to *adapt the system to the human*.

The discipline of human factors is devoted to understanding human capabilities and limitations, and to applying this information to design equipment, work environments, procedures, and policies that are compatible with human abilities. In this way we can design technology, environments, and organizations which will work *with* people to enhance their performance, instead of working *against* people and degrading their performance. This kind of *human-centered* approach (that is, adapting the system to the human) has many benefits, including increased efficiency and effectiveness, decreased errors and incidents, decreased training costs, decreased personnel injuries and lost time, and increased morale.

2.3 Human Factors Issues in the Maritime Industry

What are some of the most important human factors challenges facing the maritime industry today? A study by the U.S. Coast Guard (1995) found many areas where the industry can improve safety and performance through the application of human factors principles. Below are summaries of the "top ten" human factors areas that need to be improved in order to prevent casualties.

2.3.1 Fatigue

The NTSB has identified fatigue to be an important cross-modal issue, being just as pertinent and in need of improvement in the maritime industry as it is in the aviation, rail, and automotive industries. Fatigue has been cited as the "number one" concern of mariners in two different studies (Marine Transportation Research Board, 1976; National Research Council, 1990). It was also the most frequently mentioned problem in a recent Coast Guard survey (U.S. Coast Guard, 1995). A recent study has objectively substantiated these anecdotal fears: in a study of critical vessel casualties[5] and personnel injuries, it was found that fatigue contributed to 16% of the vessel casualties and to 33% of the injuries (McCallum, Raby, & Rothblum, 1996).

[5] A "critical" vessel casualty was defined as a vessel casualty in which there was significant damage to the vessel or property, or in which the safety of the crew was at risk.

2.3.2 Inadequate Communications

Another area for improvement is communications--between shipmates, between masters and pilots, ship-to-ship, and ship-to-VTS. An NTSB report (National Transportation Safety Board, 1981) stated that 70% of major marine collisions and allisions occurred while a State or federal pilot was directing one or both vessels. Better procedures and training can be designed to promote better communications and coordination on and between vessels. Bridge Resource Management (BRM) is a first step towards improvement.

2.3.3 Inadequate General Technical Knowledge

In one study, this problem was responsible for 35% of casualties (Wagenaar & Groeneweg, 1987). The main contributor to this category was a lack of knowledge of the proper use of technology, such as radar. Mariners often do not understand how the automation works or under what set of operating conditions it was designed to work effectively. The unfortunate result is that mariners sometimes make errors in using the equipment or depend on a piece of equipment when they should be getting information from alternate sources.

2.3.4 Inadequate Knowledge of Own Ship Systems

A frequent contributing factor to marine casualties is inadequate knowledge of own ship operations and equipment. Several studies and casualty reports have warned of the difficulties encountered by crews and pilots who are constantly working on ships of different sizes, with different equipment, and carrying different cargoes. The lack of ship-specific knowledge was cited as a problem by 78% of the mariners surveyed (National Research Council, 1990). A combination of better training, standardized equipment design, and an overhaul of the present method of assigning crew to ships can help solve this problem.

2.3.5 Poor Design of Automation

One challenge is to improve the design of shipboard automation. Poor design pervades almost all shipboard automation, leading to collisions from misinterpretation of radar displays, oil spills from poorly designed overfill devices, and allisions due to poor design of bow thrusters. Poor equipment design was cited as a causal factor in one-third of major marine casualties (Wagenaar & Groeneweg, 1987). The “fix” is relatively simple: equipment designers need to consider how a given piece of equipment will support the mariner’s task and how that piece of equipment will fit into the entire equipment “suite” used by the mariner. Human factors engineering methods and principles are in routine use in other industries to ensure human-centered equipment design and evaluation. The maritime industry needs to follow suit.

2.3.6 Decisions Based on Inadequate Information

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).

2.3.7 Poor Judgement

Risky decisions can lead to accidents. This category contained actions that were not consistent with prudent seamanship, such as passing too closely, excessive speed, and ignoring potential risks.

2.3.8 Faulty Standards, Policies, or Practices

This is an oft-cited category and covers a variety of problems. Included in this category is the lack of available, precise, written, and comprehensible operational procedures aboard ship (if something goes wrong, and if a well-written manual is not immediately available, a correct and timely response is much less likely). Other problems in this category include management policies which encourage risk-taking (like pressure to meet schedules at all costs) and the lack of consistent traffic rules from port to port.

2.3.9 Poor Maintenance

Published reports (Bryant, 1991; National Research Council, 1990) and survey results (US Coast Guard, 1995) expressed concern regarding the poor maintenance of ships. Poor maintenance can result in a dangerous work environment, lack of working backup systems, and crew fatigue from the need to make emergency repairs. Poor maintenance is also a leading cause of fires and explosions (Bryant, 1991).

2.3.10 Hazardous Natural Environment

The marine environment is not a forgiving one. Currents, winds, ice, and fog make for treacherous working conditions. When we fail to incorporate these factors into the design of our ships, platforms, and equipment, and when we fail to adjust our operations based on hazardous environmental conditions, we are at greater risk for casualties.

These and other human errors underlie almost every maritime incident. By studying incidents to understand their contributing causes, we can learn how to redesign our policies, procedures, work environments, and equipment to be more compatible with our human users and, thus, bring about improved safety and productivity. In the next sections we will discuss how to develop a human factors incident investigation program for your company.

3.0 BUILDING A HUMAN FACTORS INCIDENT INVESTIGATION PROGRAM

A well-designed company safety program is multi-faceted. Health, Safety, and Environment (HSE) management, risk assessment and management, behavior based safety management (BBSM), quality programs, and project management all play a role in improving safety. A careful Job Hazards Analysis (JHA) or Job Safety Analysis (JSA) can identify work hazards and recommend redesigns of equipment and work procedures, as well as associated precautions that can prevent accidents.

Behavior based safety management and other related processes work hand-in-hand with incident investigation to identify potential problems. Behavior based safety management is a *proactive* process which examines the workplace to identify problems *before* an incident occurs, while incident investigation is a *reactive* process which identifies workplace and procedural hazards that caused an accident or near-miss. The data from both types of processes should be used together to gain the most complete understanding of potential hazards. The fact that both these processes can be used to prevent incidents was underscored by a fatal fall that occurred at a construction site. Just prior to the accident, the company's BBSM data had shown that personnel were not hooking up or using fall protection properly. The data also identified several barriers to the safe behavior, including: lack of available hook up points; lack of available fall protection in high hazard areas; lack of training on proper use of protective equipment; unclear procedures; and discomfort associated with wearing harnesses. By collecting these kinds of upstream indicators, a company can correct the situation before an incident happens.

Unfortunately, we're not always able to foresee and prevent every type of incident that might occur. This is what makes incident investigation an important part of the company's overall safety strategy. An incident investigation and analysis program is essential to understanding the underlying, and sometimes hidden, causes of workplace incidents. Proper identification of the true contributors to accidents allows a company to establish workable preventive measures. This section discusses how to build a human factors incident investigation program.

Additional information and publications on human factors and incident investigation in the offshore industry are offered on several web sites. The American Institute of Chemical Engineers (http://www.aiche.org) offers two documents, "Guidelines for Investigating Chemical Process Incidents" and "International Conference and Workshop of Process Industry Incidents". The U.K.'s Health and Safety Executive (http://www.open.gov.uk/hse/hsehome.htm) has the publication "Human and Organisation Factors in Offshore Safety". The International Association of Oil and Gas Producers (http://www.ogp.org.uk) has a safety incident reporting system and incident statistics.

3.1 Keys to a Successful Human Factors Incident Investigation Program

Before we jump into the details of how to investigate for human factors causes of incidents, it is important to mention a few key factors which will encourage cooperation in incident investigations and will promote good data quality. These key factors are: an open, fair, improvement-seeking culture; an understanding of the purpose and scope of the incident investigation program; training for investigators on human factors; a database classification scheme (taxonomy) that supports the goals of the incident investigation program; a simple, user-friendly way of entering incident data; and feedback to show how incident data have been used to improve safety (Hill, Byers, & Rothblum, 1994).

3.1.1 An Open, Fair, Improvement-Seeking Culture

The fundamental purpose of an incident investigation is to understand the circumstances and causes of the incident with the aim of improving safety. We want to understand: what happened; how it happened; why it happened; and, most importantly, what steps can be taken to prevent it from happening again. Only by dispassionately analyzing the incident evolution in detail and determining its underlying contributing factors can we design and implement effective remedial actions. It is important to remember that we are *not* out to attribute blame: actions taken solely to "blame and shame" generally do little to prevent similar incidents from occurring in the future. This is because, as discussed in the previous section, most incidents are not the "fault" of a given person; rather, they are indicative of deficiencies within the system. Companies whose incident investigations focus on "finger-pointing" (i.e., identifying the person who is supposedly "to blame" for the incident) short-circuit their ability to find and understand the *real* causes of the incident. Only by analyzing and addressing the contributing factors – the system deficiencies – that underpin the actions of those directly involved, can we make real progress in reducing the frequency of incidents. Therefore, it is necessary to foster an open and trusting environment where personnel feel free to discuss the evolution of an incident without fear of unjust reprisal. If personnel know that the purpose of the investigation is to identify how to improve safety, and that the investigation will lead to a fair and objective analysis of the incident, they will be much more likely to participate in a candid interview. Without such a supportive environment, involved individuals will be reluctant to cooperate in a full disclosure of the events leading to an incident.

3.1.2 Common Understanding of the Purpose and Scope of the Incident Investigation Program

The incident investigation program, and the database which supports it, should be constructed to accomplish a well-defined purpose. Program managers need to agree on specific questions the program – and, therefore, the incident database – will be expected to answer. For example, a company might wish to focus on reducing maintenance incidents which result in lost time for the employee. Such a program, and its database, would need information on the type of maintenance activity being performed, the type of injury sustained (accident) or narrowly avoided (near-miss), damage to equipment or workplace, lost time and money due to injury (or potential loss, in the case of a near-miss), and causes of the of the (near-) injury (such as poor standard operating procedures, insufficient lighting, undermanning, equipment defects, inadequate task design, lack of safety policies, etc.). In contrast, a program focused on preventing hazardous material spills/emissions could have a significantly different set of factors of interest (such as type of hazmat, regulations violated, location and size of spill, fines and clean-up costs; operational activities at time of spill; events and underlying causes leading to the spill). The point here is that the goals of your incident investigation program must drive the types of questions you will want to answer, which in turn dictate the types of data you will collect during the investigations.

A knowledge of the purpose of the database will guide the form the investigation takes and will help in determining the appropriate resources to devote to the investigation. If certain causal areas are known to be particularly important, effort will be concentrated in those areas. Conversely, if the investigators do not understand the purpose of the program, they will shape their investigations around their own biases and areas of expertise, rather than around the goals of the program.

Clear guidance is needed for investigators to know what level of detail is sufficient, and what resources are needed to properly fulfill the purpose of their investigations and thoroughly report their findings. In the offshore industry this is often formalized through a “charter” which is developed at the beginning of an incident investigation. The charter identifies the investigation team, states the responsibilities of the team, its goals (e.g., to identify causes or to develop recommendations), and a timeline for the investigation. The incident investigators, and *all* personnel, must understand the program goals and how their input will help promote safety improvements. Only then will the investigators know what types of data are important to collect, and only then will employees understand why their active cooperation is important.

3.1.3 Appropriate Training for Incident Investigators

An incident investigation program rests on the abilities of its investigators. Incident investigation does not come naturally: it must be trained. Investigators need background on how incidents evolve and the myriad events and attributes which can cause or contribute to the severity of an incident. They need to know how to ask appropriate questions, how to work with uncooperative witnesses, how to build an events and causal tree (or other tool to help guide the investigation). And, of course, they need to understand the specific goals of the company’s incident investigation program.

Human factors-related information is often overlooked even by seasoned investigators if they have not been specifically trained to identify such data. While it is both natural and expected that investigators will use their individual experiences and unique areas of expertise (e.g., engineering, navigation, drilling) when conducting investigations, some individuals may not have an adequate perspective to search for or recognize human-related causes. A related problem is that if a human factors element is not overlooked entirely, it is often oversimplified. A single “obvious” human-related contributing factor may be identified, such as “inattention”, without looking for the root cause (perhaps information overload, as a result of a poor display design). As described earlier, many external factors (technology, organization, environment) affect human performance, and it takes training for investigators to understand and recognize these underlying contributors.

In the offshore industry, it is fairly common for a company to “charter” an incident investigation team when an incident occurs. These *ad hoc* team members may include a combination of workers, line supervisors, and managers. It is important to choose a team that will be fair, unbiased, and objective. While team members are usually chosen because of their experience in the area where the incident occurred, they may have little or no background in either incident investigation or human factors. If the team is going to be successful at identifying the underlying causes of the incident, then at least some of the team members must have training and experience in human factors incident investigation.

3.1.4 Incident Database Classification Scheme

The database classification scheme (taxonomy) must be directly linked to the purpose and scope of the incident investigation program. The database elements must match the level of detail that is needed to answer the safety-related questions upon which the program goals are based. Too often an incident database is constructed in a haphazard way, with the program managers trying to think up data elements without first determining the questions the database is meant to answer. The sad result is a database of little value, which falls far short of supporting safety improvements.

When it comes to human factors information, the database must be compatible with both the program goals and the level of knowledge of the investigators. The terminology used in the classification scheme must be well-defined and understood by the investigators. In some cases, tools may be needed to help the investigator determine whether a given human factor is related to the incident.

For example, the term “fatigue” is very hard to define – many of us carry our own beliefs (correct or incorrect) as to what fatigue is and how it relates to safety. In order to obtain reliable and valid data on fatigue, it may be useful to determine specific pieces of data the investigator would collect and to provide an algorithm that would use these data to determine whether “fatigue” played a role in the incident. An example of this is the Fatigue Index Score being used by the U.S. Coast Guard (McCallum, Raby, & Rothblum, 1996; see App. G): investigators collect the number of hours worked and slept in the twenty-four hours preceding the casualty and also collect information on fatigue symptoms (e.g., difficulty concentrating, heavy eyelids, desire to sit down). These data are put into an equation which tells the investigator whether fatigue is a likely cause, and therefore whether a more extensive investigation needs to be done to determine what contributed to the fatigue. When the classification scheme is based on well-defined, quantifiable data, it increases the reliability and validity of the human factors causes identified (e.g., fatigue), and, more importantly, it keeps the investigator focused on *why* the human factors cause was present (e.g., insufficient sleep due to extended port operations).

A good database should also be adaptable to the changing needs of the organization. As the organization learns lessons from the incident data, it is probable that additional items or levels of detail will be desired from investigations, requiring a modification of the classification scheme and database. One final note: while a classification scheme is extremely helpful for data analysis, it can never capture the flavor of the incident. Narrative sections are crucial for a full understanding of the evolution of the incidents and for capturing important information that just does not fit into the taxonomy.

3.1.5 Simple Data Entry

An incident database should reside on a computer system so that data analyses can be performed. It is best to have the investigators enter their own incident data, as a clerk may easily misread or misunderstand the investigator's notes. The user interface of the database needs to be efficient and user-friendly in order to promote data validity and completeness. Unfortunately, examples of poor user interfaces abound. Just as the classification scheme will determine the data collected and reported, the computer interface will determine the quality of the data entered. If a certain data field is required to be filled out, it will always be filled out, even if the data entered are of questionable quality. When the computer interface is poorly designed the system becomes an obstacle to be overcome, and effort will be focused on just getting "something" into the system, rather than spending effort on the veracity and completeness of the data entered (Hill, Byers, & Rothblum, 1994). A good incident database must be simple to use, allowing investigators to enter all relevant data easily and completely, and allowing them to skip data fields that do not pertain to the case.

3.1.6 Feedback on Results of the Incident Investigation Program

Nothing dulls an investigator's enthusiasm more than to be working hard to capture useful data, only to get the feeling that it's all going down some deep, dark hole. Feedback is crucial to a successful incident investigation program. Investigators need to see the results of their work. And all personnel need to know that the program is not just another "flash in the pan", but something to which management has an on-going commitment. Publish results of incident analyses, make specific incidents the topic of safety meetings, use the results to start discussions on how to improve safety, and let personnel know that the new policies going into effect were based on lessons learned from incident investigations. When the use of the incident database is made public, investigators will redouble their efforts to collect complete data, and personnel will be more likely to cooperate in investigations.

3.2 Investigating for Human Factors Causes

Historically, companies and agencies that investigate incidents have overlooked human factors causes almost entirely. Material deficiencies in incidents (for example, equipment malfunction or a deficiency in the structural integrity of the vessel or platform) can normally be readily identified (e.g., a shaft is broken or there's a hole in the hull). However, the real difficulty in incident investigation is to answer *why* these deficiencies occurred, and the answer is usually related to human behavior. For instance, the shaft may have broken because of company management decisions, such as cutting back on maintenance, purchasing a less costly (and less well-made) piece of equipment, or selecting less-experienced engineers. Or, the shaft may have broken due to poor supervision of operations or maintenance, or due to an error made during maintenance, or to someone who used the equipment outside its safe operating range. Each of these underlying factors needs to be probed for *why* it happened, as well (e.g., did the company cut back on maintenance to save money or to offload its minimally-manned crew? was the equipment operated outside its range due to inexperience or willful violation by the operator?). Only after the investigator understands the true underlying cause(s) can meaningful solutions be developed. In typical investigations, however, the *why* is often ignored.

Another problem with the way most investigations unfold is that individuals are usually targeted for either "incompetence" or for "criminal negligence". This is particularly true when the investigator discovers that a given individual appeared to be responsible for the incident because the individual: had fallen asleep on duty; was under the influence of alcohol or drugs on duty; violated a regulation or standard operating procedure; appeared to be inattentive; or made an inappropriate decision. While it is sometimes the case that an individual *is* incompetent or negligent, the investigator should always look for contributing causes or other factors underpinning such behavior. It is often the case that work policies, standard operating procedures, and poorly designed jobs or equipment are at the core of the problem. Sanctioning the individual will not solve the problem and only creates a culture of fear and secrecy. Discovering the real reasons which underlie a given incident and working to solve the core issues will engender trust and openness in the work culture and lead to real improvements in safety.

3.3 How an Incident Evolves

There are usually multiple causes of an incident, with multiple people and events contributing to its evolution. As mentioned in the Introduction, the accidents studied in detail by Wagenaar and Groeneweg (1987) had anywhere from 7 to 58 distinct causes, with 50% of the cases having at least 23 causes. We are often very good at identifying the error most immediately linked to an incident. This is usually an error made by one of the people at the scene of the incident, such as that made by the helmsman of the *TORREY CANYON* when he failed to take the ship off automatic pilot in time to make the turn. We call these "active failures" because they represent an action, inaction, or decision that is directly related to the incident. However, we are often not as good at identifying other contributing causes, because many of these contributing causes may have occurred days, months, or even years before the incident in question. We call these "latent conditions", because they are error-inducing states or situations that are lying dormant until the proper set of conditions arise which expose their unsafe attributes. One of the latent conditions in the *TORREY CANYON* incident was the poor design of the steering selector switch: it gave no indication at the helm as to whether steering was set to "manual" or "automatic". An even more important latent error was management pressure on the master to keep to schedule, for that sense of urgency underlay his poor decisions. In this way the human operator is "set up" to make errors because the latent conditions make the system in which he works error-inducing rather than error-avoiding.

James Reason (1990) offered a useful paradigm, often referred to as the "Swiss cheese model," that explains how the many types of contributing factors can converge, resulting in an incident[6]

[6] Reason's work underscores the fact that "human errors" and "human factors" relate to the *entire system*, not just to an individual operator. The International Ergonomics Association defines human factors as being "concerned with the understanding of interactions among humans and other elements of a system." Further, it states that the area of human factors considers the design of "tasks, jobs, products,

(Fig. 7). A company tries to promote safety and prevent catastrophic accidents by putting into place layers of system defenses, depicted in the figure below as slices of Swiss cheese. Essentially, "system defenses" refers to the safety-related decisions and actions of the entire company: top management, the line supervisors, and the workers. The Organizational Factors layer (slice) represents the defenses put into place by top management. This level of system defenses might include a company culture which puts safety first, and management decisions which reinforce safety by providing well-trained employees and well-designed equipment to do the job. The second layer of defenses is the "Supervision" layer. This refers to the first-line supervisor and his or her safety-consciousness as displayed by the operational decisions he or she makes.

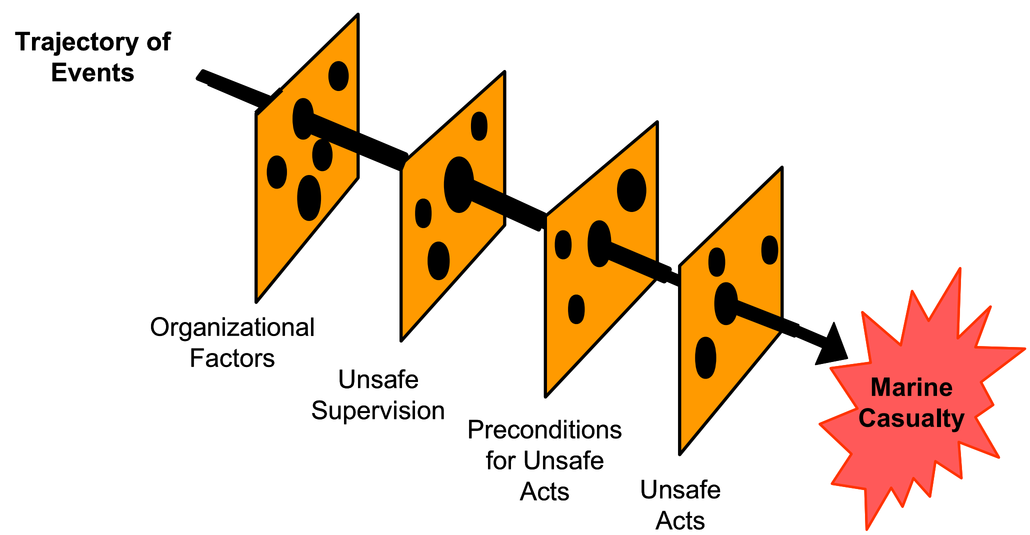


Figure 7. An Accident in the Making
(after Reason, 1990, as adapted by Wiegmann & Shappell, 1999)

For example, a good supervisor will ensure that personnel receive the proper training and mentoring, that work crews have the necessary skills and work well together, and that safety-related procedures are used routinely. The actions and "fitness for duty" of the worker make up the third layer of system defenses. In a safe system, the operator is physically and mentally ready to perform and routinely adheres to safe operating practices and procedures.

---

environments and systems in order to make them compatible with the needs, abilities and limitations of people." It is crucial to understand that in a human factors incident investigation we are *not* looking to identify a person "at fault"; instead, we are looking primarily for weaknesses in the links between the human workers and other parts of the system, such as management policies, equipment design, and work environment.

These system defenses can slowly erode over time in response to economic pressures, increasing demand for products and services, diminishing attention to promoting a safety culture, and others. Each time safety is sacrificed (e.g., by cutting back on preventive maintenance or by taking unsafe “shortcuts” in operational tasks), it puts another hole into that slice of cheese. If synergistic reductions in safety occur at all three levels of the system (that is, when the “holes” in the Swiss cheese line up), then the system no longer has any inherent protections, and it becomes an accident waiting to happen. All it takes is one mistake (unsafe act).

Here’s an example of how chipping away at system defenses can result in a casualty. Let’s say as a cost-cutting measure, a company decides to decrease the inventory of spare parts on its ships (hole in the Organizational Factors slice). One day the ship develops engine problems from clogged fuel injectors and doesn’t have sufficient spare parts (this would be analogous to an equipment “precondition”). The captain, knowing that the company would penalize him if he spent money to be towed into port (hole in Supervision, since the captain reports to the company), decides to take a risk and transit on only one engine (Unsafe Act). That engine fails, and the vessel drifts and grounds.

3.4 Improving Safety through Incident Investigation and Analysis

Maritime and offshore operations are inherently risky. Company managers have to weigh often-competing interests in safety, productivity, profitability, and customer expectations in order to be viable. Sometimes, well-meaning decisions back-fire and cause unanticipated safety problems. One way management can keep its finger on the safety pulse of the company is through incident investigation and analysis. As Fig. 8 shows, by thoroughly investigating incidents and the human errors that cause them, one can identify the holes in the system defenses and develop workable solutions.

An incident investigation program consists of five components (Fig. 8). First, the company must support the investigation of incidents. This requires objective investigators with at least a minimal amount of training in investigation techniques and a firm understanding of the purpose of the investigation and the types of data which must be collected to support the company’s objectives. Second, the company must develop and maintain an incident database. As mentioned earlier, such a database should be computerized for easier analysis. The database must be composed of a set of taxonomies (classification schemes) which will capture the incident elements of interest to the company. The database should also incorporate narrative fields so that investigators can explain events and causes in more detail. Third, the company must then support regular analysis of the incidents in the database. As will be discussed in more detail later, analysis allows the company to find patterns common to a group of incidents, and allows the determination of how frequently different types of incidents occur and, in the case of near-misses, the potential severity of the accident that was avoided. Such data are very helpful in targeting the types of safety problems that the company will want to spend time and money to solve.

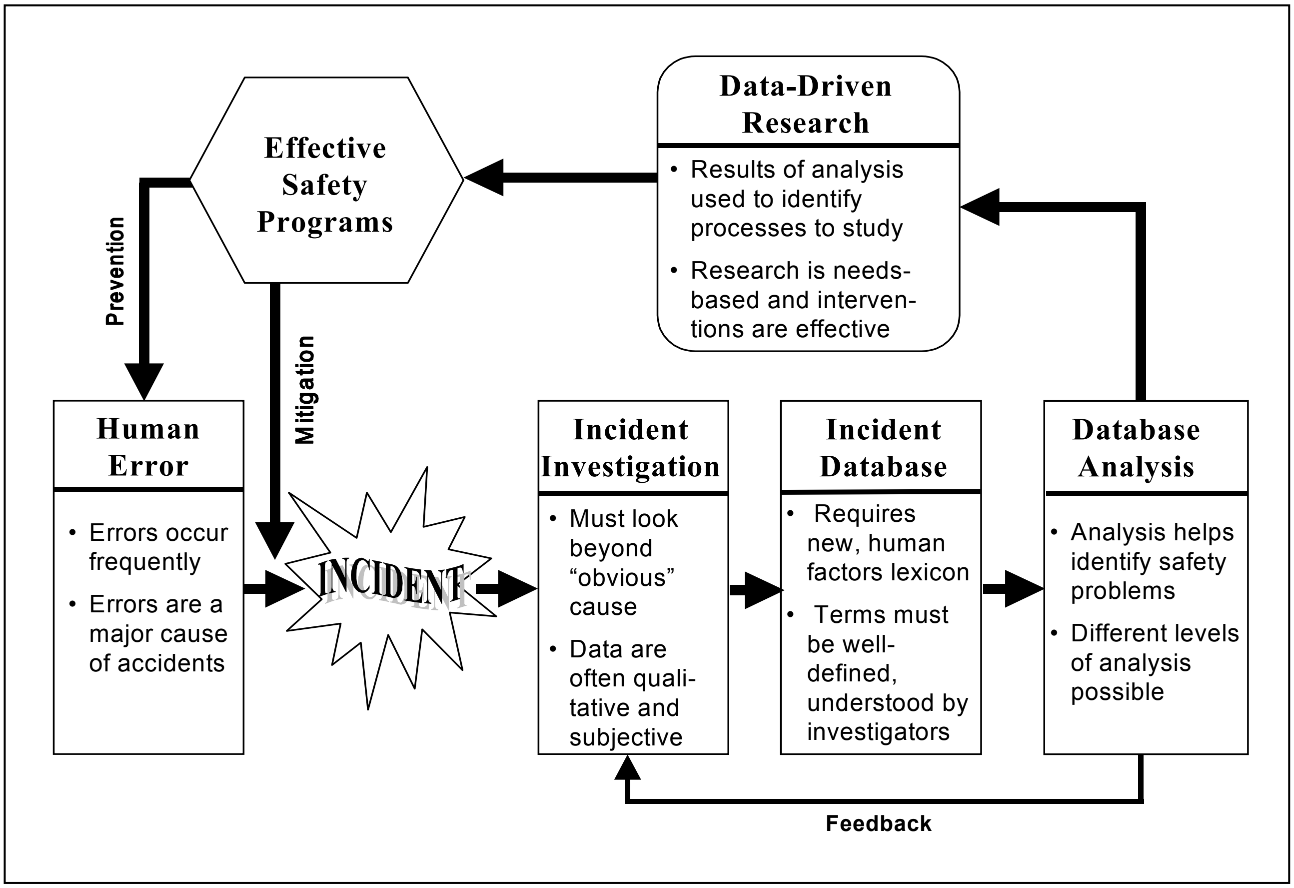


Figure 8. How An Effective Human Factors Incident Investigation Program Can Improve Safety
(Modified from Wiegmann and Shappell, 1999)

The fourth component of a successful incident investigation program is data-driven research. Incident investigation will frequently just "skim the surface" of a safety problem. The value of incident investigation and analysis is that it *identifies areas of concern.* In most cases, incident investigation and analysis will *not* be sufficient to "solve" the problem. Solving the problem will require getting more information on the policies, standard operating procedures, common work practices, equipment and job design, and employee attributes (like training, preparedness, physical and mental condition) linked to the activities or situations in which the incidents have occurred. The "research" might take the form of a risk assessment, or it may require the collection of additional, detailed information in subsequent investigations of related incidents, or perhaps a comparison of current company policies and practices with those employed by other companies ("benchmarking"). Through research, the company gains a more complete understanding of all the various contributing factors which drive the incidents of interest. The research might then extend to a comparison of the effectiveness of different prevention methods.

Finally, the result of the research step is an addition to or a revision of the company's safety program. Using the concept of "barrier analysis" (Hollnagel, 2000), the company wants to understand how safety failures arise and implement "barriers" (such as equipment "shields" to protect workers from exposure to potential harm, or procedures which prevent activities known to be hazardous) to prevent incidents. Successful *prevention* can eliminate certain hazards. Other incident causes may not be easily prevented, but there may be ways to *mitigate* (reduce) their consequences. When a safety program acts on the incident data which contains underlying causes, it will be effective.

3.5 Error Recovery

Error recovery is an important supplementary safety goal, and will be mentioned briefly here. Many offshore companies have a "zero accidents" policy which, while the ultimate safety goal, may be difficult to fully attain (Kontogiannis, 1999). In some industries, systems are being developed which focus on preventing the consequences of human error by providing opportunities for error recovery (Helmreich, et al., 2000; Sasou & Reason, 1999).

A framework developed by Kontogiannis (1999) categorizes error recovery according to the process used, the outcome, and the stage of performance. The process is usually either detection, explanation, or correction. For example, if you are using a word processor and misspell a word, one option for the spell check function is to merely *detect* the misspelled word and allow the user to decide what, if anything, to do about it. A different option has the spell checker both detect and *explain* or suggest options for correcting the word. Some word processors are even capable of *correction*, by automatically detecting and correcting misspellings as you type. Similar detection, explanation, and correction features can be built into offshore and maritime systems, either through automation or through procedures.

Outcomes of the recovery process refer to the state of the system after recovery. For example, an error-detecting system might block the error from happening and return the system to its original state prior to the error (this is called backward recovery). The stage of performance relates to the stage in which the error detection was made. For example, the outcome stage would be where an error is detected based on a mismatch between the expected outcomes of a process and the outcomes actually observed. For instance, if there is a low pressure reading and the operator erroneously turns the valve in the wrong direction, the outcome will be an even lower pressure. An error detector in the outcome stage would note the discrepancy between the present pressure reading and the higher pressure that was intended, and signal the error.

A simplified version of this framework is being used in a U.K. oil industry research project developing a human factors investigation tool (HFIT – see App. C; Gordon, Flin & Mearns, 2001). Investigators are asked three questions regarding the possible recovery process of the error: was the error detected (realized or suspected), was it understood why the error occurred, and was it corrected (e.g., by modifying an existing plan or developing a new plan)? How the error was detected (e.g., via system feedback, external communications, etc.) is also discussed. By including these types of questions into an incident investigation, it may illuminate changes to equipment or procedures which may act to prevent such errors in the future.

4.0 AN EXAMPLE OF A HUMAN FACTORS TAXONOMY: HFACS[7]

An effective incident database has at its heart a set of classification schemes or taxonomies: schemes to classify the type of incident, the type of people involved in the incident, the type of platform or vessel involved, the geographical area and weather conditions, the type of equipment that failed, the activities occurring at the time of the incident, and of course, the human factors causes. A maritime example with all these components and more is the International Maritime Incident Safety System (IMISS; Rothblum, Chaderjian, & Mercier, 2000; see App. B). It is important to understand *all* of the different types of factors (equipment, human, weather, etc.) involved in an incident. Since the offshore and maritime industries already have adequate ways of identifying equipment and other non-human contributions to incidents, this section will focus only on the identification and classification of human factors causes.

There are many, many human factors taxonomies that are in use by NASA, the Nuclear Regulatory Commission, the Transportation Safety Board of Canada, the U.K. Marine Accident Investigation Branch, and others. Some of these are listed in Appendix C; they are all useful taxonomies. These taxonomies vary with respect to how they chose to group human factors elements, the level of detail they provide, and the level of expertise required on the part of the investigator.

In order to provide an example of a human factors taxonomy and to show how it would be used during an investigation, we selected the Human Factors Analysis and Classification System (HFACS; Shappell & Wiegmann, 1997a, 2000; Wiegmann & Shappell, 1999) because it is relatively easy to learn and use, and because its effectiveness has been demonstrated through its use by the U.S. Navy and U.S. Marine Corps for aviation accident investigation and analysis. This classification scheme, as well as several of the others mentioned, is based on the well-established human error frameworks of the SHEL model (Software-Hardware-Environment-Liveware; Edwards (1972) and Hawkins (1984, 1987) as cited in TSB, 1998), Rasmussen's taxonomy of errors (1987, as cited in TSB, 1998), and Reason's (1990) "Swiss cheese" model of accident causation.

HFACS seeks to understand all the human-related contributing causes to an incident by considering the "holes" in the four layers of system defenses: unsafe acts, preconditions for unsafe acts (unsafe conditions), unsafe supervision, and organizational factors (see Fig. 9). The discussion below summarizes some of the types of latent conditions and active failures associated with these layers of system defenses. For more information, please see Shappell & Wiegmann (1997a, 2000) or Wiegmann & Shappell (1999).

[7] The majority of this section has been taken from Shappell & Wiegmann (2000). For additional information about HFACS, or to take a seminar on HFACS, please contact either Dr. Scott Shappell at scott_shappell@mmacmail.jccbi.gov and (405) 954-4082, or Dr. Doug Wiegmann at dwiegman@uiuc.edu and (217) 244-8637.

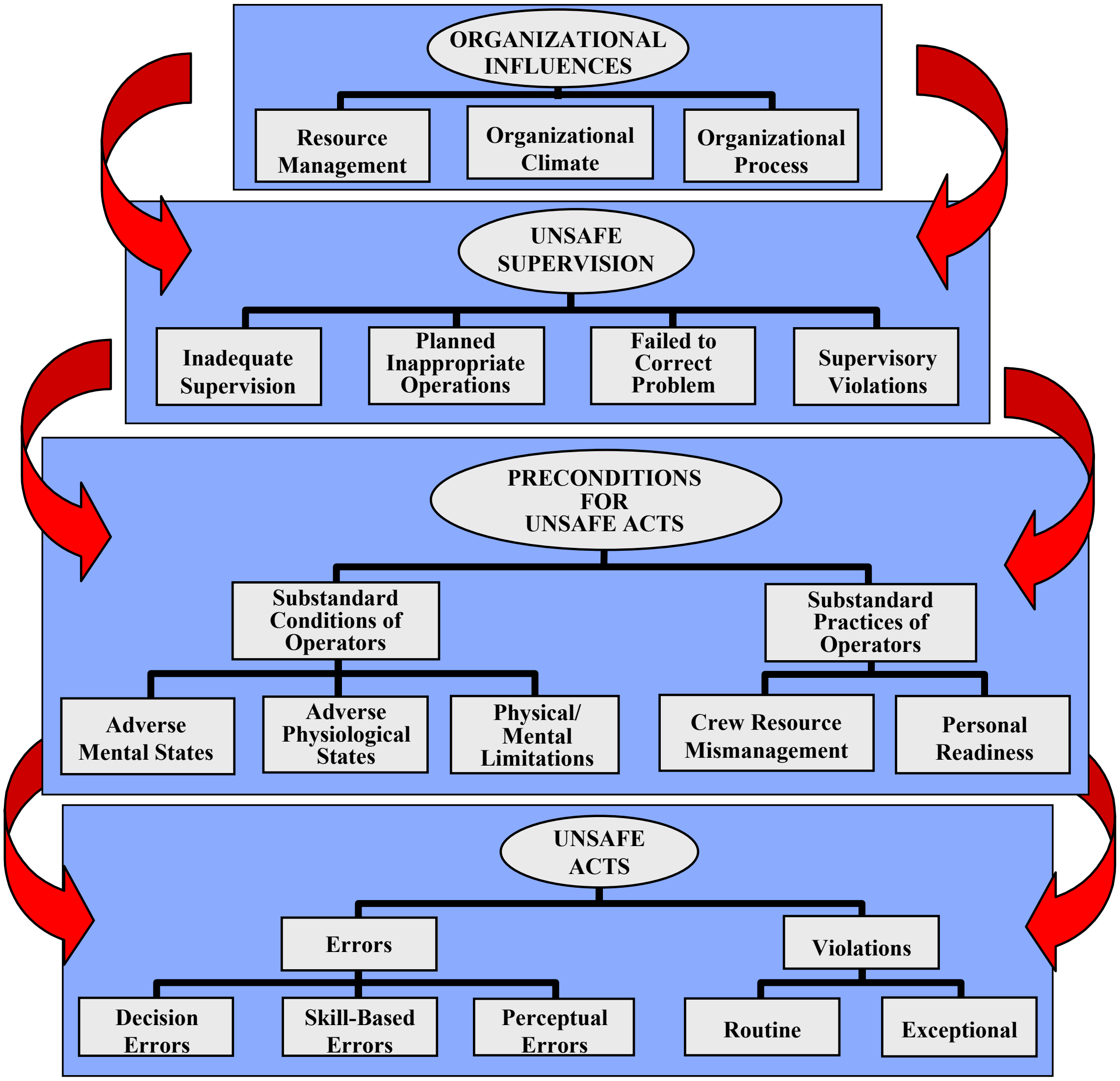


Figure 9. The Human Factors Classification and Analysis System (HFACS)

4.1 HFACS: Unsafe Acts

In an incident investigation, the investigator starts with the immediate actions and events surrounding the incident and then works backwards to uncover contributing causes. In terms of human errors, those immediately linked to the incident are typically “unsafe acts”. There are two types of unsafe acts: errors and violations.

Errors represent the mental and physical activities of individuals that fail to achieve their intended outcome; that is, the result of the person’s action was not as expected. For example, if the captain orders “right 20 degrees” when he meant to order “left 20 degrees”, that would be an error. A violation, on the other hand, is when the person’s action reflects a willful disregard for standard operating procedures or regulations (even though they probably did *not* intend to cause an incident). For example, an engineer doing maintenance might decide to “cut corners” and not perform a maintenance procedure the way it should be done. His performance is an intentional violation of the correct procedure. Errors and violations can be further subdivided, as shown in Figure 10. Errors can be decision errors, skill-based errors, or perceptual errors. Violations can be routine or exceptional.

4.1.1 Decision Errors

The decision error represents an activity or behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as “honest mistakes,” these unsafe acts represent the actions or inactions of individuals whose “hearts are in the right place,” but they either did not have the appropriate knowledge or just simply made a poor choice. These types of knowledge-based and rule-based errors have been referred to in Reason’s taxonomy as “mistakes” (TSB, 1998).

Decision errors can result from multiple causes. For example, a wrong decision can be made if the person does not fully understand the situation at hand, misdiagnoses the problem, and proceeds to apply the wrong “solution” (because he’s solving the wrong problem). Troubleshooting an electrical fault could lead to this type of procedural decision error. Decision errors can also occur if the person does not have sufficient experience to guide his decision, or if there is not enough time to fully work through the problem properly before a choice must be made (called a choice decision error). Problem-solving errors can occur when the problem is a novel one, requiring the person to reason through it.

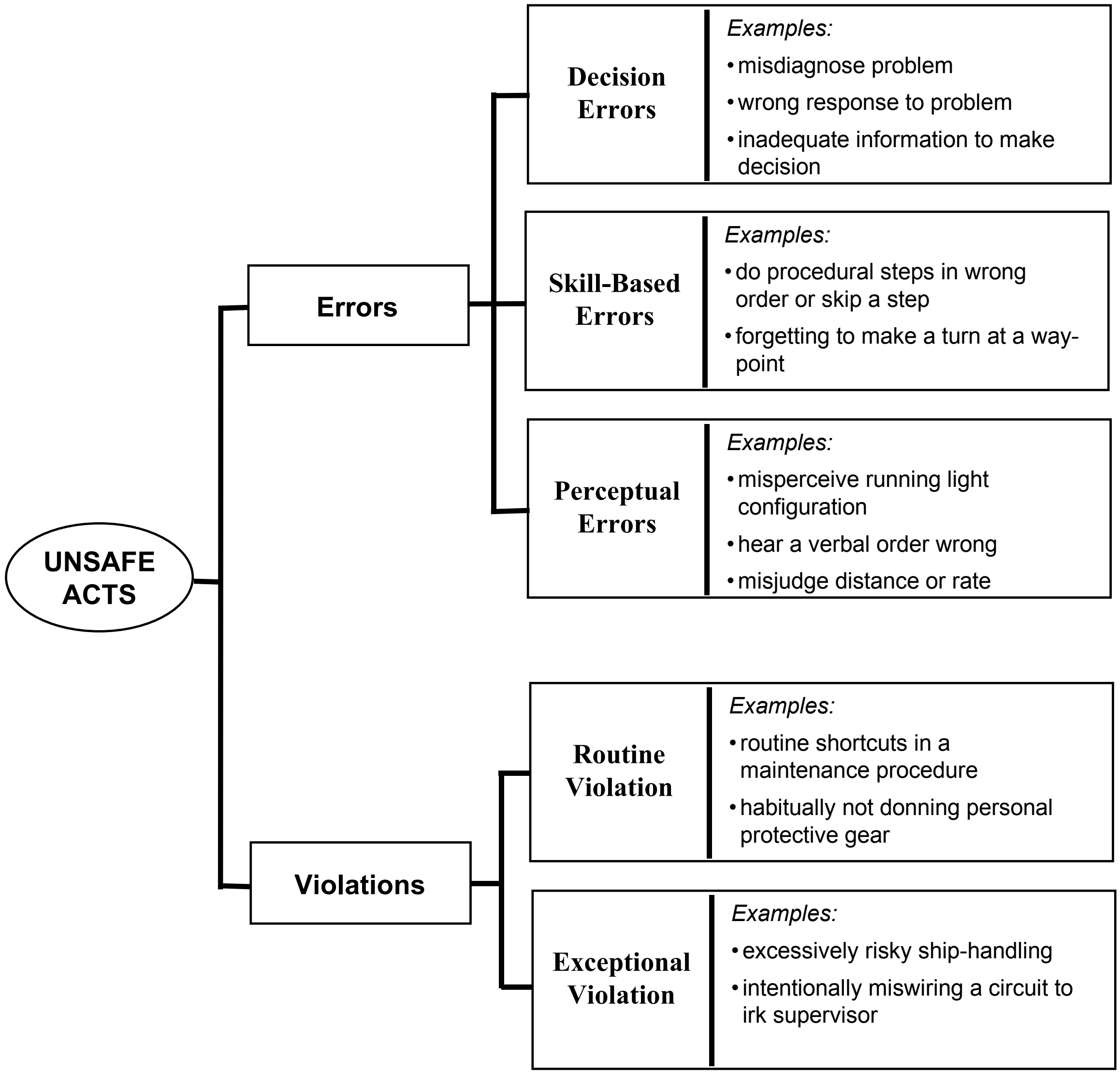


Figure 10. Classification of Unsafe Acts
(modified from Shappell & Wiegmann, 2000, and TSB, 1998)

4.1.2 <u>Skill-based Errors</u>

Skill-based errors can occur in the execution of skills or procedures that have become so well-learned that they are performed almost automatically. Routine maintenance tasks, taking navigational bearings, monitoring equipment displays, and other repetitive operations would be considered skill-based tasks. These types of tasks are sometimes performed improperly due to a failure of attention or memory. Consider the hapless soul who locks himself out of the car or misses his exit because he was either distracted, in a hurry, or daydreaming. These are both examples of attention failures that commonly occur during highly automatized behavior. Types of attention failures include omitting a step in a procedure, reversing the order of two steps, or doing the right thing at the wrong time. Attentional deficits can also result in failing to detect a problem while monitoring equipment.

In contrast to attention failures, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. Failures in memory can result in forgetting to do a planned activity or losing one's place in a series of tasks. For example, most of us have experienced going to the refrigerator only to forget what we went for. Likewise, it is not difficult to imagine that when under stress during an operational emergency, critical steps in the emergency procedures can be missed. Even when not particularly stressed, individuals can forget to complete certain steps within a procedure.

If one of these types of errors is found during an incident investigation, it is a signal to look deeper. Merely telling an operator to "pay better attention next time" will not solve the problem. These types of errors are symptoms of underlying system failures. Take, for example, the fatal accident aboard the *RIX HARRIER* (MAIB, 1997). On a July afternoon, the vessel was being moored to a jetty on the River Humber. A mooring rope had been led around a fairlead, which was situated on top of the aft bulwark rail. As the rope tightened, it sprang over the top of the fairlead, striking the officer on his right arm and throwing him against the accommodation bulkhead. Neither the officer nor the crew member helping him noticed that the mooring rope had been passed inadvertently around the fairlead. This was an error resulting from lack of attention. The investigation determined that the design of the aft mooring arrangement increased the likelihood that such an error would be made. The investigation also determined that, due to the ship's work schedules, it was likely that the officer and crew member had endured days of fragmented sleep and were suffering from chronic fatigue, a state that increases the probability of attentional deficits. So in this case, both a ship design flaw and a problem with the ship's work schedules appeared to contribute to the attentional errors that caused the death of the officer.

4.1.3 Perceptual Errors

Not unexpectedly, when one's perception of the world differs from reality, errors can, and often do, occur. Typically, perceptual errors occur when sensory input is degraded, such as navigating at night. Visual illusions, for example, occur when the brain tries to "fill in the gaps" and make sense out of sparse information. In the earlier example of the *CGC CUYAHOGA*, the captain made a perceptual error in his interpretation of the configuration of the running lights on the *SANTA CRUZ II.* Had he seen the vessel in daylight, there would have been many visual cues available to determine the type and heading of the vessel; but at night, with little visual information available, it is all too easy to misinterpret.

Another common type of perceptual error occurs when trying to communicate in a noisy environment. Static over the radio or noise from engines and generators can muffle or degrade spoken words and commands. Again, the brain will attempt to "fill in" what wasn't heard – often based on the listener's expectations, be they correct or incorrect. As an example, a ship was transiting restricted waters when the Third Engineer noticed that the lube oil pressure was low. He shouted (across a noisy engine room) to a cadet to adjust the pressure. The cadet misunderstood (perception error) and closed the valve, causing the engine to go to dead slow and creating a dangerous situation by greatly reducing the ship's maneuverability in the high-traffic waterway (McCallum, Raby, Rothblum, Forsythe, Slavich, & Smith, 2000, unpublished).

4.1.4 Routine Violations

As discussed above, errors occur when someone is trying to follow the rules and do the right thing, but gets an unexpected result. By contrast, a violation is when someone intentionally ignores or "bends" a rule. Routine violations tend to be habitual by nature and are often tolerated by supervision (in the case of not following a standard operating procedure) or by the governing authority (in the case of not following a regulation) (Reason, 1990). Consider, for example, the individual who routinely drives 5-10 mph faster than the posted speed limit (a routine violation). Since the police will rarely pull someone over for such a minor infraction, they are tolerating the violation and implicitly reinforcing the unsafe behavior. If the police were to crack down on minor speeding, people would be less likely to violate the speed limit. Therefore, if a routine violation is identified during an incident investigation, the investigator must look further up the supervisory chain to identify those individuals in authority who are not enforcing the rules.

4.1.5 Exceptional Violations

Unlike routine violations, exceptional violations appear as isolated departures from authority, not necessarily indicative of the individual's typical behavior pattern nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55 mph zone is considered an exceptional violation. Note that the violation is not considered "exceptional" because of its extreme nature. Rather, it is considered exceptional because it is neither typical of the individual nor condoned by authority. The fact that such behavior is *not* typical of the individual makes it difficult to predict and deal with exceptional violations.

4.2 HFACS: Preconditions for Unsafe Acts

Although unsafe acts can be linked to the vast majority of incidents, simply focusing on unsafe acts is like focusing on a fever without understanding the underlying disease causing it. Thus, investigators must dig deeper into why the unsafe acts took place. As a first step, it is useful to consider any preconditions for unsafe acts. There are two major subdivisions of unsafe conditions (preconditions): substandard conditions of the operators and the substandard practices they commit (Fig. 11). Substandard conditions are broken down into Adverse Mental States, Adverse Physiological States, and Physical/Mental Limitations. Types of Substandard Practices include Crew Resource Mismanagement and Personal Readiness. Each of these subcategories is discussed below.

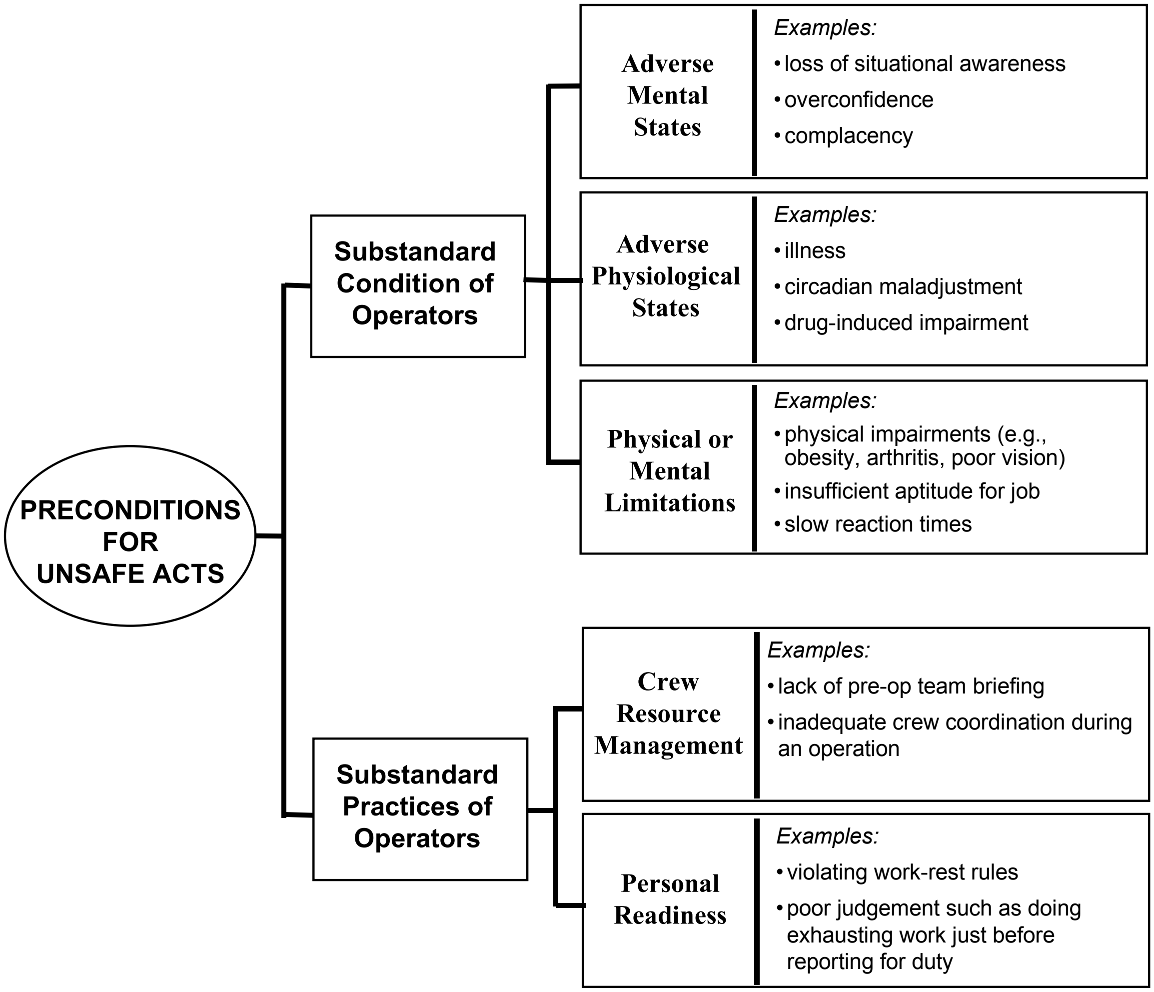


Figure 11. Classification of Preconditions for Unsafe Acts
(modified from Shappell & Wiegmann, 2000, and TSB, 1998)

4.2.1 Adverse Mental States (Substandard Conditions of Operators)

Being prepared mentally is critical in nearly every endeavor. As such, the category of Adverse Mental States was created to account for those mental conditions that affect performance. Key examples in the maritime and off-shore industries are loss of situational awareness, overconfidence, and complacency. Predictably, if an individual loses situational awareness, the likelihood increases that an error will occur. In a similar fashion, pernicious attitudes such as overconfidence and complacency increase the likelihood that a violation will be committed. Clearly then, any framework of human error must account for pre-existing adverse mental states in the causal chain of events.

4.2.2 Adverse Physiological States (Substandard Conditions of Operators)

This category refers to those medical or physiological conditions that preclude safe operations. For example, illness can have a negative impact on our performance. Nearly all of us have gone to work ill, dosed with over-the-counter medications, and have generally performed sufficiently well. However, the side-effects of antihistamines, and the fatigue and sleep loss that often accompany an illness can be detrimental to decision-making. For example, over-the-counter antihistamines decrease vigilance, performance on divided attention tasks, and short-term memory, resulting in a 14% loss of productivity and an increase in errors (Kay, 2000). Sleep loss, even in healthy individuals, increases the risk of accidents. Every April when the U.S. “springs ahead” to daylight savings time, there is a significant increase in automobile accidents: and this is from a mere *one hour decrease* in sleep time (Coren, 1998; Monk, 1980). Therefore, it is incumbent upon any safety professional to account for these sometimes subtle medical and physiological conditions within the causal chain of events.

4.2.3 Physical/Mental Limitations (Substandard Conditions of Operators)

The final substandard condition involves individual physical and mental limitations. Specifically, this category refers to those instances when task or situational requirements exceed the capabilities of the operator. For example, the human visual system is severely limited at night. Yet, most people do not take this into account when driving a car at night, and do not slow down or take other precautions. Similarly, there are occasions when the time required to complete a task exceeds an individual’s capacity. Individuals vary widely in their abilities to process and respond to information. It is well documented that if individuals are required to respond quickly (i.e., less time is available to consider all the options thoroughly), the probability of making an error goes up markedly. Consequently, it should be no surprise that when faced with the need for rapid processing and reaction times, as is the case in emergencies, all forms of errors would be exacerbated.

In addition to the basic sensory and information processing limitations described above, there are at least two additional instances of physical and mental limitations that need to be addressed, albeit they are often overlooked by most safety professionals. These limitations involve individuals who simply are not compatible with a given job, because they are either unsuited physically or they do not possess the aptitude to do it. For example, some individuals simply do not have the physical strength required to operate manual valves or haul heavy equipment. Likewise, not everyone has the mental ability or aptitude for every job. The difficult task for the safety professional is identifying whether physical or mental aptitude might have contributed to the incident causal sequence.

Clearly then, numerous substandard conditions of operators can, and do, lead to the commission of unsafe acts. Nevertheless, there are a number of things that we do to ourselves that set up these substandard conditions. Generally speaking, the substandard practices of operators can be summed up in two categories: crew resource mismanagement and personal readiness.

4.2.4 Crew Resource Mismanagement (Substandard Practices of Operators)

Operations in the off-shore and maritime industries depend on good communications and teamwork. Communication and coordination is essential, not just between workers on a given task, but between teams working on complementary or coordinated tasks. On a ship, communications may be important between members of the same department (e.g., two engineers repairing a piece of equipment, or passing information during a watch relief), between departments (the deck officer may need to notify engineering of an upcoming maneuver), between ships (for meeting and passing arrangements), and between the ship and other groups or authorities such as Vessel Traffic Service, bridge tenders, dock workers, and the vessel agent. The need for communication and coordination is often overlooked, leading to incidents. One study of maritime casualties found that a lack of communication contributed to 18% of vessel casualties and 28% of personnel injuries (McCallum, Raby, Rothblum, Forsythe, Slavich, & Smith, 2000).

Here’s an example of how such crew resource mismanagement can result in a serious incident. A barge was moored to a quarry loading facility by a pull cable that was controlled from the facility. The deckhand on the barge noticed that the pull cable was caught under a deck fitting, and walked over to free it. Before he reached it, a dock worker started the winch to take the slack out of the mooring line. As the cable tightened, it snapped off the fitting and struck the deckhand with such force that he required surgery. In this case, both the deckhand and the dock worker should have – but didn’t – alert the other to their plans: an obvious failure of crew coordination. A serious injury was the unhappy consequence of this lack of crew resource management (Rothblum, 2000).

4.2.5 Personal Readiness (Substandard Practices of Operators)

In every occupation, people are expected to show up for work ready to perform at optimal levels. Nevertheless, personal readiness failures occur when individuals fail to prepare physically, mentally, or physiologically for duty. For instance, violations of work-rest rules, use of intoxicants and certain medications, and participating in exhausting domestic or recreational activities prior to reporting for duty can impair performance on the job and can be preconditions for unsafe acts. While some of these maladaptive behaviors may be addressed by rules and regulations, most are left up to the judgement of the individual. It is necessary for the individual to understand that some “off-time” activities can be detrimental to subsequent job performance. The incident investigator needs to probe for personal readiness and activities that may have degraded it.

4.3 HFACS: Unsafe Supervision

In addition to investigating those causal factors associated directly with the operator, it is necessary to trace the possible causal chain of events up the supervisory chain of command (Reason, 1990). It has been estimated that 80% of offshore platform accidents have their predominant roots in supervisory and organizational factors (Bea, Holdsworth, & Smith, 1997). There are four categories of unsafe supervision: inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations (Fig. 12). Each is described briefly below.

4.3.1 Inadequate Supervision

The role of any supervisor is to provide the opportunity to succeed. To do this, the supervisor, no matter at what level of operations, must provide guidance, training opportunities, leadership, and motivation, as well as the proper role model to be emulated. Unfortunately, this is not always the case. For example, it is not difficult to conceive of a situation where adequate crew resource management training was either not provided, or the opportunity to attend such training was not afforded to a particular crew member. Conceivably, coordinated teamwork would be compromised, and if an emergency situation arose, the risk of an error being committed would be exacerbated and the potential for an incident would increase markedly.

In a similar vein, sound professional guidance and oversight is an essential ingredient of any successful organization. While empowering individuals to make decisions and function independently is certainly essential, this does not divorce the supervisor from accountability. The lack of guidance and oversight has proven to be the breeding ground for many of the violations that have crept into the cockpit. As such, any thorough investigation of incident causal factors must consider the role supervision plays (i.e., whether the supervision was inappropriate or did not occur at all) in the genesis of human error.

4.3.2 Planned Inappropriate Operations

Occasionally, the operational tempo and/or the scheduling of personnel is such that individuals are put at unacceptable risk, crew rest is jeopardized, and ultimately performance is adversely affected. Such operations, though arguably unavoidable during emergencies, are unacceptable during normal operations. Therefore, the second category of unsafe supervision, planned inappropriate operations, was created to account for these failures.

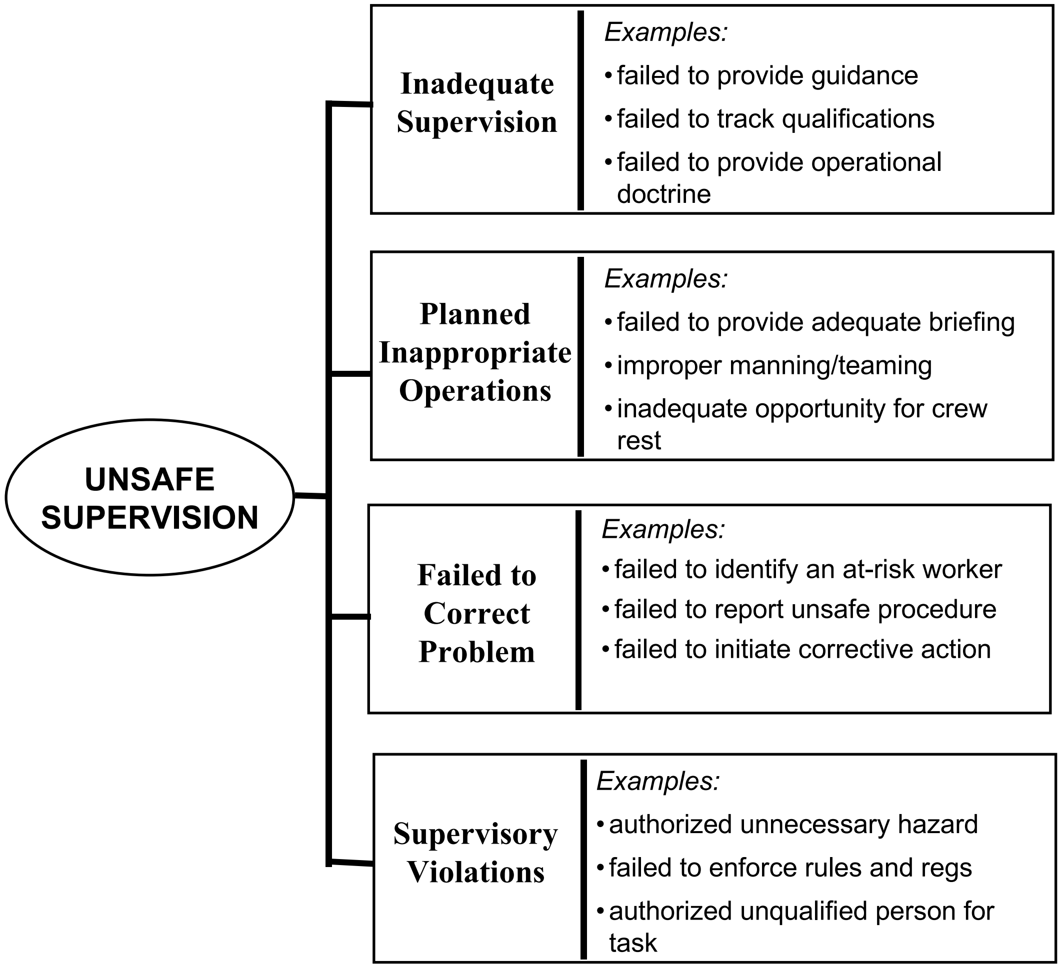


Figure 12. Categories of Unsafe Supervision.
(modified from Shappell & Wiegmann, 2000)

Take, for example, the issue of improper team complements. In aviation it is well known that when very senior, dictatorial captains are paired with very junior, weak co-pilots, communication and coordination problems are likely to occur. This type of personality mismatch is apt to happen in any team environment, and can (and do) contribute to tragic accidents (such as the crash of a commercial airliner into the Potomac River shortly after takeoff in 1982). When team member selection is not taken into account, gross perceived differences in authority and experience can cause more junior team members to be ignored, effectively eliminating an important input to the team as a whole.

4.3.3 Failure to Correct a Known Problem

The third category of known unsafe supervision, Failed to Correct a Known Problem, refers to those instances when deficiencies among individuals, equipment, training or other related safety areas are "known" to the supervisor, yet are allowed to continue unabated. For example, a given worker might have a reputation for risky behavior or cutting safety margins too closely. If the supervisor knows this and allows the behavior to continue, an incident may be the unsurprising consequence. The failure to correct the behavior, either through remedial training or, if necessary, removal from the job, can put the entire operation at risk. Likewise, the failure to consistently correct or discipline inappropriate behavior fosters an unsafe atmosphere and promotes the violation of rules.

4.3.4 Supervisory Violations

Supervisory violations, on the other hand, are reserved for those instances when existing rules and regulations are willfully disregarded by supervisors. Although relatively rare, supervisors have been known occasionally to violate the rules and doctrine when managing their assets. For instance, sometimes individuals are assigned to do a task for which they are unqualified, either through the lack of sufficient training, or even lacking the appropriate license. The failure to enforce existing rules and regulations or flaunting authority are also violations at the supervisory level. While rare and possibly difficult to identify, such practices are a flagrant violation of the rules and invariably set the stage for the tragic sequence of events that predictably follow.

4.4 HFACS: Organizational Influences

As noted previously, fallible decisions of upper-level management directly affect supervisory practices, as well as the conditions and actions of operators. Unfortunately, these organizational errors often go unnoticed by safety professionals, due in large part to the lack of a clear framework from which to investigate them. Generally speaking, the most elusive of latent failures revolve around issues related to resource management, organizational climate, and operational processes, as detailed in Figure 13.

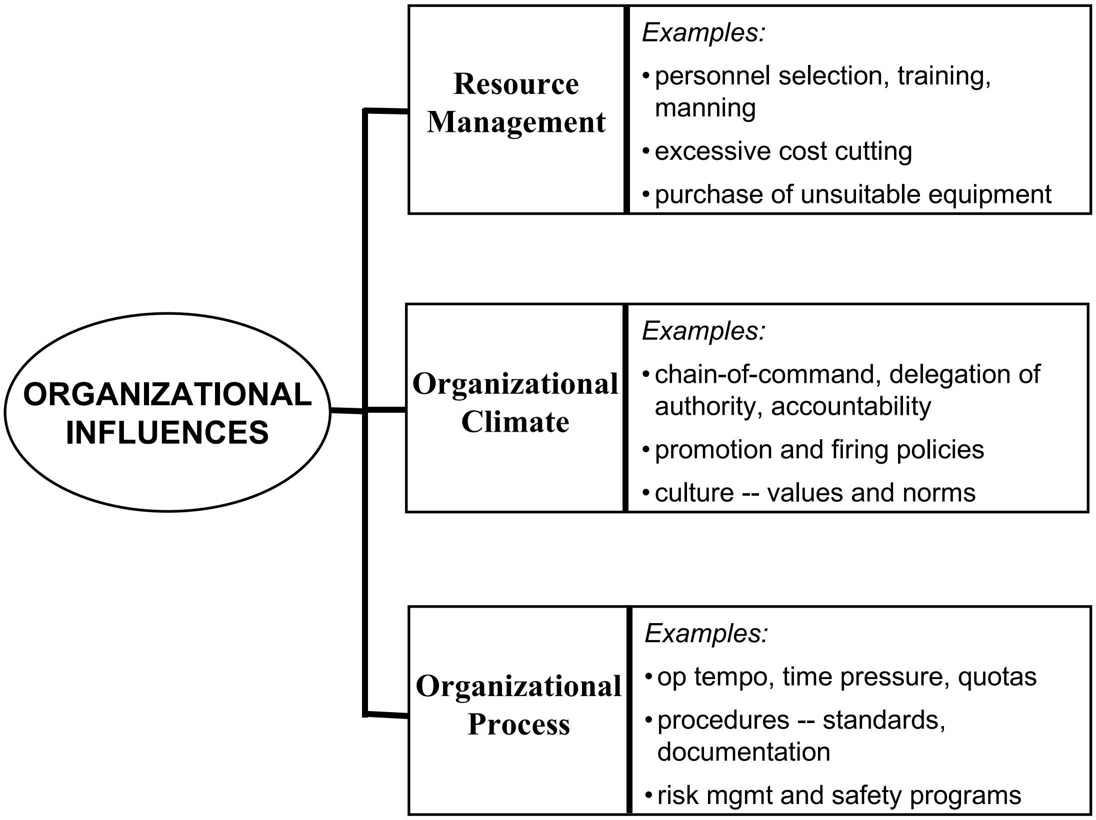


Figure 13. Organizational Factors Which Contribute to Incidents
(modified from Shappell & Wiegmann, 2000)

4.4.1 Resource Management

This category encompasses the realm of corporate-level decision making regarding the allocation and maintenance of organizational assets such as human resources (personnel), monetary assets, and equipment and facilities. Generally, corporate decisions about how such resources should be managed center around two distinct objectives – the goal of safety and the goal of on-time, cost-effective operation. In times of prosperity, both objectives can be easily balanced and satisfied in full. However, there may also be times of fiscal austerity that demand some give and take between the two. Unfortunately, accident reports show us time and again that safety is often the loser in such battles and, as some can attest to very well, safety and training are often the first to be cut in organizations having financial difficulties. If cutbacks in such areas are too severe, worker proficiency may suffer, leading to errors and incidents.

Excessive cost-cutting could also result in reduced funding for new equipment or may lead to the purchase of equipment that is sub-optimal and inadequately designed for the task. Other trickle-down effects include poorly maintained equipment and workspaces, and the failure to correct known design flaws in existing equipment. The result is a scenario involving unseasoned, less-skilled workers using poorly maintained equipment under less than desirable conditions and schedules. The ramifications for safety are not hard to imagine.

4.4.2 Organizational Climate

Climate refers to a broad class of organizational variables that influence worker performance. In general, organizational climate can be viewed as the working atmosphere within the organization. One telltale sign of an organization's climate is its structure, as reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Just like in the operational arena, communication and coordination are vital within an organization. If management and staff within an organization are not communicating, or if no one knows who is in charge, organizational safety clearly suffers and incidents do happen (Muchinsky, 1997).

An organization's policies and culture are also good indicators of its climate. Policies are official guidelines that direct management's decisions about such things as hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, incident investigations, and the use of safety equipment. Culture, on the other hand, refers to the unofficial or unspoken rules, values, attitudes, beliefs, and customs of an organization. Culture is "the way things *really* get done around here."

When policies are ill-defined, adversarial, or conflicting, or when they are supplanted by unofficial rules and values, confusion abounds within the organization. Indeed, there are some corporate managers who are quick to give "lip service" to official safety policies while in a public forum, but then overlook such policies when operating behind the scenes. Safety is bound to suffer under such conditions.

4.4.3 Organizational Process

This category refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standardized operating procedures and formal methods for maintaining checks and balances (oversight) between the workforce and management. For example, such factors as operational tempo, time pressures, incentive systems, and work schedules are all factors that can adversely affect safety (Fig. 13). There may be instances when those within the upper echelon of an organization determine that it is necessary to increase the operational tempo to a point that overextends a supervisor's staffing capabilities. Therefore, a supervisor may resort to the use of inadequate scheduling procedures that jeopardize crew rest and produce sub-optimal crew complements, putting the operation and its workers at an increased risk of a mishap. Organizations should have official procedures in place to address such contingencies as well as oversight programs to monitor such risks.

Regrettably, not all organizations have these procedures nor do they engage in an active process of monitoring operator errors and human factors problems via anonymous reporting systems and safety audits. As such, supervisors and managers are often unaware of the problems before an incident occurs. It is incumbent upon any organization to fervently seek out the “holes in the cheese” and plug them up, before they create a window of opportunity for catastrophe to strike.

4.5 The Benefits of Using HFACS

The Human Factors Analysis and Classification System (HFACS) framework bridges the gap between theory and practice by providing investigators with a comprehensive, user-friendly tool for identifying and classifying the human causes of incidents. The system, which is based upon Reason’s (1990) model of latent and active failures (Shappell & Wiegmann, 1997a), encompasses all aspects of human error, including the conditions of operators and organizational failure. Still, HFACS and any other framework only contribute to an already burgeoning list of human error taxonomies (see, for example, Appendix C) if it does not prove useful in the operational setting. In this regard, HACS has recently been employed by the U.S. Navy, Marine Corps, Army, Air Force, and Coast Guard for use in aviation accident investigation and analysis. To date, HFACS has been applied to the analysis of human factors data from approximately 1,000 military aviation accidents. Throughout this process, the reliability and content validity of HFACS has been repeatedly tested and demonstrated (Shappell & Wiegmann, 1997b). HFACS has also been implemented by other types of organizations; an example of its use by the Marine Facilities Division of the California State Lands Commission in the investigation of incidents at marine terminals is provided in Section 8 and Appendix E.

Given that accident/incident databases can be reliably analyzed using HFACS, the next logical question is whether anything unique will be identified. Early indications within the military suggest that the HFACS framework has been instrumental in the identification and analysis of global human factors safety issues, such as trends in operator proficiency, causes of specific accident types, and problems such as failures of crew resource management (Shappell & Wiegmann, 2000). Consequently, the systematic application of HFACS to the analysis of human factors accident data has afforded the U.S. Navy and Marine Corps (for which the original classification system was developed) the ability to develop objective, data-driven intervention strategies.

Additionally, the HFACS framework and the insights gleaned from database analyses have been used to develop innovative incident investigation methods that have enhanced both the quantity and quality of the human factors information gathered during incident investigations. However, not only are safety professionals better suited to examine human error in the field, but using HFACS, they can now track those areas (the “holes in the cheese”) responsible for the incidents as well. Only now is it possible to track the success or failure of specific intervention programs designed to reduce specific types of human error and subsequent incidents. In so doing, research investments and safety programs can be either readjusted or reinforced to meet the changing needs of safety.

5.0 PUTTING IT ALL TOGETHER: INVESTIGATING AN INCIDENT FOR HUMAN FACTORS CAUSES

5.1 Introduction

As stated earlier, in an incident investigation, the investigator starts with the immediate actions and events surrounding the incident and then works backwards to uncover contributing causes. *Who, where, when, what,* and *how* are all useful questions to get information relevant to the incident; but asking *why* is what will help the investigator “drill down” into the contributing, latent conditions that need to be identified and resolved in order to avoid similar incidents in the future. Remember from our introductory discussion that it’s not just the people you want to concentrate on, but also the ways in which *technology, environment, and organizational factors influenced human performance.*

5.2 Incident Investigation: Going Beyond the Obvious

If we are to learn from an incident, it is very important to go beyond the “obvious” cause and ferret out the underlying, contributing causes. Here’s an example. During the early hours of a November morning, the *DOLE AMERICA*, a Liberian-registered refrigerated cargo vessel, collided with the Nab Tower, a conspicuously-lit, man-made construction in the eastern approaches to The Solent off the Isle of Wight (MAIB, 1999). The ship had left her berth in Portsmouth and was proceeding seaward with the Norwegian captain, a Filipino officer, and a helmsman on the bridge. The captain was in charge, and he set a course to pass to the east of the tower. Suddenly, he saw on the starboard bow what he thought was the red portside light of a vessel at close range, crossing from starboard to port and presenting an imminent risk of collision. The captain ordered starboard helm before going to the front of the bridge to confirm what he thought he had seen. He then called the officer to join him, and the officer confirmed the presence of a red light and reported a second red light to starboard of the first. The captain then ordered hard to starboard helm. When no further lights were seen ahead, the captain ordered hard to port helm, still with the intention of passing to the east of the Nab Tower. The ship struck the tower shortly afterwards.

The immediate cause of the collision was the master’s inappropriate and unquestioned helm order to port (unsafe act – decision error). However, the following contributing factors were important to this casualty:

- From his position at the front of the bridge, the captain was unaware of the ship’s heading and her exact position in relation to the tower (precondition for unsafe act – substandard practice – crew resource mismanagement).
- No discussions took place between the captain and the officer concerning the ship’s progress (precondition for unsafe act – substandard practice – crew resource mismanagement).

- The captain and the officer failed to work as an effective team, probably due, in part, to their differing nationality and social backgrounds, and to an autocratic management style (precondition for unsafe act – substandard practice – crew resource mismanagement *and* organizational factor – organizational climate).
- With no dedicated lookout to refer to, the captain called the officer to join him at the front of the bridge, thereby removing his only source of navigational information (unsafe act – decision error).
- The ship's manager provided no specific instructions to its officers regarding voluntarily offering relevant information to the captain (organizational factor – organizational climate).

While the immediate cause was the captain's poor decision making due to inadequate information, future avoidance of this type of incident depends on correcting the underlying unsafe conditions and organizational factors. Changing the autocratic management style that was in place in this company to one of crew resource management, and training the bridge team to operate more effectively by empowering the officer to actively contribute to navigational decisions (particularly relevant to a multi-national crew) are keys to preventing such a casualty. Had the investigation stopped with the "obvious" cause, the true precursors to this incident would have remained hidden, and remedial actions based only on the immediate cause would have been ineffective.

5.3 A Tool for Investigation: Events and Causal Factors Charting

Before one can begin identifying the human error causes of an incident, one needs a way to represent how an incident happened. There are a number of tools that can be used to get varying levels of detail surrounding the events of an incident and what might have contributed to it. Some of these include timeline analysis, link analysis, barrier analysis, work safety analysis, human error HAZOP, and human error analysis. Most of these can be used either during a safety audit (to understand the work conditions and identify risks *before* an incident occurs) or during an incident investigation. A good introduction to these methods may be found in Kirwan (1997).

Another method that is more directly related to understanding the progression and causes of an incident is Events and Causal Factors Charting (Hill & Byers, 1992a). This method was originally developed by the National Transportation Safety Board for the analysis of accident investigations. It highlights the major events in the progression of an incident and also associates contributing causes to each event. "Contributing causes" include not only active and latent human errors, but also equipment problems, weather, and anything else which may have influenced the events surrounding the incident. Events and causal factor charting can be helpful in organizing and understanding the sequence of events and also in identifying holes or inconsistencies in the incident information collected.

To illustrate how Events and Causal Factors Charting can be used, let's take a closer look at the *TORREY CANYON* incident that was introduced in Section 2 (Hill & Byers, 1992b).

5.3.1 *TORREY CANYON* Synopsis

The Captain of the *TORREY CANYON* was experienced, careful, and a stickler for details. The *TORREY CANYON* was traveling from Kuwait to Wales with a cargo of 100,000 tons of oil. They were heading for Angle Bay, British Petroleum's (BP) deep-water terminal on the western tip of Wales. The day before the *TORREY CANYON* was due to arrive at Angle Bay, the captain was contacted by BP's agent, who told him of impending decreases in the tide at Milford Haven, at the entrance to Angle Bay. He was told that if the *TORREY CANYON* did not catch high tide on the next evening, it would have to wait outside the harbor for most of a week for the next tide high enough to get the ship in. Now, to have a ship of that size sitting idle for five days is very expensive, and the captain was determined to reach Milford Haven on time. This didn't seem to present any problem at the time; to be ready to catch the high tide the next evening the *TORREY CANYON* had to get to Milford Haven and it had to transfer cargo from the midship tanks to the fore and aft tanks to even out the ship's draft. At sea, the tanker drew 52 feet 4 inches amidships, but that was too deep to make it into Angle Bay, so they had to shift cargo. The captain estimated the transfer would take about four hours and planned to make the transfer after they reached Milford Haven. Still, there seemed to be plenty of time.

The next morning, the captain asked to be called when the Scilly Islands were sighted. The Scillies are made up of 48 tiny islands and contains a number of submerged large rocks and sandbars. There were 257 shipwrecks there between 1679 and 1933. The captain was intending to sight the Scillies to starboard, pass them to the west and then go into Milford Haven. However, when the Scillies were sighted, and he was called, they were off the port bow. Rather than turn and go west around the islands, the captain decided he needed to save time and would pass between the Scilly Islands and Land's End, the southwesternmost tip of England. The passage between Land's End and the Scillies is divided into two parts by an island and each of those parts have further obstructions within them. The captain decided to take the western channel. He did not have a copy of the Channel Pilot for the region and he was not particularly familiar with the area. The *TORREY CANYON* was making full speed when it met some fishing boats in the channel, which delayed it making a turn. After taking a bearing from the unfamiliar landmarks, the captain realized that he had overshot his turn and the channel. When he ordered hard to port, and the helmsman turned the wheel, nothing happened. The captain realized that the steering selector switch was set incorrectly on autopilot, reset it to manual, and the turn to port was begun. The *TORREY CANYON* then ran into a granite reef so hard that it could not be pulled off. The Royal Air Force eventually bombed the wreck in an effort to burn some of the oil before it washed up on the beaches.

During the official inquiry which followed, it was pointed out that the captain had plenty of time to get to Milford Haven if he had transferred his cargo while underway[8]. The chairman of the board of inquiry reportedly stated after the hearing, "He [the captain] didn't want to dirty his deck, to come into port looking sloppy" (Hill & Byers, 1992b). Perrow (1984, p. 184) points out, that as most accidents do, this accident involves many "if only" statements:

- If only the captain had not forgotten to put the helm on manual, they might have turned in time;
- If only the fishing boats had not been out that day, he could have made his turn earlier;
- If only he had prudently slowed down once he saw the fishing boats, he could have turned more sharply;
- once deciding to risk going through the Scilly Islands he used a peculiar passage through them – if only he had used another passage, it might have been safer (even faster).

We'll never know precisely why the captain made the decisions he made.

5.3.2 An Event and Causal Factors Chart of the *TORREY CANYON* Incident

To do an Event and Causal Factors Chart, we begin by determining the major events that occurred. Working backwards from the accident, there are four major events:

- The *TORREY CANYON* fails to make its turn in time and runs aground;
- The captain takes the western channel between the Scilly Islands and Land's End;
- The *TORREY CANYON* goes east of the Scilly Islands;
- The Scilly Islands are sighted to the NW (port) rather than to the NE (starboard).

These four events would be placed in boxes (to denote that they are "events") across the top of the page, as shown below in Figure 14.

[8] This accident occurred years before the *Exxon Valdez* and the environmental protection legislation that followed. At the time of the *TORREY CANYON* incident, transferring oil while underway was standard operating procedure for many companies.

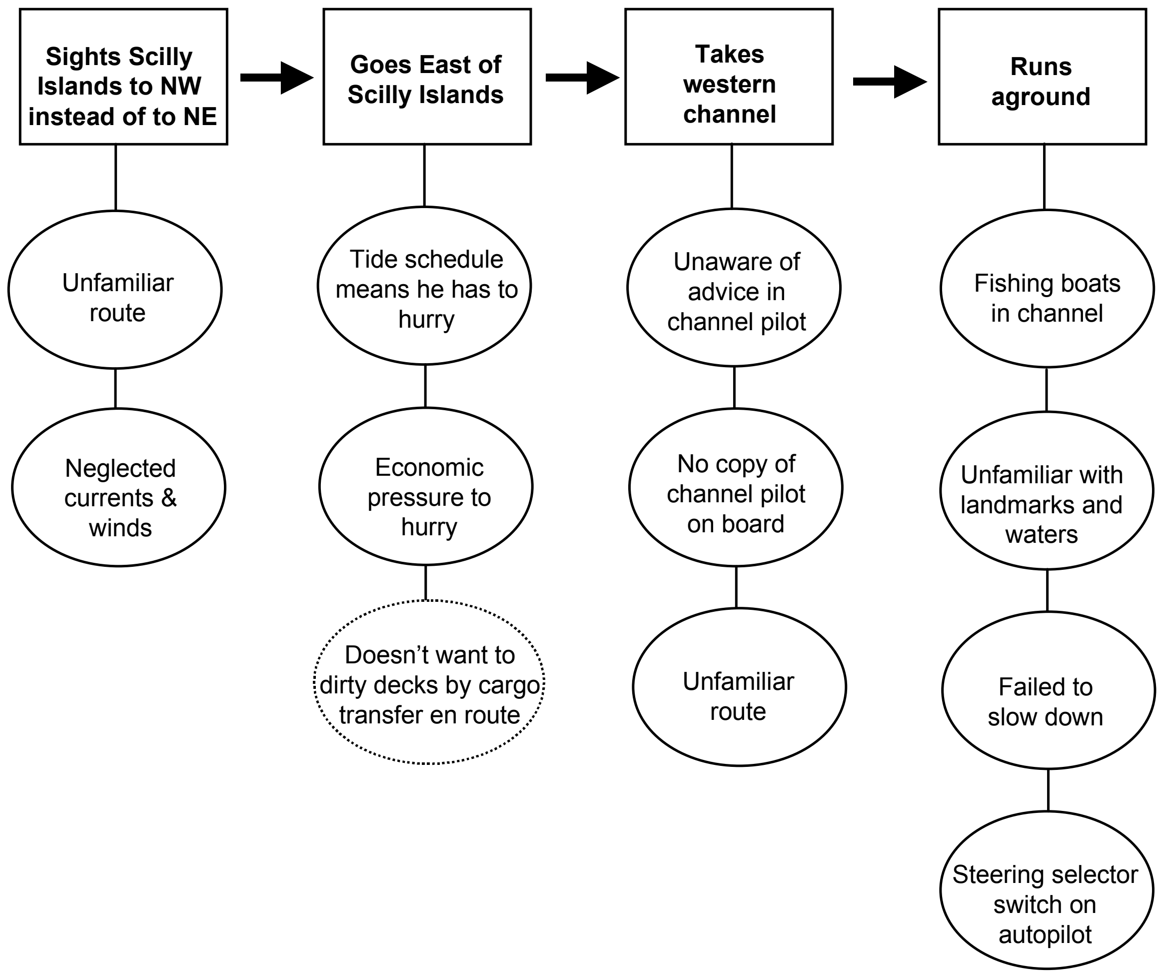


Figure 14. Events and Causal Factors Chart for *TORREY CANYON* Grounding
(after Hill & Byers, 1992)

Below each event box, we list the perceived causes of the event, depicted as ovals (solid ovals for established causes, and dotted ovals for assumed causes). We "drill down" into the causes by asking *why*. For example, when we ask *why* the *TORREY CANYON* failed to make the turn in time (thereby running aground), we find four different issues:

- The *TORREY CANYON* failed to begin its turn in time because there were fishing boats in the way;
- The captain was unfamiliar with the waterway and landmarks, making him late to recognize the turning point and initiate the turn;
- He failed to slow down and was going too fast to make the turn;

- The steering selector switch was in the wrong position (autopilot), and by the time it was corrected, it was too late to make the turn.

While the Events and Causal Factors Charting often ends at this point, we want to take it a step further for the purpose of determining active and latent human factors causes. To do this, it is helpful to remember the human-system approach discussed in Section 2 (refer to Fig. 2). Human errors result not only from errors made by a given person, but, more importantly, human errors usually result from suboptimal *interactions* between people and organizational, technological, or environmental factors. As you drill down seeking contributing causes, keep asking yourself the following questions to help you identify human errors:

- *Did some aspect of the involved person contribute to the incident?* (consider knowledge, skills, experience, motivation, alertness, physical and mental states, use of medicines or drugs, personal problems, etc.)
- *Did some aspect of interpersonal interactions contribute to the incident?* (consider communication, definition of roles and responsibilities, experience working as a team, autocratic vs. empowered style, etc.)
- *Did some aspect of the interactions between the people and the organization contribute to the incident?* (consider training and qualification requirements, crew/team complement, work schedules, safety culture, supervision, policies regarding economic pressure, etc.)
- *Did some aspect of the interactions between the people and the technology contribute to the incident?* (consider equipment layout, whether equipment is designed to do the job, how information is provided from the equipment to the user, whether controls can be easily operated, whether displays are legible, whether the design obstructs proper maintenance, etc.)
- *Did some aspect of the interactions between the people and the environment contribute to the incident?* (consider the workplace environment in terms of lighting, noise, temperature, vibration, ship motion, fog, snow, etc.; also consider the regulatory and economic environment and their impact on job behavior)

The human-system approach and HFACS are complementary ways of looking at human errors. In the human-system approach, we identify the *locus* of the error. That is, we determine whether the error resulted because of a deficiency in a given person's actions or decisions, or whether there was a poor interaction between multiple people or between people and technology, organization, or environment. HFACS identifies the parts of the company's organization that had the *responsibility* for preventing the error. That is, with HFACS we determine whether the individual (Preconditions for an Unsafe Act), the line supervisor (Unsafe Supervision), and-or management (Organizational Influences) had the responsibility for preventing the error. By identifying the level(s) of the organization that had the responsibility for preventing an incident, we identify the part(s) of the organization where changes must be made to solve the human error problems.

Now let us look again at the Events and Causal Factors Chart of the *TORREY CANYON* grounding and use the human-system approach and HFACS to identify the underlying human factors causes of the last event, “Runs aground.” To do this, we would continue to ask *why*. To ask why there were fishermen in the way doesn’t get us anywhere with this particular case[9]. Note that the presence of the fishermen is, in fact, an environmental factor that interacts with the captain; but since neither the captain nor the company have any control over the presence of fishermen, that aspect of the incident is ignored. The captain *did* have control over his *response* to the presence of the fishing vessels, and that will be discussed in the third causal factor.

“Drilling down” on the second causal factor, the fact that the captain was unfamiliar with the waterway, is more enlightening. The captain was unfamiliar with the route, because it was not the route he had planned to take. Furthermore, he did not have a copy of the Channel Pilot on board, and so could not avail himself of helpful information. *Why* did he not have a copy of the Channel Pilot, when he had planned to take a nearby route? While we don’t have the answer to this question, it might have involved an error in HFACS Organizational Influences – Organizational Process if the company had not established that ships carry information about all routes it would transit. Or, perhaps the company had the policy, but the captain had failed to ensure that the document was onboard and available for use; this would be an example of Unsafe Supervision – Supervisory Violation. As you can readily see, depending on who was responsible (the company or the captain), the type of corrective action needed would be vastly different.

Asking *why* the captain failed to slow down when he saw the fishing vessels (which was determined by the board of inquiry to be the prudent action to have taken), the probable answer is that the captain felt pressured to make good time, and that pressure negatively influenced his judgement. While there’s no question that the captain’s unsafe act (going too fast) was based on a decision error, we need to continue to ask *why*. *Why* did the captain feel such a compulsion to make good time? As pointed out in the incident synopsis, had the captain missed the evening high tide at Milford Haven, the *TORREY CANYON* may have had to sit idly waiting for several days before the next tide of sufficient depth to allow her to pass. This spawns several issues for further investigation. Given that the tidal depths at Milford Haven were known, why did the company elect to send a tanker that could only get through Milford Haven on certain days (i.e., did the company consider lightening the *TORREY CANYON’s* load or sending a different vessel(s) that had a draft more compatible with the tides at Milford

[9] Although this question is a good one in certain sections of the U.S. where fishing regulations limit fishing seasons to only a day or two, causing greatly congested waterways on those days. Asking *why* in these cases may point out a flaw in the regulations, showing that these regulations need to consider not only conservation but waterway mobility, as well.

Haven? – potential HFACS Organizational Influences – Resource Management issue)? If the *TORREY CANYON* had gotten into Milford Haven too late to make the high tide, how would that have affected the captain? Did the company have a policy which would have penalized the captain for missing the tide, thus encouraging him to take risks (HFACS: Organizational Influences – Organizational Climate)? Or, perhaps, was this a self-imposed pressure due to the captain's pride at making schedule and resulting in his taking unnecessary risks (Unsafe Supervision – Supervisory Violation)? There is an obvious tension between the pressure to make good time and safe navigation. Depending on how it evolved (organizational policy or supervisory deficiency), the appropriate correction will vary.

Finally, we have the causal factor of the steering selector switch being in the wrong position. When we ask *why*, we will find a procedural issue: why was the ship on autopilot in a hazardous navigating environment? The answer to this question could be a combination of factors such as: it was put there inadvertently (HFACS: Unsafe Act – Skill-based Error); it was put there intentionally to allow the helmsman to do another task (Unsafe Act – Routine Violation); or perhaps it was left on autopilot too long, due to inadequate bridge team coordination (Precondition – Substandard Practices – Crew Resource Mismanagement). Using the human-system approach, we might ask whether there was a suboptimal interaction between the people and the technology. Specifically, *why* didn't the helmsman know that the ship was on autopilot? The answer is that there was no indication of the steering selector setting at the helm! The steering selector control was located where it could not be seen when standing at the helm. Whereas the *locus* of this error is the interaction between the user and the technology, note that the *responsibility* for the error is at an entirely different level. On the one hand, this is a design error on the part of the equipment manufacturer; however, since the company most likely had no control over the manufacturer's design, this is not a useful avenue to pursue. But on the other hand, this might also be an error on the part of company management for selecting and purchasing unsuitable equipment and-or installing it in an unsuitable manner (HFACS: Organizational Influences – Resource Management).

By charting first the primary events that led to the incident, and then by asking *why* until the (many) contributing causes are found, one can establish the reasons why an incident happened and trace the layers of responsibility from the individual(s) to the preconditions, to supervisory errors, and to unsafe organizational influences. The combination of Events and Causal Factors Charting, the human-system approach, and the Human Factors Analysis and Classification System (HFACS) can be a powerful tool for ferreting out the true underlying causes of incidents and identifying parts of the system which need to be corrected in order to prevent recurrences of similar problems.

5.4 The Art of Incident Investigation

Incident investigation is somewhat of an art. It takes great skill to build a rapport with and interview people associated with the incident[10]. It also takes a great deal of knowledge about the technical and human factors aspects of the incident to ask the right questions and identify the important issues (this is the reason for having investigation *teams* – no one person is likely to have all the requisite skills and knowledge). Likewise, there is no one method or "best" set of questions to ask that will work for all investigations (Appendix H gives a sample of human factors questions that could be asked). It takes experience to spot potential issues and to know what avenues of questioning will be most fruitful in a particular incident. It takes experience and skill to hunt for underlying causes and to fit the pieces of the puzzle together.

Incident investigation is also not a serial endeavor: it is highly iterative. As Figure 15 depicts, there is a cyclical process of gathering information, organizing it into the sequence of events and causes that led up to the incident, and looking for the underlying human factors causes. Oftentimes after the initial round of interviews, it will become apparent that the sequence of events has missing pieces, or that some of the information appears contradictory. This necessitates additional interviews or re-interviews. As you begin to feel you understand the sequence of events, you may find that you still lack the information to identify the types of human errors that were made and the underlying causes of these errors. More questioning is needed. Sometimes an exploration of the human errors will bring to light that the sequence of events is still incomplete. And so it goes, back and forth, asking questions, organizing data, finding holes, and asking more questions, until you can finally produce a set of events, causes, and underlying human errors that "hang together" and make a sensible explanation for how the incident evolved. Patience and persistence are two traits of successful investigators!

In this section we have repeatedly stressed that the good investigator keeps asking "*why?*" It is useful to consider when to *stop* asking why. Asking *why* is a great tool for identifying underlying contributors to the errors that caused the incident. But if taken to extremes, it can become almost absurd. In general, we want to keep asking *why* as long as the answer is still something that has practical significance to the incident and is *under the company's control* to make changes[11]. In the *TORREY CANYON* incident, for example, we elected *not* to consider why

---

[10] For a discussion of interviewing techniques, as well as other good material on the collection of evidence, see Center for Chemical Process Safety (in preparation).

[11] There are times when we *do* want to look for causes that are beyond the company's control. Some incident causes have ramifications for offshore or maritime safety in general and may necessitate changes to equipment, legislation, or codes of practice. For example, if a regulation appeared to be a cause of the incident, then that information needs to be brought to the attention of the appropriate authorities so that the regulation can be revised. In the *TORREY CANYON* example, the poor design of the steering selector mechanism, because it could easily cause similar problems for others, should have been discussed with the manufacturer, to prompt a redesign, and reported in industry publications to warn others of the hazard. While the main thrust of this paper is to help companies use human factors incident investigation to improve their own safety, we all have the responsibility to share this knowledge in order to improve the safety of the industry as a whole.

there were so many fishing vessels in the channel, because that was totally out of the control of the company. But we *did* elect to consider the captain's *response* to those fishing vessels (i.e., the fact that he did not slow down), because his response *is* within his (and the company's) control. There will always be extenuating circumstances. We need to focus on how the company *responds* to those circumstances in a way that gets the job done safely.

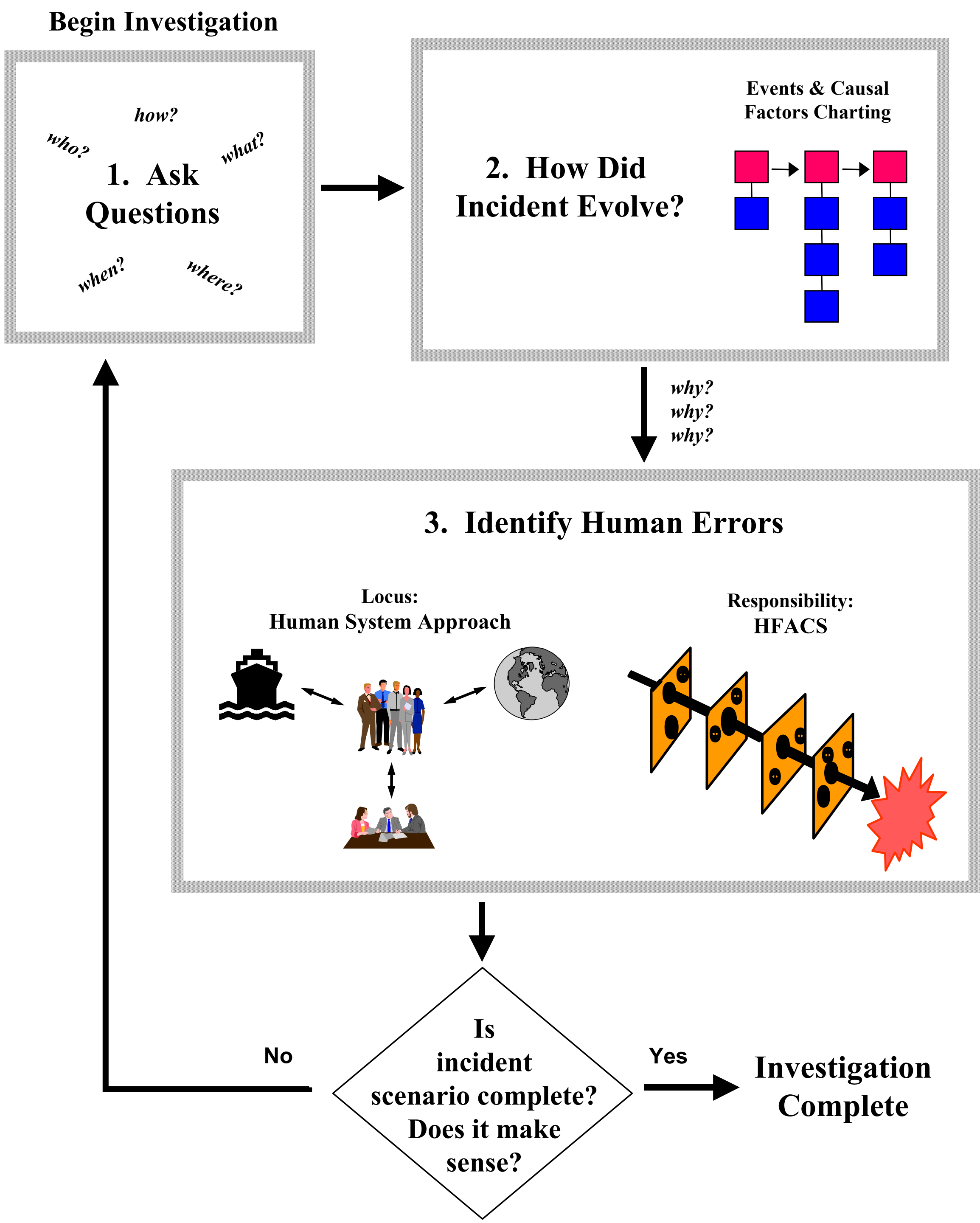


Figure 15. The Incident Investigation Process

6.0 ANALYZING INCIDENT DATA

Now that you've been running your incident investigation program for awhile, what do you do with all those data? There are many ways to make good use of the data collected from incident investigations. Here are a few ideas.

6.1 Learning from Individual Incidents

This is the simplest way to learn from your incident investigation program. Individual incidents can be discussed at safety meetings, allowing personnel to gain an understanding of how different incidents evolved and how an accident was avoided. This type of information sharing can stimulate discussion of similar occurrences and potential changes to procedures, policies, training, equipment usage, etc. that might help prevent future incidents.

While case-by-case studies can be beneficial, they have a drawback. By focusing on a single incident, there is no way to know what facets of that incident may represent general problems as opposed to things that were unique to that particular incident. Most companies would rather spend their money fixing frequently-occurring problems than smaller, once-in-a-lifetime problems. The way to get a feeling for the importance and the frequency of a problem is through data analysis, and several approaches to analysis are discussed below.

6.2 Identifying High-Risk Activities or Facilities Using Simple Frequency Analysis

Frequency analysis can be an effective way to identify problem areas on which you need to focus. For example, say an offshore drilling company has three rigs and wants to know whether all three have about the same number of incidents. A simple frequency analysis entails adding up the number of incidents reported over a given period of time (e.g., one year) by the crews of each rig (Fig. 16).

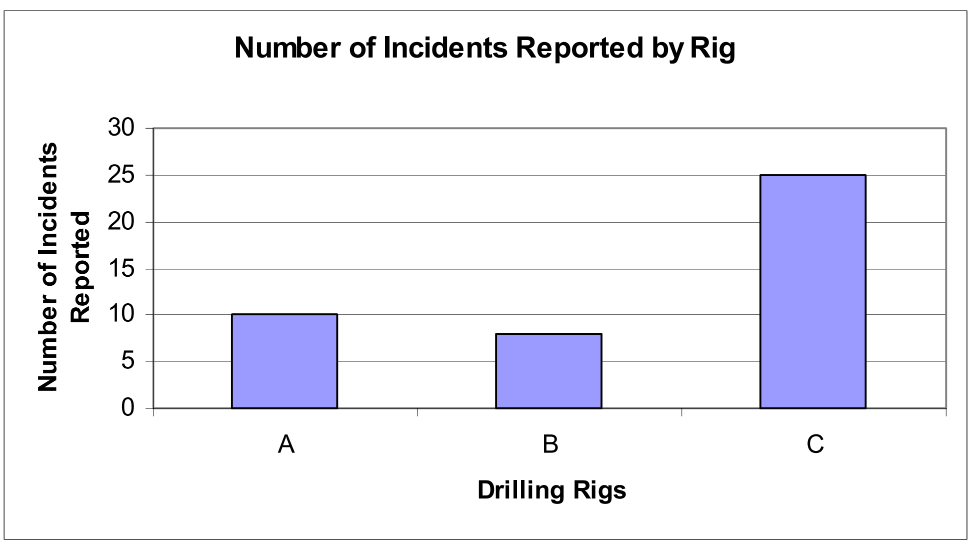


Figure 16. Example of a Frequency Analysis

In the example shown in Figure 16, it is obvious that Rig C has reported over twice as many incidents as has either Rig A or Rig B. Looks like Rig C has a problem, right? Well, not necessarily. You need to go deeper and find out *why* Rig C has reported more incidents. Maybe the crew members on Rig C are very excited about the new incident investigation program and are being vigilant for and reporting every incident that arises, while the crews on Rigs A and B are only reporting the incidents they consider to be "important" in some respect. Or maybe Rig C is larger, does more operations, and has more people working on it than either A or B – if Rig C is doing four times the work that is done by either Rig A or B, then C's true incident rate would actually be *lower* than that on A or B! This shows the necessity for considering how to make an "apples to apples" comparison. However, if Rigs A, B, and C are roughly equivalent in all respects, then C might truly have a safety problem that needs to be identified and solved. One way to look into this in more depth would be to do more frequency analyses by type of operation, or by type of equipment used, or by some other relevant factor. In this way you can isolate which operations or equipment appear to be related to the higher incident rates (for example, perhaps when looking just at Operation X, Rig C's incident rate is the same as that for A and B; but when looking just at Operation Y, Rig C's incident rate is much higher than that for A or B).

6.3 Looking for Trends

A simple extension of the frequency analysis discussed above is to compare frequencies over time to look for trends in the data. Perhaps you have made some changes to a standard operating procedure to reduce injuries. Is the new SOP helping? To find out, you could plot the number of injuries in the years prior to the new SOP and compare that to the number of injuries since the new SOP was put into place. Or maybe the SOP has been helpful in reducing certain types of injuries but not others. A plot, like that presented in Figure 17, could help the company spot areas of concern. In this example, most of the injury rates are fairly consistent over the four years shown. However, three injury categories show some interesting changes. "Struck By/Against" and "Slips/Trips/Falls" both show marked decreases. In this particular case, the company had built and put into service 18 new ships in 1996-1999. The learning curve for operating the new ships may have contributed to exaggerated "Struck By/Against" rates in 1998 and 1999, with the decrease in 2000 showing that the crews had become familiar with the new ships. The decreased rate of slips, trips, and falls is attributed to the company's purchase of new safety shoes (designed for the restaurant industry to keep traction on wet floors) – a successful safety intervention! The third item of interest is the relatively greater rate of injuries in the "Chemical Spray" category over the last two years. This appears to be due to the fact

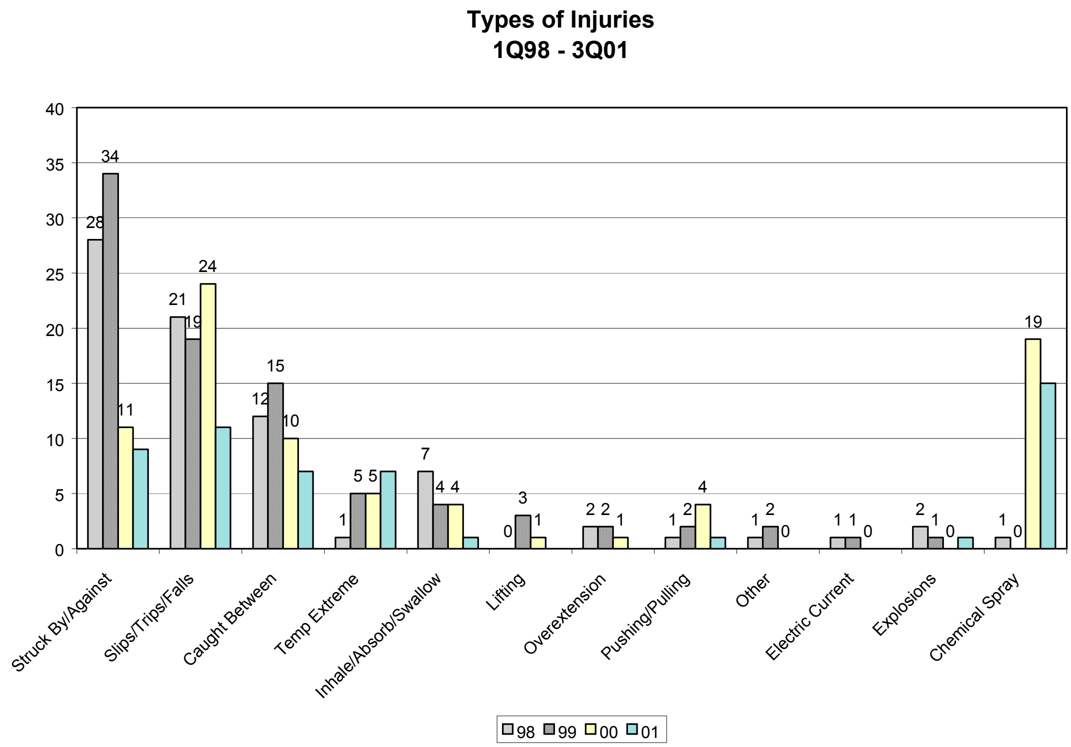


Figure 17. Example of a Trend Analysis
(Data courtesy of Stolt-Nielsen Transportation Group)

that new crews were hired to man some of the newer ships, and these crew members did not have previous experience on a chemical tanker. Stolt is addressing this problem with an intensive training course taught by experienced Captains and Chief Mates, a course which has proved very successful in the past. This type of finding alerts a company to the need for getting additional data to understand the contributing causes to such incidents so that productive safety interventions can be designed and implemented.

Frequency and trend analysis are often supplemented with cost data to help a company decide where to focus its next safety intervention. While frequency data tell you how often a given type of incident happens, it does not tell you the severity or consequence of the incident. Therefore, it is helpful to combine frequency data with cost (or some other measure of severity) to determine which types of incidents are most in need of controls. For example, Figure 17 shows a much higher frequency of slips, trips, and falls than injuries associated with temperature extremes. Going solely by the frequency data, one would assume the slips, trips, and falls are more important to control. However, if most of the slips, trips, and falls have a relatively minor consequence (that is, the injury caused is mild), then it may not warrant much attention. Let’s say that on the average, the injury caused to the workers in these slips, trips, and falls is so minor that nothing more than first aid is needed and the employee can return immediately to the job. However, let's say that the result of the average injury due to extreme temperatures (e.g., heat stroke or frostbite) requires hospitalization and one week of lost time. So even though the *frequency* of the temperature-related incidents is only about a quarter of that due to slips, trips, and falls, their *severity* is much worse. The "total cost" (frequency x average cost) of the temperature-related incidents is much greater than that for the slips, trips, and falls, making the reduction of temperature-related incidents a higher priority for the company.

A word of warning about trend analysis: just because the data appear to show a trend does *not* necessarily mean there really is a significant trend present. Data can be highly variable (that is, the number of incidents can fluctuate greatly from one time period to the next). It is not uncommon to see rather large changes in the numbers of incidents from year to year. When you are dealing with a small number of data points (e.g., comparing yearly incident frequencies from 1999 to 2000), you cannot see the underlying variability. One way to get a better appreciation for the variability is to look at the data by month or by quarter instead of by year. The most accurate way to identify true differences in frequencies and establish real trends is by using statistical analysis (for example, fitting the data to a linear function (linear regression) and determining whether the slope is significantly different from zero).

Both frequency analysis and looking for trends are ways to identify operational variables that may require closer examination. Notice that while the frequency or trend analysis will show you areas of concern, it does not answer the question as to *why* these differences are occurring. Once you've isolated the types of activities, operations, or situations of interest, you can use the next analysis technique to explore your incidents further.

6.4 Looking for Similar Incidents

If each incident report is coded with the type of incident (e.g., oil spill), and the activity during which it happened (e.g., filling a tank), one can search the database to identify all the incidents which had these features in common. One immediate advantage to this is it helps to identify your high-frequency events. Another big advantage is that you can now re-read the incident narratives and look for other similarities that might lead to the identification of a safety hazard that needs to be fixed. For example, in the case of spills caused by overfilling a tank, it may be that an overfill alarm needs to be added, or that the standard operating procedure needs to be changed so that the tank is continuously monitored by a crew member, and-or the fill rate decreased as the tank gets close to being filled. This type of analysis is an excellent way to identify equipment design flaws and poor operating procedures. The FAA-sponsored, NASA-run Aviation Safety Reporting System, has used this method successfully to identify equipment defects, runway design problems, and to make improvements to air traffic control protocols.

6.5 Determining Under What Conditions a Given Error Happens

In the construction of the incident database, it can be useful to do a risk assessment of various operations to identify things that "might" go wrong. The database can then be used to see under what conditions things actually *do* go wrong. For example, in a study of communications errors, the types of operations that depend on good communications were identified (e.g., vessel navigation with a marine pilot on board requires good communications between the pilot and the ship's bridge team; safe meeting and passing agreements depend on good ship-to-ship communications). The potential need for communication was then tagged in the database by answering five simple questions, such as "Was there a pilot navigating?" or "Were there two or more vessels involved in this casualty?". In analyzing the accident data, it was found that of the accidents in which one of these five questions was answered "yes", 76% of them had a communications error as a contributing factor to the accident. This is a powerful way to identify high-risk activities and situations.

6.6 Looking for Underlying Causes Using Meta-Analysis

If your incident investigators are adept at asking "why" enough to get to underlying human error causes, then you can use your incident database to determine which types of causes may precipitate many of your incidents. To extend the example above of communications-related casualties, the incident investigators used a form to identify specific communications problems, such as "did not communicate", "did not send information in a timely manner", "message was interrupted", "did not interpret the information correctly", and others. For each problem identified, the investigator went on to consider a list of contributing factors, such as "inadequate knowledge of company policies for communications", "limited English skills or knowledge", "did not operate communications equipment correctly", "distracted or interrupted by other tasks", "assumed there was no need to communicate", and others (see App. G for the complete communications investigation protocol).

A frequency analysis of the communication problems showed that the single biggest problem was a failure to communicate. That is, in 68% of the accidents, someone had information that could have prevented the accident, but chose not to tell anyone. These "failure to communicate" casualties were isolated and a frequency analysis was done to identify the most frequent contributing factors. While this identified factors such as "incorrect interpretation of the situation", "assumed incorrectly that other party already knows", and others, it didn't give a good sense of what might be at the crux of these accidents.

To get a clearer picture of what was going on, a "meta-analysis" was done in which the narratives of the different casualties were reviewed and additional characteristics of the situations were identified. The result was the finding that the most common apparent underlying cause in 92% of these "failure to communicate" accidents was that the person did not perceive a safety threat, either because he had misinterpreted the situation or because he failed to think about the ramifications of the situation beyond his own specific job responsibilities (that is, he did not consider how his actions might affect other people). These types of behaviors show a deficit in "situation awareness". The meta-analysis also showed that in almost half of these accidents, there was a second person who did not speak up. This person perceived the safety threat, but assumed it was not his job to say anything (he assumed someone else was aware of the problem and would take care of it). This failing shows a lack of "ship resource management". The meta-analysis allows one to go beyond the specific data categories in the incident database and to find underlying causes that may tie other, seemingly-disparate causes together. In a sense, a meta-analysis is like putting a puzzle together. Each database element is a piece of the puzzle, but the meta-analysis helps us see how to put the pieces together and get greater meaning from them. In this case, it was the meta-analysis which most effectively pointed us at the true underlying problems, suggesting the types of interventions (improvements in situation awareness and ship resource management) that would be productive.

6.7 Identifying Relationships Among Incident Attributes by Statistical Analysis

Statistics can be used to draw out meaningful relationships among elements of incidents, and sometimes they can be used to infer probable cause. Statistical analysis was used in a couple ways in a recent study of fatigue-related accidents (McCallum, Raby, & Rothblum, 1996). The purpose of the research was to understand not only how many marine accidents were related to fatigue, but also to look for underlying contributing factors (in other words, what was causing the fatigue). A database was established using scientific literature to identify the questions that should be asked (the resulting fatigue investigation questions can be found in App. G). The fatigue investigation was administered during routine casualty investigations, and the database was used to find out what attributes were significantly related to fatigue (that is, what data items had statistically different values in the fatigue-related accidents compared to accidents that did not result from fatigue). One set of tests looked at the number of hours worked by mariners who caused injuries (either to themselves or to another crew member).

The statistical tests (*t-tests*) determined that the number of hours on duty at the time of the accident, and the number of hours worked in the last 24/48/72 hours were all significantly different for the fatigue-related and non-fatigue injury cases. The averages for each of these comparisons are plotted below (Fig. 18). One must be careful about jumping to causal conclusions. In some cases, the difference seen between two groups may be due to something very different than what is being tested (remember our example of the number of incidents reported by the different oil rig crews). However, in this case, the scientific literature supports the relationship between long work hours and increasing fatigue. Therefore, these data were taken as strong evidence that an underlying cause of these fatigue-related injuries was long work hours.

Statistical analysis was used a second way in this study. It was used to consider all the different factors that were correlated with fatigue-related accidents and to come up with a quick "screening test" for fatigue. Because the full fatigue investigation took about 40 minutes, it was desirable to find a few questions that would indicate whether fatigue appeared to play a role, and whether, therefore, the investigator should collect all the fatigue data. A multiple regression analysis was performed to determine which factors were most predictive of fatigue-related casualties. The result was a simple *Fatigue Index* equation consisting of just three questions (the number of hours slept in the last 24 hours, the number of hours worked in the last 24 hr.,

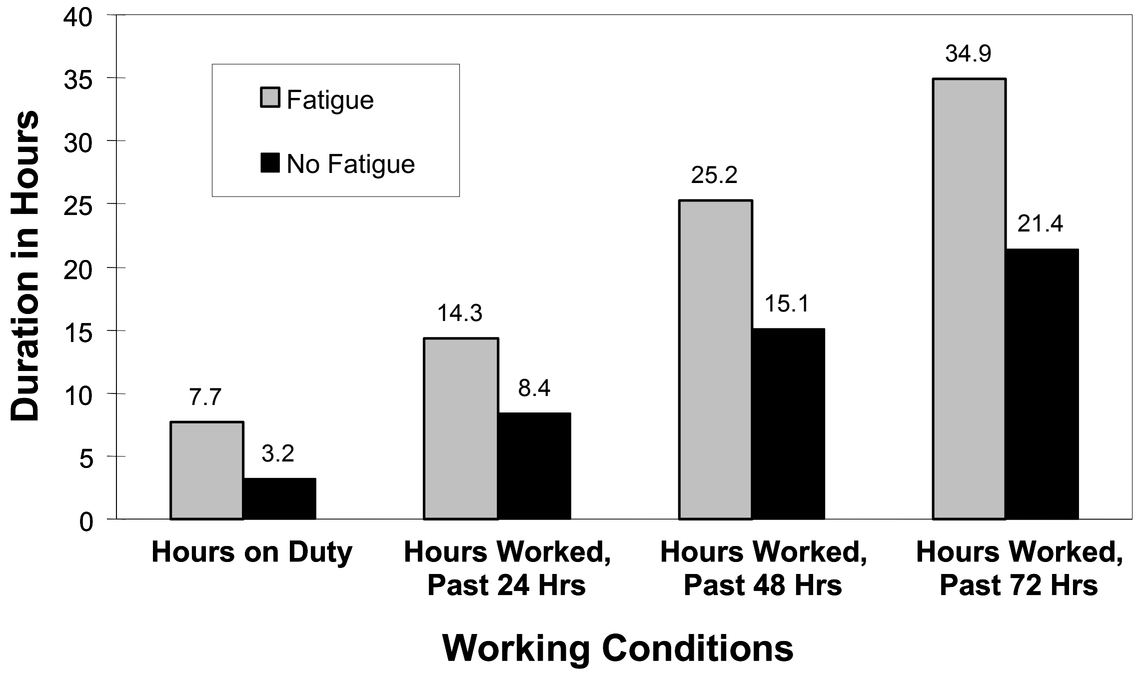


Figure 18. Result of Statistical Analysis of Incident Database Items
(from McCallum, Raby, & Rothblum, 1996)

and the number of fatigue symptoms experienced by the mariner). When the data from both the fatigue and non-fatigue casualties were put into this equation, it was found to be 80% correct in its ability to identify whether a given casualty was fatigue-related or not (the fatigue index worksheet is in App. G).

The purpose of statistical analysis is to determine whether apparent differences in data points are just due to the variability of the data or whether they are due to a true underlying difference or trend. For example, in Figure 17, the incidence of "caught between" injuries varies greatly over the four years shown. Is the downward trend from 1999 through 2001 "real", or is it just a matter of the normal variability of the data? Statistical tests can be used to determine this. It should be noted that just because something turns out to be "statistically significant", it does *not* necessarily mean that it is "important" or significant in practical terms. The size of the significant difference could be very small. For example, Figure 16 compared the number of incidents on three drilling rigs. It might be that the incident rate on Rig B is significantly lower than the rate on Rig A. But since both have a relatively low rate of incidents, from a practical standpoint, the difference just isn't interesting (not worthy of taking action).

6.8 After the Analysis

Webster's Dictionary (G & C Merriam Company, 1973) defines *data* as, "factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation." The operative word is *basis*. The analysis of incident data serves as nothing more than a basis or a point of departure for discussion, reasoning, and perhaps additional study. It is not until the data have been pondered, organized, understood, and put into proper context that these bits of disparate facts turn into valuable and useful information. This subsection discusses two areas in which one needs to go beyond the data analysis in order to fully understand the data and take appropriate action.

6.8.1 Data-Driven Research: the Link Between Data Analysis and Solving Safety Problems

You cannot solve safety problems simply by analyzing incident data. In general, the analysis of incident data will identify a potential problem that then needs to be studied before it can be solved. For example, if you plot your company's injury data and find that a large percentage of the injuries are from slips, trips, and falls, you have identified a problem, but not a solution. The next step would be to investigate further and understand what seems to be causing the slips, trips, and falls. Where do these injuries occur and under what conditions? Are deck surfaces slippery or are stairway treads worn? Have personnel been provided with proper footwear, and if so, are they *wearing* it? (You'd be surprised at the number of times companies provide personnel protection gear of one sort or another, only to find that employees refuse to use it because it's either uncomfortable or interferes in some way with other aspects of their jobs. Protective gear must be designed to be compatible with the workers' needs and workplace tasks.)

As was discussed earlier (see Fig. 8 in Sec. 3), the analysis of incident data is the precursor to *data-driven research* used to understand the problems identified by the analysis. "Research" may be as simple and low-tech as a discussion with employees and line supervisors to get their perceptions of the problems and potential solutions, or it can be as detailed and intensive as a full-blown scientific study. The point is that the analysis of the incident data is a *starting point*, and that it takes follow-up study to understand the genesis of a problem and to devise successful safety interventions.

6.8.2 It May Be Data, But It's Not Necessarily Telling You Anything

One final caution: a database is only as good as the data that are put into it. If the investigator doesn't ask all the relevant questions, the database *cannot*, by definition, have the relevant data. This harks back to the recommendations given in Section 3 for building a successful incident investigation program. If the company does not promote an open, fair, and improvement-oriented culture, or if there isn't a common understanding about the scope and purpose of the incident investigation, or if the investigators are not appropriately trained, or if the incident database is hard to use, the data that populate the incident database may be less than accurate and complete. Obviously, analyses based on such data will be of questionable value ("garbage in, garbage out").

Even with the best of intentions, things may happen which affect the database. For example, a simple change in policy affecting which incidents will be investigated may result in the appearance of a greatly increased (or reduced) incident rate when comparing data from periods before and after the policy went into effect. Let's say a company decides to forego incident investigation on any incident which costs the company less than $10,000. If there are types of incidents which are predominantly low-cost, the frequency of those incidents will appear to be dramatically reduced after the policy takes effect (even though the true frequency of the incidents has not changed, or even increased – they just aren't being investigated anymore). Training for investigators may result in a better understanding of the classification scheme (such as HFACS) they are using. While this should result in improved data reliability in the future, it may also give the appearance of changes in certain types of incident rates (because some incidents may have been misclassified prior to the training).

Never put blind faith in your incident data analysis: always be on the lookout for procedural or other reasons (unrelated to actual incident rates) that might be affecting the analytic process. Keep records of changes made to the database, investigation policy, and investigator training – these could be great time-savers in understanding "mysterious" trends. Keeping records of important company policy or procedural changes can also be helpful in understanding changes in incident frequencies. The more you know about changes in the way you do business – both in the company at large and in the incident investigation program specifically – the better you will be able to differentiate between spurious "trends" and true safety issues.

6.9 Summary of Analysis Techniques

Data analysis can be used to identify areas in need of safety interventions. Oftentimes, data analysis shows an interesting trend, but does not give you sufficient information to take action. This will require follow-up studies to better define the problems and suggest workable solutions. Data analysis can also point out where the database and-or investigation procedures are lacking. For example, you may find out the company has a high rate of slips, trips, and falls – but that doesn't tell you enough about the problem. The database might need to be modified to add information on the types of slips, trips, and falls (e.g., where they occur, what operations were in progress, how much lost time resulted), and the incident investigators may need to ask additional questions to illuminate the causes of these accidents. Recall that Figure 8 shows a feedback loop from Database Analysis back to Incident Investigation. Data analysis is a great way to learn about the strengths and weaknesses of your investigation methods and database.

This section has provided examples of ways you can learn from your incident data. Frequency analysis and looking for trends are simple procedures that anyone can do quickly with the aid of a spreadsheet application. Looking for similar incidents and determining conditions which tend to be associated with them are fairly simple procedures, although a database with relevant index variables is helpful for doing such analyses efficiently. Statistical analysis, while requiring more expertise on the part of the safety analyst, can provide great benefits by finding underlying correlations and relationships. The important thing is not to let your incident data just sit there: analyze it and make it work for you.

7.0 FINDING SAFETY SOLUTIONS

Let's say you've collected incident information and run some analyses. Now you want to develop measures to prevent these incidents from recurring. What do you do? How do you find solutions that will be *effective*? Oftentimes, finding effective solutions is elusive. A study of offshore operations in an international oil and gas company demonstrates what can happen (Bryden, O'Connor, & Flin, 1998). This company had an incident investigation program. The database contained information on technical and human factors causes of the incidents and suggested remedial actions. Analysis of the recommended remedial actions showed that only 10% of them addressed the underlying causes of the incidents, while another 31% addressed only direct causes and no underlying causes. The shocker was that 59% of the recommended remedial actions were "quick fixes" which did not address the causes of the incidents at all! The ineffective quick fixes tended to be things such as telling the worker not to do it again, or mentioning the danger at the next safety meeting. A safety program based on trying to motivate the worker not to repeat a dangerous action, without taking steps to solve the underlying causes, is doomed to failure.

On the other hand, it is not so surprising that companies might fall into such a "quick fix" trap. One might say that the biggest problem with having a successful incident investigation program is that now there are data about which management must not only *think*, but also *do something constructive!* Perrow put it this way (Perrow, 1986, as quoted by Hollnagel, 2000, p.1):

> Formal accident investigations usually start with an assumption that the operator must have failed, and if this attribution can be made, that is the end of serious inquiry. Finding that faulty designs were responsible would entail enormous shutdown and retrofitting costs; finding that management was responsible would threaten those in charge; but finding that operators were responsible preserves the system, with some soporific injunctions about better training.

Remember Reason's (1990) Swiss cheese model – each slice of cheese (excluding unsafe acts) represents a layer of system defenses. The fact that incidents are occurring means that one or more of these layers of system defenses requires repair: they are not effective barriers to prevent unsafe outcomes. Hollnagel (2000), like Reason, has suggested that in order to prevent incidents, we must go beyond finding a single "root cause" (or making the operator the scapegoat, per Perrow) and understand how to improve the barriers (system defenses). Barriers can either avert an incident from taking place, or reduce the magnitude of the negative consequences (prevention and mitigation, respectively, as depicted in Fig. 8).

7.1 The Triangle of Effectiveness: A Guide to Safety Interventions

Gerry Miller (2000; Miller et al., 1997) adds his voice to those of Reason and Hollnagel in decrying the past tendency to place the blame for industrial incidents solely on "operator error". Instead, it is his contention that even the most safety-conscious employee will occasionally initiate unsafe acts at the job site, and that sometimes these acts are encouraged, led, or even coerced upon the employee by a variety of factors beyond the employee's control. However, Miller states that these acts can be prevented, or at least the consequences of the acts mitigated, through the application of barriers or safety interventions. He illustrates this concept through his "triangle of effectiveness" (see Fig. 19), which presents eight levels of barriers that can be used to prevent or mitigate incidents[12]. Starting at the base of the triangle, these eight elements are:

- Policies and culture[13] – management policies and corporate culture which promote a safe, human-centered work environment;
- Workplace design – ergonomically-designed and arranged equipment;
- Environmental control – keeping lighting, temperature, noise, etc. within human-compatible ranges;
- Personnel selection – selecting the right people for the job;
- Training and standard operating procedures (SOPs) – ensuring workers have the necessary knowledge and skills to do the job, and that SOPs are correct and consistent with best practices;
- Interpersonal relationships (communication) – the exchange of necessary information between team members;
- Job aids – understandable, easy-to-use task instructions and warning placards;
- Fitness for duty – ensuring that workers are alert, focused, and capable of safe job performance.

All eight barriers are important, Miller concludes, and must be included in a total behaviorally-based safety program. It should be emphasized, however, that the elements at the base of the triangle (i.e., policies & culture, workplace design, and environmental control) have the most significant impact on safety and should form the backbone of a company's safety program. (Each of these eight barriers will be discussed in more detail in the next section)

In Reason's model, these elements (at the base of the triangle) are controlled by the "Organizational Factors" layer of defenses. When the organization (company management) makes poor decisions, such as the selection of equipment which is not designed to support the

[12] Miller uses this triangle both as a model for accident causation and as a guide to selecting safety interventions. Like Reason's framework, Miller's emphasizes the multiplicity of causes of a given incident and attributes the causes to the lack or failure of barriers (system defenses in Reason's jargon). In this paper we have chosen to focus on Miller's triangle as a means for selecting interventions, since it bridges the gap between Reason's organizational model of system defenses (management – line supervisor – worker) and the concrete needs of a shipping or offshore company to select specific means to solve identified safety problems.

[13] Miller calls this factor "Management Participation". Workshop participants felt "Policies and Culture" was a more intuitive label.

human operator, that single poor decision has an enormous "trickle down" effect because so many operators and operations are affected. Such poor decisions at the Organizational Factors layer very often become latent contributors to incidents. In a similar fashion, *good* decisions made at the Organizational Factors layer, such as the selection of well-designed equipment (or other human-centered decisions contained at the base of the triangle), contribute very positively to the safety program, again because of the numbers of people and operations they touch.

Interventions based solely on elements at the top of the triangle (such as fitness for duty and job aids) will have the least impact on workplace safety, and therefore should have a lesser emphasis within the company's safety program. The factors at the top of the triangle depend primarily on the actions of individual workers. Interventions at this level are on a one-by-one basis – a less efficient and less effective way of dealing with safety issues.

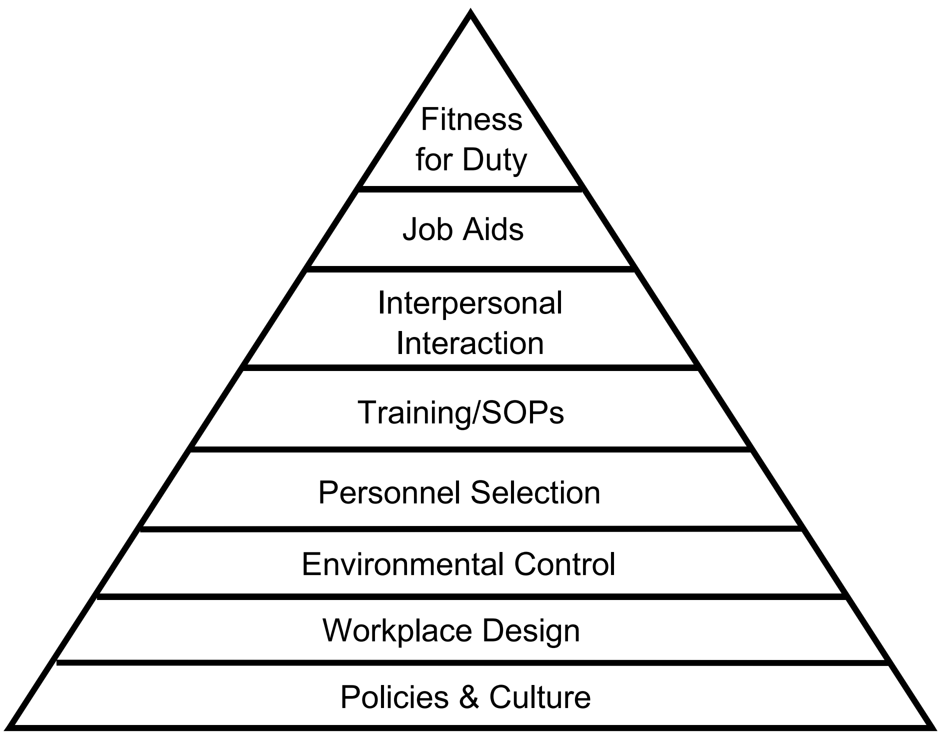


Figure 19. The "Triangle of Effectiveness" for Safety Interventions to Reduce Human Error
(after Miller, 2000)

An example will help to clarify this. Let's say Joe needed emergency medical attention because he accidentally sheared off one of his fingertips while cutting metal sheeting to make a repair. Telling Joe to "be more careful" will not likely have a big impact on safety. Training all the repair crews on the correct procedure for cutting sheet metal will have more of an impact, since more of the workforce is made aware of the problem and a way to protect themselves (assuming, of course, that supervision and peer pressure encourage and reinforce their behavioral changes). But the best way to prevent this type of incident is by having equipment that has been designed with a "guard" to prevent one's fingers from contacting the cutting mechanism (workplace design level).

Hollnagel (2000) points out that the purpose of an incident investigation program is to identify barriers (system defenses) that have failed or barriers that were missing which allowed an incident to happen. A good safety intervention program repairs and-or develops as many of these barriers as possible. Miller's (2000) addition to this line of thinking is that when it is not possible to implement all the relevant barriers, selecting those towards the base of the triangle will reap better protection than selecting only those towards the tip. Just as we need to probe deeper to find the underlying latent factors which cause incidents, we also want to make safety "fixes" and focus our safety program at the deepest levels possible (at the base of the triangle).

7.2 Relationship Between Reason's "Slices of Cheese" and the Triangle of Effectiveness

As shown in Figure 20, different layers of system defenses are related to different elements within the triangle of effectiveness. The Organizational Factors layer has the greatest span of control, and therefore, the greatest capacity for effective intervention. Remember that "organizational factors" refers to the policies, procedures, and decisions put into place by upper management. Management is usually responsible for designing the procedures and developing the work policies implemented by the line supervisors and workers. As such, this layer of system defenses can influence seven of the eight elements within the triangle of effectiveness, and is the only layer of defense which can effectively impact the most important lower three elements (see top of Fig. 20).

The Supervision layer of defenses represents the interventions that can be controlled by line management. Note that whereas the organizational factors layer is generally in charge of designing and developing policies and procedures, supervisors are responsible for carrying out those policies and procedures. This automatically limits the effectiveness that supervisors can exert, since they often cannot change existing policies and procedures, only report back on those which may appear to be latent factors in incidents. The middle section of Figure 20 displays the types of interventions to which supervisors can contribute. While they are not always directly involved in hiring and firing, line supervisors generally are involved in "personnel selection" from the standpoint of assigning people to tasks. In a similar vein, while they might not be involved in training or writing standard operating procedures (SOPs), they are responsible for seeing that these are properly carried out. They may also be the ones who recommend workers for remedial or advanced training.

The worker has the smallest span of control over safety interventions. The worker's level is basically contained within the layer of system defense called "Preconditions for Unsafe Acts". It becomes the worker's responsibility to adhere to standard operating procedures, learn to use equipment properly, communicate clearly, use job aids when needed, and to stay fit for duty. If, for example, a standard operating procedure is deficient or a management work-rest schedule causes excessive fatigue on the job, the worker's span of control is too limited to allow for meaningful intervention at that level. This is why it is so important to look for interventions at the base of the triangle, at the organizational factors layer of system defense.

Now let's discuss each the intervention elements within the "triangle of effectiveness" and see how they relate to the "layers of system defenses".

7.2.1 Policies & Culture

Management policies and corporate culture depend on the active participation of upper management in promoting a human-centered work environment and worksite. As such, policies and culture are key to an effective error reduction program: they are the base on which everything else rests. Management participation should be demonstrated in a variety of ways. It should be visible in its support and active encouragement of an open, "safety first" corporate culture, where "safety first" is not just a motto but a corporate mission. An atmosphere that provides incentives for personnel to question and improve work environments and standard operating procedures shows a caring management philosophy. Management actions and decisions should be *human-centered*, enabling the best personnel performance. Examples of

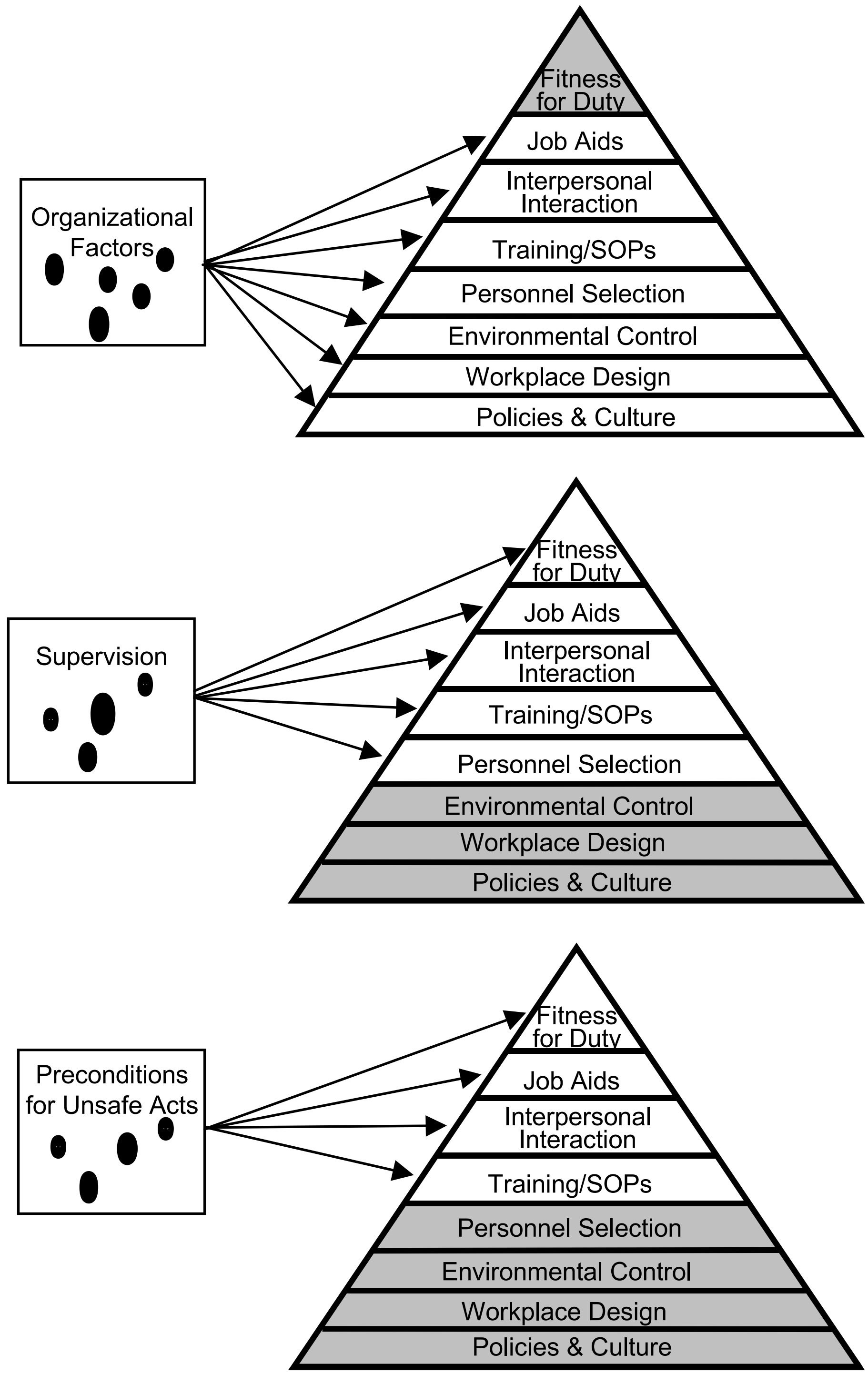


Figure 20. Types of Interventions Needed to Plug the "Holes" in the Layers of Defenses.

Different layers of system defenses ("slices of cheese" at left) can be bolstered by – and have the power to implement – different sets of interventions (unshaded elements in the triangles).

how management can demonstrate its commitment to a good employee safety program include establishing safe work loads and schedules based on known human physiological limitations and requirements (e.g., work-rest cycles); the creation of easily-understood and achievable company policies and practices; the establishment and consistent application of rewards (or punishments) for compliance (or lack thereof) with company policies; creation of reasonable product delivery schedules; providing physical facilities and equipments designed to match human capabilities and limitations; insistence on good facility maintenance; and a commitment to uncovering the underlying causes of incidents. By definition, management policies and corporate culture are a part of the "Organizational Factors" level of defenses. Whenever such organizational factors (like the examples just given) are discovered during an incident investigation, management policies and culture should be considered when designing interventions to stop future such incidents.

7.2.2 Workplace Design

Good, ergonomic workplace design can be extremely effective in reducing incidents. As underscored earlier in this paper, poor design of vessels, platforms, equipment, and work environments is an underlying precondition that can "set up" the human operator to make errors. In fact, the American Bureau of Shipping states that 88% of shipboard injuries and 50% of fatalities are the result of poor design (McCafferty, 2000). Unfortunately, examples of poor design abound in the maritime industry. As Miller says (2000, p. 7), "You cannot overcome human errors induced by poor design of the work place with more training, more manuals or written procedures, exhortations to work safer, or threats of punitive actions for job accidents."

Good design is not a mystery: there have been decades of human factors research into a plethora of design facets. Further, there has been considerable experience acquired over the past decade in the offshore and shipping industries with applying HFE design criteria to new and remodeled facilities. In addition, well-established and accepted human factors design standards and guidance now exist for the maritime industry (ASTM, 1995; American Bureau of Shipping [ABS], 1998; ABS, 2001). In fact, when HFE design principles are introduced at the beginning of the design of a facility or system, it can drastically reduce life-cycle costs and prevent the need for costly modifications down the road (because it was built right the first time).

Good workplace design requires proactive management involvement; it is almost always beyond the span of control of the workers or line supervision. Thus, incidents resulting from workplace design flaws, even though some may be considered "equipment preconditions", must look to the Organizational Factors layer of the organization for effective safety interventions.

7.2.3 Environmental Control

Lack of environmental control is another widespread, latent cause of maritime and offshore incidents. This element of the triangle refers to the work environment: temperature, humidity, lighting, noise, and vibration. Human beings have “safe operating ranges” just like equipment. Put a human in an environment that is outside his safe operating range, and he becomes an accident waiting to happen. Miller (2000, p.8) relates an all-too-frequent occurrence:

> As just one example, studies have shown that crane accidents are the second most frequent cause of injuries and fatalities on offshore platforms in the Gulf of Mexico (GOM). Yet, operator cabs on these cranes are traditionally not environmentally controlled. Some years ago during a visit to an offshore platform it was noted ... [that the temperature inside a crane cab was] 122 degrees F. With this combination of heat and July GOM humidity is it any wonder that an operator error of omission (i.e. the operator did not complete an act that he was suppose to have done) occurred that day resulting in damage to the crane and platform.

Emphasizing the importance of proper workplace environments, the American Bureau of Shipping (ABS) has prepared human performance-based environmental standards for both ships and offshore structures. These standards will be issued in 2002.

7.2.4 Personnel Selection

It has long been recognized that certain jobs require special physical, mental, or social skills not possessed by everybody who would like to work in those jobs. Finding the right people for the job is what personnel selection is all about. As an example, special physical and psychological screening tests have been used for at least the last thirty years in the public safety sector to screen out those who would not be suitable for the law enforcement or fire safety professions. If a person is selected to work in a job for which he/she is not suited, that can result in an increased probability of that person contributing to a workplace accident.

Personnel selection should consider the personality traits and special abilities needed for a given job. Just because someone has the desire to work in a particular job, or even has spent twenty years working elsewhere in the company, that doesn’t necessarily qualify that person for the open position. A given job may have certain physical requirements (e.g., good color vision for an electrician, or good visual acuity and depth perception for a crane operator), as well as intellectual aptitudes (e.g., good communication skills for a supervisor) and psychological requirements (e.g., good judgement and coolness under stress for a ship master or offshore installation manager).

As a "barrier" to incidents, personnel selection is active at two different levels. The Organizational Factors level (upper management) usually presides over personnel selection in terms of hiring and firing by developing job descriptions and qualifications requirements. A company which takes the quality of its personnel seriously can do much to ensure the right people are placed in the right jobs. The Supervision layer of system defenses also contributes significantly in terms of the way personnel are assigned to tasks. Again, if the supervisor takes this job seriously, the right numbers of people, fit for duty, and with the right qualifications can be assigned to operational and maintenance duties, helping to ensure safety.

7.2.5 Training and Standard Operating Procedures (SOPs)

Training and SOPs make up the next element in the triangle[14]. "More training" has too often been management's sole, knee-jerk remedy to incidents. As already stated, more training can *not* make up for inattention given to other barriers such as workplace design, environmental control, and management policies. Another frequent limitation to training is that it is assumed that someone who is experienced at a given task is therefore qualified to train others. Such training is haphazard, often poorly performed, and usually incomplete. There are rigorous methods (such as Instructional Systems Development) for analyzing tasks, determining performance objectives, and training and testing to these objectives (McCallum, Forsythe, Smith, Nunnenkamp & Sandberg, 2001). As automated systems become more prevalent in the maritime and offshore industries, thorough training, not just in the task at hand, but also in the operational parameters of the equipment, becomes increasingly necessary (Sanquist, et al., 1996). In summary, before resorting to training, make sure it really is the answer to the problem; and if training is what's needed, then it's worth doing right.

The second part of this element is standard operating procedures. Many times incidents occur *not* because the worker lacked skills or knowledge, but because the *SOP* was not designed appropriately for the given conditions. The Training/SOP element acts as a safety intervention in all three layers of system defenses (Fig. 20). At the Organizational Factors layer, the responsibility is to institute sufficient training and effective, safe SOPs. At the Supervision layer, the training/SOP defense is to ensure trained personnel are assigned to tasks and that they use the SOPs. At the Preconditions layer, the worker must ensure that he/she has the required training to do assigned work and that he/she understands and consistently uses SOPs. While all three layers of system defense are necessary to ensure safe operations, it is clear that a "hole" in the Organizational Factors layer (e.g., a decision to provide only the most basic training/SOPs, or to shirk the responsibility and place it wholly on supervision's shoulders) will do the most harm, since that "missing barrier" will affect the entire workforce.

---

[14] Miller refers to this element just as "training". However, a recent study (McCallum, Forsythe, et al., 2000) notes that many incidents attributed to inadequate knowledge and skills are actually promoted through incorrect SOPs, as opposed to insufficient training, per se.

A final note on standard operating procedures. Many of them are written so poorly that personnel are unable to use SOPs effectively. SOPs are important for safe operation, and they should be well-written in order to convey the needed information to the users. A good tutorial on writing SOPs is given by Information Mapping[15].

7.2.6 Interpersonal Relationships (Communication)

Interpersonal relationships (communication) is what makes teams work. Offshore, shipboard, and dockside activities all depend on teamwork. In earlier times, the Offshore Installation Manager or the ship's Master was the unquestioned authority in a one-way, top-down, chain of command (Miller, 2000). However, most shipping and offshore companies (and many other industries, such as aviation and nuclear power) have recognized that "crew resource management" is an essential component of safety. Personnel need to feel empowered to speak up, question, and double-check decisions and actions of other team members (including supervisors). Research has shown that when crew members do not communicate effectively, accidents result: 28% of personnel injuries and 18% of vessel casualties were related to inadequate communications (McCallum, Raby, Rothblum, Forsythe, Slavich & Smith, 2000, unpublished).

In the maritime and offshore environments, poor communications can be caused by factors in addition to a lack of crew resource management. Physical constraints (separating persons who need to be together via poor layout of rooms or facilities), inappropriate organizational structure which puts too many chains of command between individuals who need to communicate, and overloading workers so that they do not have the time to communicate can all contribute to poor interpersonal communications. This is a factor that is often, and mistakenly, overlooked in incident investigations.

Good communication is a safety intervention that must be established at all three layers of system defense. As was the case with Training/SOPs, the Organizational Factors layer must lay the foundation by making two-way communication a part of company culture and facilitate it through good workplace design and policies. Supervisors must actively support and encourage effective communications within and among teams. And to keep communications from becoming a Precondition for Unsafe Acts, workers need to be involved, responsive members of their work teams.

[15] For more information about seminars by Information Mapping, please see their web site at http://www.infomap.com or call (800) INFO MAP (463-6627).

7.2.7 Job Aids

Job aids come in several forms such as hazard identification (warning) signs, operator and maintainer manuals, and specific operating procedures. These can be of help in reducing human-induced incidents, especially when learning a new task, performing a task that is done infrequently, or completing a job that must be performed in an exact sequence. However, a poorly prepared job aid can lead to incidents rather than prevent them. Examples of critically important job aids found on ships and platforms are the lifeboat launching instructions and the operating instructions for manually releasing the fire fighting suppressant system. Unfortunately, these safety-critical instructions are typically confusing and difficult to understand (Miller, 2000).

There is a lot of research available on how to prepare good job aids, instructional placards, and warning signs (Curole, McCafferty & McKinney, 1999; Laughery, Wogalter & Young, 1994; Wogalter, Young & Laughery, 2001; and seminars by Information Mapping[11]). One concept, called *information mapping* (Curole, et al., 1999), utilizes research on the human learning process to provide very specific guidelines on how to prepare manuals, procedures, checklists and other printed and-or pictorial job aids. Properly prepared job aids can be a useful barrier to the prevention of maritime incidents. By the same token, poorly-written or missing job aids can contribute to incidents and are an important aspect to be considered both during the incident investigation and in the preparation of preventive recommendations.

7.2.8 Fitness for Duty

Fitness for duty is another term for adverse mental or physiological states that are severe enough to reduce the individual's capacity to perform. These states can be due to physiological conditions of illness or fatigue, or to the use of alcohol or drugs (including over-the-counter medications). These states can also be psychological in nature such as emotional trauma due to family or financial problems, or from a neurotic or even psychotic disorder. If any of these things is sufficient to distract or otherwise impact the person's performance of safety-related duties, it can be a definite contributor to an incident. This is another factor that is often overlooked during the incident investigation process, but should receive attention.

Essentially, fitness for duty is the responsibility of the worker to keep it from becoming a precondition. Line supervisors have a responsibility to ensure that workers are, in fact, fit for duty. This is the one element of the triangle that the Organizational Factors layer doesn't explicitly address (for example, work-rest policies and worksite environment, both of which can affect an employee's physiological and mental fitness for duty, would fall under other triangle elements).

Fitness-for-duty testing is a controversial area. There are some tests available for determining whether a person is under the influence of drugs or alcohol or severely fatigued; however, the reliability of most of these tests is a hotly-debated issue. Some trucking companies have successfully used a simulator-type test to ensure a trucker's driving performance is up to par before getting on the road. Such scientifically-validated and operationally-relevant screening techniques have yet to be developed for the maritime and offshore industries.

An alternative approach to testing is to implement a crew endurance program (Comperatore, Rothblum, Kingsley, Rivera, & Carvalhais, 2001). This type of program educates personnel as to how fitness for duty can affect not only job performance but long-term health and assists personnel in controlling the hazards that affect fitness for duty (note that such a program would be part of the Policies & Culture and Training/SOP elements of the triangle, not the Fitness for Duty element). Since many of the variables that influence fitness for duty are job-related (e.g., fatigue from poorly designed work schedules, or lack of coordination and manual dexterity from working in too-cold temperatures), a crew endurance program helps to prevent latent factors at all three layers: organizational factors, supervision, and preconditions for unsafe acts.

To summarize, the precursor for effective safety solutions is an in-depth analysis of incidents. Only by understanding all the latent factors which contributed to an incident can one determine what "barriers" would be effective in either averting or reducing the effects of similar incidents in the future. It is helpful to establish "barriers" or interventions within all layers of system defenses in order to reduce the likelihood of future incidents. However, when this is not feasible, try to implement interventions in the areas of policies & culture, workplace design, and environmental control, as these are often latent factors for many incidents and are usually more effective at preventing incidents than interventions towards the tip of the triangle of effectiveness. One last key to successful interventions: make your safety interventions "SMART"; that is, they should be <u>s</u>pecific, <u>m</u>easurable, <u>a</u>ttainable, <u>r</u>easonable, and <u>t</u>imely.

8.0 USER EXPERIENCES WITH STARTING AN INCIDENT INVESTIGATION PROGRAM

This section provides two examples of agencies which have begun to incorporate human factors incident investigations. Their experiences demonstrate how human factors incident investigation is used and provide some "lessons learned".

8.1 U.K. Marine Accident Investigation Branch

8.1.1 <u>Background</u>

The Marine Accident Investigation Branch (MAIB) is an independent division of the United Kingdom's Department for Transport, Local Government and the Regions (DTLR). The chief inspector reports directly to the Secretary of State, and is empowered to investigate marine accidents and hazardous incidents occurring onboard or to UK registered ships worldwide, and to all other vessels within UK territorial waters. Each year MAIB receives over 2,000 incidents. Presently, about 60 field investigations are undertaken annually by 13 inspectors working individually or as a team. Such field investigations, including the formal report produced, take about 10-12 months. MAIB inspectors also investigate about 550 additional incidents by paper and telephone.

The fundamental purpose of an MAIB investigation is to determine the circumstances and causes of an accident or incident with the aim of improving the safety of life at sea and the avoidance of accidents in the future. It is *not* the purpose to apportion liability nor to apportion blame: MAIB is not an enforcing authority; that role is taken by the Maritime and Coastguard Agency, a totally separate organization within the DTLR. An MAIB investigation is conducted in accordance with the provisions of *The UK Merchant Shipping (Accident Reporting and Investigation) Regulations 1999*, and aims to determine: what happened; how it happened; why it happened; and what can be done to prevent it from happening again.

8.1.2 Events Leading to Human Factors Investigations

In the 1980's the Surveyor General Organization (predecessor of the Maritime and Coastguard Agency) commissioned the Tavistock Institute of Human Relations, London, to carry out a series of studies on the human element in shipping casualties. This was done in order to understand, and hence reduce, the dangers associated with human frailty in the United Kingdom merchant fleet. This was the first systematic attempt to consider human error in shipping casualties in the UK. Some of the recommendations from the study were that:

- More attention should be paid to the structure, order, and timing of questions in accident investigation.
- A check-list of human element questions should be developed to help the investigator in relating his thoughts to the general body of human factors knowledge.
- A search for alternative explanations to accidents should be consciously developed. This would discourage a pre-occupation with finding a single best explanation, which may be counterproductive to revealing the true facts about specific casualties.
- Regular seminars should be conducted to exchange experiences about casualty investigation.
- A computerized and flexible accident data system should be developed to aid human factors research.

MAIB was set up as a separate organization in July 1989. It was chartered to investigate accidents, keeping this function separate from the Maritime and Coastguard Agency's responsibility for the regulation of ship safety.

8.1.3 MAIB's Classification of Human Factors Causes

MAIB began with a relatively simple taxonomy of human factors, looking mainly at operator error and organizational factors. In 1994, MAIB developed a more comprehensive classification of human factors contributions to accidents and incidents. Based on Reason's model of accident causation, the classification developed aimed to show how active human errors or violations are shaped by latent failures. MAIB currently has six top-level human factors classifications:

- External bodies liaison (e.g., regulations)
- Company & organization

- Crew factors
- Equipment
- Working environment
- Individual

There are sub-classifications under each of these headings (see Appendix D for the full taxonomy). The database was designed to encourage the examination of accident context either from the individual outwards to the regulatory and policy context, or from the context and company inwards to the vessel and the individuals who operate it. In this way, MAIB increases the likelihood of identifying contributing factors at all levels. Some of these levels may be related: for example, company policy on training may influence skills and knowledge at an individual level. In many cases, there will be unrelated human factors areas which contribute to an accident. All the human factors causes which can be identified from the evidence available should be classified.

8.1.4 Human Factors Training for MAIB Inspectors

The development of inspector skills and understanding of human factors investigation has been an evolutionary process. The thirteen MAIB inspectors work under one roof in Southampton which provides an ideal opportunity to share with each other, on a daily basis, experiences with accident investigation. Initially, MAIB inspectors attended human factors training courses provided by the Transportation Safety Board of Canada and by Det Norske Veritas (DNV) in Atlanta. Inspectors were encouraged to attend seminars and lectures on human factors.

This was an ad-hoc, but to some extent effective, approach to introducing a more formal method of human factors investigation. However, a significant drawback was the difference in terminology used by the varying sources of training and guidance. This hindered investigation team effectiveness and made quality assurance of the investigation process and reporting difficult and inconsistent.

To enable a common understanding of human factors investigation, an MAIB training course was developed to achieve a more consistent and reliable approach by inspectors to evaluate the human factors causes of accidents. A certain amount of consistency of reporting and data input has been achieved, but inconsistency and occasional confusion does sometimes arise. MAIB tries to overcome these problems by internal seminars on human factors, regular reviews and audits of the investigation process and outcomes, and attendance of the MAIB course. The course content adapts to the changing needs and experience of the inspectors.

The most recent MAIB course lasted two days and included topics such as: a general introduction to human factors (human performance, teamwork, basic methods, terms, and tools); human factors and accident investigation, including models of causation; human error and error analysis (such as, what is human error, why does it occur, how is it assessed, performance influencing factors, the SHEL model, preventing errors and violations and minimizing the impact of errors, safety management, and safety culture).

A formal approach to human factors investigation has also highlighted the importance of effective interviewing techniques. Consequently, attendance by all inspectors on an in-house interviewing techniques course run by an experienced trainer is mandatory. Continuous development of inspector competence in human factors investigation is also promoted through mini-coaching sessions, self-study, and the day-to-day application of MAIB's formal investigation process. As a result, MAIB now has a team of inspectors competent in the investigation and identification of human factors contributors to marine casualties.

8.1.5 Benefits of MAIB's Database

More than 1,000 accidents investigated by MAIB inspectors are recorded in the database. A measure of success of the database is the increasing demand from diverse interests in the marine industry. Excluding MAIB, the main users of the database are the Maritime and Coastguard Agency (MCA), university researchers, and consultants, all seeking patterns and trends in accident types and causes. Information in the database has been particularly helpful to the MCA who, along with other flag states, is introducing codes of operational inspections and risk assessments and certificates of competency based on performance standards.

The historical information from similar accidents has also proven to be a powerful tool to promote MAIB arguments for safety changes. For example, MAIB analysis has uncovered trends in accidents during lifeboat launching and recovery caused by a multiplicity of human factors. The study was able to identify common factors leading to these accidents, and the risks associated with lifeboat launching systems, by examining the common problems encountered. Operators make mistakes in maintenance and operation of launching equipment because of overly complex design and inadequate operator manuals. Over the years, the size and weight of lifeboats and equipment have increased, diminishing the ability of seamen to handle launching and recovery operations safely. The database analyses have allowed MAIB to understand the problems and to make safety recommendations.

8.2 California State Lands Commission, Marine Facilities Division

8.2.1 Background

The Marine Facilities Division (MFD) of the California State Lands Commission is headquartered in Long Beach, California. Created in 1990, the MFD is tasked with pollution prevention at marine oil terminals. Towards this end, MFD inspectors monitor activities and enforce regulations at 85 marine facilities along the California coast. Inspectors oversee and evaluate the safety of such operations as oil transfers to and from oil tankers and barges and make comprehensive inspections of marine oil terminals and pipelines. At a Facility's request, Division Specialists also conduct safety management assessments aimed at identifying potential trouble areas in an organization's defenses against adverse incidents.

8.2.2 Initiation of Human Factors Investigations

MFD specialists and inspectors also investigate oil spills as a means of informing prevention strategies. Up until recently, those inquiries identified personnel, organizational, and equipment factors as primary or secondary causes of spills, but without clearly distinguishing active failures from latent system conditions. Additionally, it was difficult to capture within the investigation framework the multiple factors that often conspired to bring about a single adverse event. In May of 2001, MFD introduced its inspectors to the Human Factors Analysis and Classification System (HFACS; Wiegmann & Shappell, 1999) and has begun using that model to support inquiries and to analyze system failures that contribute to spills. The HFACS taxonomy was selected in part because it is particularly well-suited for prevention, in that it encourages a focus on failed system defenses, rather than on individual failures. This allows users of the resulting data to address the appropriate system components in devising prevention strategies.

8.2.3 Adaptations to HFACS

It was initially clear that MFD needed to extend the tool to cover certain structural and mechanical faults as well as environmental conditions in order to cover the spectrum of contributors to oil spills. Note that this is not a deficiency on the part of HFACS: HFACS was intended to guide the human factors portion of an investigation. Naturally, there will be equipment factors, weather factors, and other non-human factors that contribute to many casualties and incidents. It will be necessary for any company to develop its own set of classifications to capture these types of problems. However, MFD observed that most of the contributing factors to oil spills were, in fact, human factors, so they found it handy to use HFACS as their main classification tool and add the equipment and environmental factors to it.

Their complete investigation taxonomy is shown in Appendix E (see "HFACS Layer Guides"). Equipment factors were appended to the Layer 1 Guide (Unsafe Acts from HFACS) as "Structural/Mechanical Damage/Failure". This is the equipment analog of an unsafe act, in that the damage or failure appears as the immediate cause of an incident (e.g., the oil spill appeared to be caused by a damaged valve). Similarly, equipment and environmental factors were added to the Preconditions layer (Layer 2). Just as "complacency" is an adverse mental state (precondition) that can lead to a routine violation (unsafe act) like taking a shortcut that causes an incident, substandard equipment design, such as an ambiguous display, can be the precondition for an unsafe act (misreading the display and causing an incident). In this way, MFD combined the major oil spill causal factors – both human and non-human – into a single, HFACS-like taxonomy.

Adaptations were made to the human factors taxonomy as well. HFACS was originally developed for aircraft accidents, and thus incorporates certain terminology and causal factors related to aviation (such as "hypoxia" and "spatial disorientation"). These terms were dropped. Maritime industry specific terms are captured using event data forms, which require an incident specific statement of the actor (an individual or group, or a structure/part) and a situation-specific description of the action/inaction or system failure that contributed to the incident. This remains an ongoing process.

8.2.4 Training and Job Aids

HFACS was introduced to MFD when their human factors analyst took a full-day workshop on the topic led by Drs. Wiegmann and Shappell. He then developed and provided training on HFACS to MFD's inspectors and specialists. Discussions among MFD staff occur during monthly meetings, and along with input from other maritime industry representatives, these meetings led to modifications in the taxonomy (discussed above) and to the development of job aids. The job aids used by MFD inspectors are provided in Appendix E.

New job aids and revisions of existing ones are considered regularly in response to issues that arise during monthly meetings. Situation-specific guidance sheets are presently under development to guide team members in collecting essential information in response to particular circumstances. Guidance is in a bulleted "If – then" form. For example,

> If the incident involves *turning an incorrect valve*,
>
> Then
>
> - photograph the valve and its immediate area;
> - ask about a history of such incidents;
> - ask whether the involved personnel were experienced with the equipment;
> - detail communications leading up to the action.

The intention of these sheets is to assure that relevant data are collected before they are lost.

8.2.5 Benefits of Human Factors Investigations

MFD is less than a year into using the revised HFACS investigation tool, and is still learning about the process and making changes to its procedures. However, an early analysis of six incidents shows that inspectors are learning to use the tool. Of the 21 causal factors identified, 20 could be completely categorized by the inquiry team – which included marine safety inspectors, specialists and a human factors analyst – using HFACS.

Not surprisingly, inquiry teams were more successful at identifying unsafe acts and preconditions than they were at finding problems in other latent factors like unsafe supervision and organizational influences. Team members felt that they had sufficiently considered and identified all relevant unsafe acts in five (of the six) incidents, and had identified all the preconditions in four of the incidents. However, teams judged that they had identified all the potential types of unsafe supervision in only three of the incidents, and had identified all the organizational factors in only one incident.

There are five issues that may contribute to the difficulty of identifying latent factors. The first is that it can take substantial time and resources (on the parts of both the investigator and those being investigated) to dig beneath the surface and unearth latent factors. Sufficient time is not always available. Second, when a regulatory body (such as MFD) or an employer is also the investigator, the fear of punishment can be a disincentive for those under investigation to fully cooperate and help identify latent factors. Third, necessary information may be unavailable, either because it is confidential (e.g., personnel records) or unrecoverable (e.g., a momentary state of mind, an absent maintenance record). Fourth, organizational influences in particular sometimes only become apparent over the course of several incidents rather than in a single one. Team members have addressed this through incorporating a structured note rather than assigning a contributing factor when they have reason to believe – but not definitive evidence – that an organizational factor is among weakened defenses in a particular case. Finally, those conducting the inquiry may lack the know-how or experience to ask the appropriate questions. This can occur for those with considerable maritime knowledge as well as those with human factors knowledge, since for any one investigator that knowledge is likely to be centered around particular areas (ship, terminal, company operations, or management), and their ability to establish a comfortable rapport with key individuals related to the incident will vary accordingly.

While there are too few cases yet to allow for meaningful analysis, there have already been "lessons learned" that can help commercial companies improve safety. MFD is starting a newsletter as a way of sharing this information with the marine terminal companies. Another benefit from these initial uses of HFACS has been the discovery of an area in which MFD can improve its reviews of preventative maintenance programs. Additionally, notes have been expanded to capture instances when "outside influences" – factors other than terminal and vessel organizations – contribute to incidents. In summary, MFD's human factors incident investigation program has gotten off to a good start and shows promise in discovering how marine terminals can change their policies and operations to improve safety and reduce oil spills.

8.3 Stolt-Nielsen Transportation Group

8.3.1 <u>Background</u>

Stolt-Nielsen S.A. is one of the world's leading providers of transportation services for bulk liquid chemicals, edible oils, acids, and other specialty liquids. The company, through its parcel tanker, tank container, terminal, rail and barge services, provides integrated transportation for its customers. Stolt-Nielsen Transportation Group owns 72 ships involved in the chemical parcel trade: 51 ships in world-wide trade and 21 ships in coastal trade in Europe and the Far East.

Stolt-Nielsen has developed a full International Ship Management (ISM) Quality and Safety Program for its ships. This program is to the highest standards of the industry and is audited by three classification societies. The safety program tracks and investigates all incidents and uses statistical process control methods to identify trends. In turn, this information is used to develop training and educational programs designed to reduce risks and losses. As an industry leader, Stolt-Nielsen also shares its data and benchmarks with other companies through groups such as the National Safety Council[16].

8.3.2 Human Factors Incident Investigation

Stolt-Nielsen has been doing incident investigation for a number of years. Since it already had an ongoing training and Quality Assurance program, the incident investigation program was added under the same umbrella at minimal cost to the company. In 1992, a human factors investigation taxonomy was added. Stolt's investigation form (see App. F), while simpler than those used by MAIB and MFD, has nevertheless proven to help the company detect and correct a variety of safety hazards.

Incident investigation is a combined responsibility of ships' officers and of Stolt's Division of Marine and Safety Services. Officers are trained on incident investigation, and other Quality Assurance topics, every three years. Because Stolt's officers and crew are from around the world, training is an expensive undertaking. All incident forms are sent to the Assistant Manager of Marine and Safety Services, who completes the investigation. By having a single person ultimately responsible for the incident data helps to keep the data reliable (consistent use of terms and coding). The major problem with investigating incidents is that the fleet is distributed worldwide, making timely and accurate reporting a challenge. However, persistence on the part of the investigator and a shared understanding of the importance of the incident program has led to a successful program.

The Assistant Manager is also responsible for the data analysis, which is a "plus", since the analyst knows the terminology and understands the constraints under which the data were collected, which in turn reduces the likelihood that unwarranted data comparisons will be made. Stolt analyzes their incident data quarterly, looking both for trends within the company and benchmarking their incident rates against those of other shippers that are members of the National Safety Council. "Lessons learned" from incident analyses are disseminated widely through the company via Loss Control Bulletins and training programs.

8.3.3 Benefits of the Incident Database

Stolt enjoys a lower incident rate than the industry average (Fig. 21), due in large part to its attentive tracking of incidents and responsive safety interventions. Stolt uses frequency analysis and analyzes trends over years to identify safety problems and track the success of its interventions. As described in the Analysis section, Stolt had used incidents to determine that crew members suffered a high frequency of slips, trips, and falls. In response, the company acquired new safety shoes designed for better traction on wet surfaces. Follow-up statistics

[16] The Waterborne Transport Division of the National Safety Council currently keeps safety data that members can use for benchmarking. There are plans to produce guidance and training to help members improve their safety analysis and benchmarking capabilities. For more information, please see their website at http://www.waterbornetransport.com or contact William Boehm by phone at (281) 860-5043 or by email at wboehm@stolt.com .

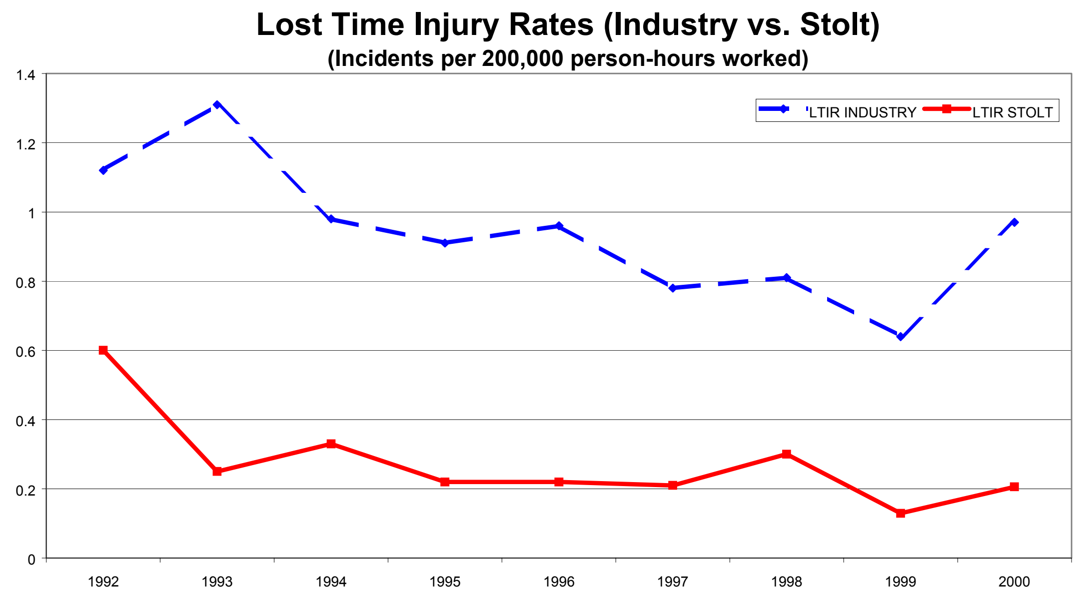


Figure 21. Comparison of Lost Time Injury Rates between Stolt and an Industry Average from 1992 through 2000
This is an example of how Stolt uses incident data to benchmark its safety relative to other companies. (Data courtesy of Stolt-Nielsen Transportation Group.)

revealed a marked decrease in slips, trips, and falls, which appear to show the success of the intervention.

Another use of incident data is shown in Figure 22, which depicts a comparison of the frequencies of various types of injuries (data for the first three quarters of 2001). As can be seen in the graph, injuries to the head and eyes happened most frequently, and these findings were supported by data from prior years. Thus, Stolt has reviewed the types of safety glasses and hardhats used by crew members and have identified problems with the current safety equipment. An alternate type of safety glasses is now being tried which hopefully will provide better protection. Regarding hardhats, one of the problems discovered was that current hardhats were uncomfortable, and crew members did not wear them consistently. A new type of head protection – a ball cap with a "butcher's hard cap" inserted inside – is being trialed as a result.

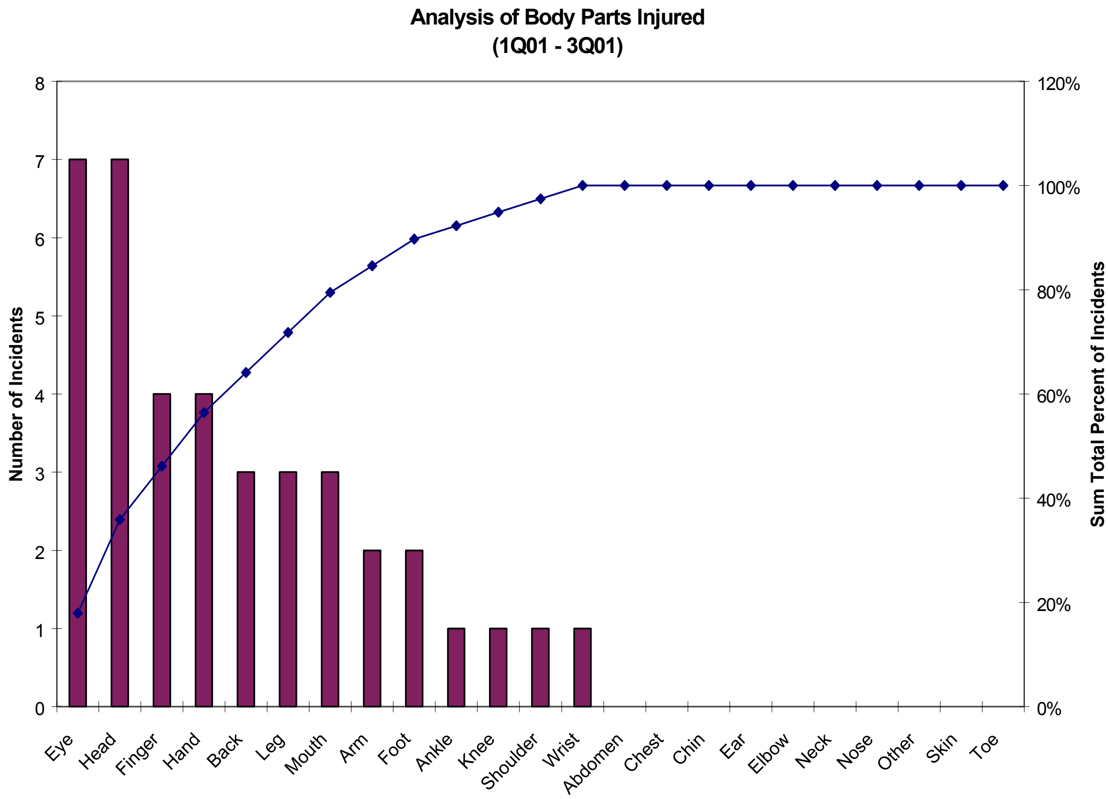


Figure 22. Number of Incidents as a Function of Body Part Injured. (Data from first three quarters of 2001; courtesy of Stolt-Nielsen Transportation Group.) This shows how Stolt uses incident data to identify safety hazards.

Stolt regards its incident investigation program to be a resounding success. By using incident investigation as a part of its overall Quality Assurance program, Stolt has been able to identify and correct safety problems, many of which have human factors causes. Through a consistent focus on incident causes and efforts to remediate those causes, Stolt has achieved lower injury, accident, and pollution rates than the industry average. The company is justifiably proud of its safety record.

9.0 SUMMARY

As we have seen, human error (and usually multiple errors made by multiple people and at multiple levels of the organization) contributes to the vast majority (over 80%) of marine casualties and offshore incidents, making the prevention of human error of paramount importance if we wish to reduce the number and severity of maritime and offshore incidents. Many types of human errors were described, the majority of which were shown not to be the "fault" of the human operator. Rather, most of these errors tend to occur as a result of technologies, work environments, and organizational factors which do not sufficiently consider the abilities and limitations of the people who must interact with them, thus "setting up" the human operator for failure.

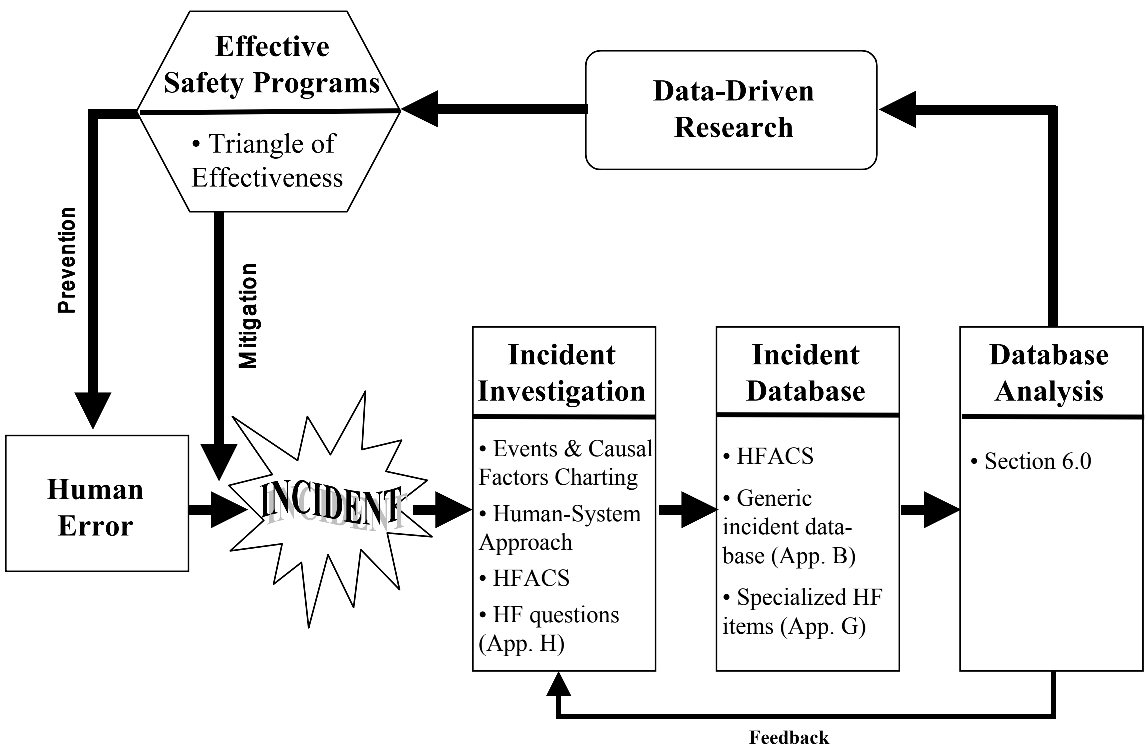


Figure 23. Tools for an Effective Incident Investigation Program

Incident investigation that includes an analysis of human error is needed if we are to prevent these incidents in the future. This paper has presented several different tools that can be used to perform a human factors incident investigation and to use the resulting data to improve the company's safety program (Fig. 23). Appendix H presents a selection of human-related questions that can be asked to identify potential human error issues. The human-system approach helps the investigator consider suboptimal interfaces and interactions between people, technology, organization, and environment that may have contributed to the incident.

Reason (1990) created a useful framework for categorizing the types of human error. His "Swiss cheese" model considers not just the unsafe acts of the operator, but also considers several layers of system defenses that may need mending if the safety program is to be effective: preconditions for unsafe acts, unsafe supervision, and organizational factors. Reason's model has been captured in the Human Factors Analysis and Classification System (HFACS; Shappell & Wiegmann, 1997a, 2000; Wiegmann & Shappell, 1999), an incident investigation system which has been used widely and successfully in military and industrial incident investigation. HFACS was presented in this document because it is relatively easy to learn and use, and because it has a history of enabling successful safety programs. HFACS can be used by the offshore and maritime industries to supplement existing incident data systems with human factors information. For companies that have not yet begun an incident investigation program, additional classification schemes, both for specific human-related errors (fatigue, communications, and skills and knowledge) and for non-human incident data (e.g., vessel or platform type, activities/operations during which the incident occurred, environmental and weather conditions that may have played a role) are provided in the Appendices. Event and Causal Factors Charting was introduced as an additional tool to aid in understanding the events that led to an incident and the causal factors that underlie those events. Used together, Event and Causal Factors Charting followed by an HFACS analysis of the causes can provide a powerful way to represent the development of an incident and to identify the system failures that generated and perpetuated the incident.

It cannot be overemphasized that a good incident database is only the starting point for a successful incident prevention program. An open, fair, improvement-seeking culture, a common understanding of the purpose and scope of the incident investigation program, appropriate training for incident investigators, a simple, user-friendly database, and feedback on the results of the incident investigation program are all essential elements to the collection of valid and complete incident data. In addition, regular analysis of the incident data is required to identify potential problems and to evaluate the results of new safety programs. Several data analysis techniques were summarized that can help companies make the most of their incident data. As was pointed out, one cannot do data analysis blindly – one must consider changes in policies and procedures that may have had an effect on the way data were collected and classified. Thoughtful analysis will help to distinguish spurious results from real trends that may require intervention. Follow-up studies ("data-driven research") are usually needed to thoroughly understand a given safety issue and determine what types of interventions may be needed.

Finally, we considered how to select interventions based on the types of system defenses that have failed. By linking Reason's "Swiss cheese" with Miller's "triangle of effectiveness", we have a tool for finding the most effective ways to solve safety problems. While traditional safety management seems to focus on reprimanding, cajoling, and "more training", the triangle of effectiveness shows that these are the least effective ways for reducing incidents. A safety culture must start at the top, and so, too, must the most effective interventions. Management participation, human-centered workplace design, and human-compatible environmental control may require more up-front effort than “yet another training course”, but because these elements are integral to the safe design and operation of the workplace, they will reap much larger safety benefits. The safety-conscious organization “starts at the top” when developing safety interventions to protect its employees, products, and the environment.

Human errors *can* be reduced significantly. Other industries have made tremendous progress in controlling human error through careful documentation of incidents, analysis of incident data, follow-up studies, and top-down, human-centered interventions. Indeed, maritime/offshore industries can do the same: the U.K.’s Marine Accident Investigation Branch, California’s Marine Facilities Division, and Stolt-Nielsen Transportation Group have all shown that the maritime/offshore sector can put human factors incident investigation to effective and profitable use. By using human factors incident investigation to identify weaknesses in our system defenses, and by crafting safety interventions through the human-centered design of technologies, work environments, and organizations, we can support the human operator and foster improved performance and fewer incidents.

10.0 REFERENCES

1. American Bureau of Shipping [ABS] (1998). *Guidance Notes on the Application of Ergonomics to Marine Systems.* New York: Author.
2. American Bureau of Shipping [ABS] (2002). *Guide for Crew Habitability on Ships.* December, 2001. Houston, TX: Author.
3. American Society of Testing and Materials [ASTM] (1995) *Standard practice for human engineering design for marine systems, equipment, and facilities.* Standard F1166-95a. West Conshohocken, PA: Author.
4. Bea R. (1997) Accident and Near-Miss Assessments and Reporting. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.
5. Bea R., Holdsworth R., & Smith C. (1997) Human and Organizational Factors in the Safety of Offshore Platforms. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.
6. Bryant D.T. (1991) *The Human Element in Shipping Casualties.* Report prepared for the Dept. of Transport, Marine Directorate, United Kingdom.
7. Bryden R., O’Connor P., & Flin R. (1998) Developing CRM for the Oil and Gas Industry: A human factors approach. Poster presentation at the Human Factors and Ergonomics Society 42nd Annual Meeting, October 5-8, 1998.

8. Card J.C. (1997) The Coast Guard, Offshore Industry, and the Human Element. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.

9. Center for Chemical Process Safety. (1992) "Guidelines for Investigating Chemical Process Incidents". American Institute of Chemical Engineers: New York.

10. Center for Chemical Process Safety. (in preparation) "Guidelines for Investigating Chemical Process Incidents" (update to the 1992 edition). American Institute of Chemical Engineers.

11. Comperatore CA, Rothblum AM, Rivera PK, Kingsley LC, Beene D, and Carvalhais AB. (2001) *U.S. Coast Guard Guide for the Management of Crew Endurance Risk Factors - Version 1.1*. U.S. Coast Guard Research and Development Center Report No. CG-D-13-01. Washington, D.C.: U.S. Dept. of Transportation, U.S. Coast Guard. Available on the web at: http://www.rdc.uscg.gov/Reports/CGD1301Report.pdf

12. Coren S. (1998) Sleep deficit, fatal accidents, and the spring shift to daylight savings time. Presented at INABIS '98 – 5th Internet World Congress on Biomedical Sciences at McMaster University, Canada, Dec. 7-16, 1998. Available on the web at http://www.mcmaster.ca/inabis98/occupational/ coren0164/index.html

13. Cormier P.J. (1994) *Towing Vessel Safety: Analysis of Congressional and Coast Guard Investigative Response to Operator Involvement in Casualties Where a Presumption of Negligence Exists.* Masters Thesis, University of Rhode Island.

14. Curole M., McCafferty D., and McKinney A. (1999) Human and Organizational Factors in Deepwater Applications. Paper presented at the Offshore Technology Conference (OTC# 10878), Houston, TX, May 3-6, 1999.

15. Det Norske Veritas (1995). Presentation on safety management systems to the U.S. Coast Guard, February 9, 1995.

16. Edwards E. (1972) Man and machine: Systems for safety. In *Proceedings of the BALPA Technical Symposium,* London.

17. Ferguson S.J. & Landsburg A.C. (1998) BIMCO/USCG partner for safety: all aboard for NMSIRS! BIMCO Bulletin, *93* (6), 42-48.

18. Franklyn C. (2000). *Incident Investigation Training Course*. Houston, TX: Risk, Reliability and Safety Engineering (RRS), Inc.

19. G & C Merriam Company (1973) *Webster's New Collegiate Dictionary*. Springfield, MA: Author.

20. Gordon R., Flin R. & Mearns K. (2001) Designing a human factors investigation tool to improve the quality of safety reporting. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting,* 1519-1523.

21. Gudmestad O.T., Gordon R., Bellamy L., Brabazon P., Craig M., Lee G., Moore J.F., Rettedal W.K., Snell R., & Vegge A. (1997) The Role of Human and Organisational

Factors (HOF) in the Fabrication, Installation and Modification (FIM) Phases of Offshore Facilities.

22. Hawkins F.H. (1987) *Human Factors in Flight.* Aldershot, U.K.: Gower Technical Press.

23. Helmreich R., Klinect J., et al. (2000) Models of threat, error and CRM in flight operations. In *Tenth International Symposium on Aviation Psychology.* Columbus, OH: The Ohio State University.

24. Hill S.G. & Byers J.C. (1992a) How to Apply Human Factors in Investigation. Lesson 5 from A Human Factors Module for the U.S. Coast Guard Investigation Department Course.

25. Hill S.G. & Byers J.C. (1992b) Introduction to the Human Element in Marine Casualties. Lesson 1 from A Human Factors Module for the U.S. Coast Guard Investigation Department Course.

26. Hill, S.G., Byers, J.C., and Rothblum, A.M. (1994) Gathering and recording human-related causal data in marine and other accident investigations. In *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, 1994, pp. 863-867.

27. Hollnagel E. (2000) Barrier Analysis and Accident Prevention. Paper presented at the 5th Australian Aviation Psychology Symposium, November, 2000.

28. Howard M., Fleming M.T., Holt J., McSween T., Moreno M., Perron P., & Reece M.D. (1997) Improving Offshore Drilling, Workovers, Production Operations and Maintenance Through Practical Application of Human and Organizational Factors. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.

29. Kay G. (2000) Medical Workshop (talk on neuropsychology, antihistamines, fatigue, and performance). Paper presented at Alertness 2000: Tools for Managing Fatigue in Transit. Oct. 26-27, 2000, Arlington, VA.

30. Kirwan B. (1997) Evolving Human Factors in Offshore Operations. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.

31. Kontogiannis T. (1999) User strategies in recovering from errors in man-machine systems. *Safety Science, 32*, 49-68.

32. Laughery K. R. Sr., Wogalter M.S., and Young S.L.. (Eds.) (1994) *Human Factors Perspectives on Warnings.* Santa Monica, CA: Human Factors and Ergonomics Society.

33. Marine Accident Investigation Branch [MAIB]. (1977) *Inspector's Report of an Investigation into a Fatal Accident on board RIX HARRIER at Immingham Oil Jetty on 22 July 1997.*

34. Marine Accident Investigation Branch [MAIB]. (1999) *Report on the Investigation of the Collision of DOLE AMERICA with the Nab Tower in the Eastern Approaches to The Solent on 7 November 1999.* MAIB Marine Accident Report.

35. Marine Transportation Research Board [MTRB]. (1976) *Human Error in Merchant Marine Safety.* Washington, DC: National Academy of Science. AD/A-028 371.

36. Maritime Safety Committee [MSC]. (1998) *Role of the Human Element in Maritime Casualties.* Report of the Joint ILO/IMO adhoc Working Group on Investigation of Human Factors in Maritime Casualties. MSC 69/13/1. London: International Maritime Organization.

37. McCafferty D.B. (2000) HF Design Standards. Paper presented at Maritime Human Factors Conference 2000, Linthicum, MD, March 13-14, 2000.

38. McCallum M.C., Forsythe A.M., Raby M., Barnes A.E., Rothblum A.M., and Smith M.W. (2000, unpublished) *Skill and Knowledge Limitations in Marine Casualties: A Research Study to Develop and Evaluate Investigation, Reporting, and Analysis Procedures.* Study performed for the U.S. Coast Guard Research and Development Center.

39. McCallum M.C., Forsythe A.M., Smith M. W., Nunnenkamp J.M., and Sandberg G.R. (2001) *Developing Performance-Based Assessments of Mariner Proficiency.* U.S. Coast Guard Research & Development Center Report # CG-D-06-01 (ADA390929). Washington, D.C.: Department of Transportation, U.S. Coast Guard.

40. McCallum M.C., Raby M., and Rothblum A.M. (1996) *Procedures for Investigating and Reporting Human Factors and Fatigue Contributions to Marine Casualties.* Washington, D.C.: U.S. Dept. of Transportation, U.S. Coast Guard Report No. CG-D-09-97. AD-A323392.

41. McCallum M.C., Raby M., Rothblum A.M., Forsythe A.M., Slavich A., and Smith M. W. (2000, unpublished) *Communications Problems in Marine Casualties: A Research Study to Develop and Evaluate Investigation, Reporting, and Analysis Procedures.* Study performed for the U.S. Coast Guard Research and Development Center.

42. Miller G.E. (1997) *U.S. Coast Guard Human Factors Engineering (HFE) Program Training Course.* Course prepared and delivered for U.S. Coast Guard Vessel Compliance Division (G-MOC).

43. Miller G.E. (1999) Human Factors Engineering (HFE): What It Is And How It Can Be Used To Reduce Human Errors in The Offshore Industry. Paper given at the OTC Conference (OTC# 10876), Houston, TX, May 3-6, 1999.

44. Miller G.E. (2000) The Current and Suggested Role of Human and Organizational Factors (HOF) for the Reduction of Human Induced Accidents and Incidences [sic] in the Maritime Industry. Paper presented at Maritime Human Factors 2000, Linthicum, MD, March 13-14, 2000.

45. Miller G.E. (2001) The Human Element and the Maritime, Changing the Mindset. Paper given at the Marine Log Sixth Annual Conference on the Role of the Human Element in Maritime Operations, Washington, D.C. April 24-25, 2001.

46. Miller G.E., Bockosh G., Edmondson N., Holdsworth R., Khandpur R., Mello J., & Mirabella J. (1997) Further Developments of Standards, Specifications, and Guidelines Related to Human and Organizational Factors (HOF) to Reduce Human Error in Offshore Facilities Operations. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.

47. Monk, T.H. (1980) Traffic accident increases as a possible indicant of desynchronosis. *Chronobiologia, 7,* 527-529.

48. Muchinsky P.M. (1997) *Psychology Applied to Work* (5th edition). Pacific Grove, CA: Brooks/Cole Publishing Company.

49. National Research Council [NRC]. (1990) *Crew Size and Maritime Safety.* Washington, DC: National Academy Press.

50. National Transportation Safety Board [NTSB]. (1981) *Major Marine Collisions and Effects of Preventive Recommendations.* Report No. NTSB-MSS-81-1.

51. Perrow C. (1984) *Normal Accidents: Living with High-Risk Technologies.* Basic Books.

52. Rasmussen J. (1987) The definition of human error and a taxonomy for technical system design. In J. Rasmussen, K. Duncan, and J. Leplat (Eds.), *New Technology and Human Error.* Toronto: Wiley.

53. Reason J. (1990) *Human Error.* New York: Cambridge University Press.

54. Rothblum A. (2000) Human Error and Marine Safety. Presented at the Maritime Human Factors Conference 2000, Linthicum, MD, March 13-14, 2000.

55. Rothblum A., Chaderjian M., and Mercier K. (2000). Development and Evaluation of the International Maritime Information Safety System (IMISS). Presented at the Society of Naval Architects and Marine Engineers, IMISS Public Meeting, May 2000.

56. Rothblum A.M. (2000). Don't Just Stand There, *Say Something:* Communications Errors in Maritime Casualties. Paper presented at the Maritime Human Factors Conference 2000, Linthicum, MD, March 13-14, 2000.

57. Sanquist T.F., Lee J.D., McCallum M.C., and Rothblum A.M. (1996). *Evaluating Shipboard Automation: Application to Mariner Training, Certification, and Equipment Design*. Proceedings of the Public Forum on Integrated Bridge Systems, held March 6-7, 1996 in Vienna, VA. Washington, D.C.: National Transportation Safety Board.

58. Sasou K. & Reason J. (1999) Team errors: Definition and taxonomy. *Reliability Engineering and System Safety, 65,* 1-9.

59. Shappell S.A. & Wiegmann D.A. (1997a) A human error approach to accident investigation: The taxonomy of unsafe operations. *International J. Aviation Psychology, 7*(4), 269-291.

60. Shappell S.A. & Wiegmann D.A. (1997b) A reliability analysis of the Taxonomy of Unsafe Operations. *Aviation, Space, and Environmental Medicine, 68,* 620.

61. Shappell S.A. & Wiegmann D.A. (2000) *The Human Factors Analysis and Classification System-HFACS.* FAA Office of Aviation Medicine Report # DOT/FAA/AM-00/7. Washington, D.C.: Department of Transportation, Federal Aviation Administration.

62. Transportation Safety Board of Canada. (1994) Working Paper on Tankers Involved in Shipping Accidents 1975-1992.

63. Transportation Safety Board of Canada [TSB]. (1998) *An Integrated Process for Investigating Human Factors.* Montreal: Author.

64. U.K. P&I Club (1992). The United Kingdom Mutual Steam Ship Assurance Association (Bermuda) Limited. *Analysis of Major Claims*.

65. U.S. Coast Guard (1995) *Prevention Through People: Quality Action Team Report.* Washington, DC: U.S. Coast Guard.

66. Wagenaar W.A. and Groeneweg J. (1987) Accidents at sea: Multiple causes and impossible consequences. *Int. J. Man-Machine Studies, 27,* 587-598.

67. Wenk E. Jr. (1997) Safety, Corporate Culture and Corporate Character. In R.G. Bea, R.D. Holdsworth, and C. Smith (Eds.), *1996 International Workshop on Human Factors in Offshore Operations.* New York: American Bureau of Shipping.

68. Wiegmann, D. A., and Shappell, S. A. (1999) *A Human Factors Approach to Accident Investigation*. Workshop presented at the Human Factors and Ergonomics Society 43rd Annual Meeting.

69. Wogalter M.S., Young S.L., and Laughery K. R. Sr. (Eds.) (2001) *Human Factors Perspectives on Warnings, Vol. 2: Selections from Human Factors & Ergonomics Society Proceedings, 1994-2000.* Santa Monica, CA: Human Factors and Ergonomics Society.

APPENDIX A. SAMPLE INCIDENT REPORTING FORM[17]

The first step in learning from incidents is to find out that they happened! This appendix presents a form that can be used by workers to report incidents and near-misses. If your company's incident database is to contain information from both investigated (i.e., someone acts on the information in the reporting form and opens an investigation of the incident) and non-investigated (i.e., the reporting form is the only source of information) incidents, it becomes important to be able to judge the "goodness" or validity and completeness of the incident data. You may want to add a field to your database to show whether the incident was investigated or not (or the degree to which it was investigated). Another example of rating the completeness of the incident data is shown in App. E at the bottom of the HFACS Event Data Form. All these incidents are investigated, and the investigators mark whether they believe they were able to do a full investigation.

The reporting form in this appendix was developed for the anonymous reporting of near-misses. As such, it requests information about both the incident and the person reporting the incident. Information about the reporter is requested in order to infer the likelihood that the reporter has experience in the incident context (that is, is the reporter likely to know what correct procedures should have been, and would he/she understand the ramifications of the steps that led to the incident). Question 6 seeks to aid the assessment of the reliability of the reported information by finding out whether the person who reported it was actually involved in the incident first-hand. In this way, one can attempt to weigh the potential value of the information in the incident report.

[17] based on a prototype of the International Maritime Information Safety System (IMISS; see Rothblum, Chaderjian, & Mercier, 2000).

Incident Reporting Form

Tell us about yourself

1. In what maritime sector are you involved?
- ❑ deep draft
- ❑ inland
- ❑ off-shore
- ❑ terminal
- ❑ recreational
- ❑ other ______________________________

2. What is your specific job? (*e.g., Ordinary Seaman, 2nd Asst. Engineer, drilling supervisor, dock worker, USCG XO)*

3. Type of vessel / facility / structure where you typically work? *(e.g., crude oil tanker, tension leg platform, liquid bulk terminal)*

Incident / Potential Hazard

4. Type of incident or hazard (e.g., near-collision, near-injury; buoy off-station, dangerous work practice)

5. When did the incident / hazard occur?

Date: ____/____/____
mm / dd / yy

Time: _________ am/pm

- ❑ dawn
- ❑ daylight
- ❑ dusk
- ❑ night

6. How were you involved in the incident (or discovering the hazard)?
- ❑ directly involved – I was an active participant.
- ❑ indirectly involved – I was at the scene, and saw/heard everything that happened.
- ❑ observed from a distance – I did not see/hear everything.
- ❑ not involved – I heard about this from someone else.
- ❑ other *(describe):*

7. Type of vessels, platforms, structures, or facilities involved *(e.g., lineboat, trawler, shipyard, jack-up rig)*:

8. Describe the visibility, weather, and water conditions.
(e.g., overcast, light rain, no wind, river stage 8 ft. and rising)

9. Where did it happen? *(specify the waterway, port, location on ship, etc.)*:

10. What specific operation(s) was occurring at the time of the incident or hazard? *(e.g., normal bridge/pilothouse watch, normal engineroom watch, cargo transfer operation, ballasting, making tow, fishing)*

11. Describe what happened. What were the events which led up to the problem? How was the problem discovered? What happened next? *(be as specific as possible, and put events in the order in which they happened)* For a potential hazard, describe the situation and what *could have happened.*

12. What do you think caused the incident or contributed to the events surrounding the incident? *(Consider: decisions; actions; inactions; information overload; communication; fatigue; drugs or alcohol; physical or mental condition; procedures; policies; design of equipment / ship / facility / waterway; crew / workers (experience, manning); weather; visibility; equipment failure (why did it fail?); maintenance.)*

13. What went right? How was an accident avoided? *(Consider: corrective actions; contingency plans; emergency procedures; luck.)*

14. How can we prevent similar incidents (correct the hazard)? What changes need to be made? By whom? This block is also for describing Lessons Learned, Safety Tips, and Suggestions.

APPENDIX B. DATABASE ITEMS ON GENERAL INCIDENT INFORMATION[18]

(to be collected *in addition to* the human error data)

Time, Location, and General Conditions

Date: ___/___/___.
mm / dd / yy

Month and Year: ___/___.
mm / yy

Day of Week: Su Mo Tu We Th Fr Sa

Local Time: ______ (24-hr clock)

Location of vessel/platform/facility
- Port/Harbor
- Terminal
- Pier
- At Anchor
- Restricted waters (marked channel, bay, etc.
- Ocean (≥ 12 nm)
- Coastal (< 12nm)
- Inland waters
- River
- Great Lakes
- Lake
- Bay / Sound / Strait
- Offshore Platform in State Waters (<3nm)
- Offshore Platform in Federal Waters (>3nm)
- Other ______________________________

Specific Location
- Lat: _____
- Long: ______
- Type of Aid to Navigation: _____
- Waterbody / Waterway name: __________________________
- Port / Harbor name: ____________________________
- Water depth _______ ft.
- Mile Marker_________

[18] based on a prototype of the International Maritime Information Safety System (IMISS; see Rothblum, Chaderjian, & Mercier, 2000).

Light
- Dawn (morning twilight)
- Daylight
- Dusk (evening twilight)
- Night

Visibility
- Visibility: ______ nm
- Clear
- Cloud cover
- Fog
- Other

Weather

Calm	Thunderstorm
Rain	Sleet
Snow	Hurricane
Hail	Tornado
Waterspout	
Other ________________________	

Water Conditions

Salinity (fresh/salt) _________
river stage ____ ft. Rising OR Falling
Flood stage ____ Above gauge level ___ At gauge level _____
Below gauge level ____ Low gauge level ____
Swells:_______ ft. OR sea state _____
Wave height _______ ft; Wave period_________ sec; Wave Direction ______degrees
Current velocity: _________
Current direction__________
Ebb/Flood
Tide: Rising/ Falling Hours since high/low water_______
Obstructed/Floating debris: Describe___________________________
Other ________________________

Wind: direction: _____ speed: ____ kts.

Number of vessels involved _____

Number of facilities/platforms involved ______

Number of people involved _____

Vessel activity, Vessel #1 (check all that apply)

Vessel not underway
Docked
At anchor
Moored

Vessel in port
Docking/undocking
Mooring/Releasing Lines
Maneuvering
Shifting dock-to-dock
Embark/disembark pilot
Embark/disem.
Passengers
Transfer oil/chemicals
Transfer containers
Transfer bulk cargo
Transfer break bulk
Bunkering
Tug escort
Break Bulk Cargo
Other cargo activity _____
Other port activity ______

Transiting

Channel inbound
Channel outbound

Port inbound
Port outbound
Open waters transit
Great Lakes transit
Meeting

Passing/Overtaking
Crossing
Overtaking
Tug escort
Other transit _________

Fishing
Fishing
Trolling
Trawling
Longlining
Dive
Siening
Dragging
Hauling Gear
Setting Gear
Setting pots/traps
Fish processing
Other fishing __________

Towing
Towing/pushing/hip
Locking
River upbound
River downbound
Make/break tow
Other towing _________

Other Commercial Activity
Production (platform)

Logging
Drilling Crew shift

Tank cleaning
Ballasting/deballasting
Lightering
Bunkering/Fueling

Transfer-related
Cargo Transfer at Anchor
Diving
Touring
Launch Service
Other commercial _______

USCG / Military
CG – patrolling
CG – boarding
CG – interdiction
CG – transit
CG – towing
CG - setting buoys
CG - ice breaking
CG – assist
CG - helo ops
UNREP Ops
Other CG ops _________
Other military ops _______

Test & Repair
Testing main engines
Shut-down Engines/Cargo
Equipment testing
Deck Machinery
Electronics
Maintenance
Repairs
Safety Equipment Test

Engine Dept Equipment Test
Deck Equipment Test
Cargo Monitor Equipment Test

Other Vessel Activities
Recreational boating
Evacuation
Prep for extreme event (e.g., hurricane)
Other _______________

Vessel Activity, Vessels #2 and #3 (repeat above)

Facility Activity (check all that apply)

Maintenance	Rail Operations	VTS operations
Equipment testing	Truck Operations in Yard	Bridge opening/closing
Dry docking	Training Workers	Lock operations
Dock loading/unloading	Oil Transfer	Other activity ________
Dock crane operations	Dry Bulk Transfer	
Loading Containers	Break Bulk Transfer	
Staging Containers	Chemical Transfer	

Incident/Hazard Event (check all that apply)

Vessel/platform event

Abandonment	Evasive maneuver	Loss of electrical power
Allision	Explosion	Loss of maneuverability
Blowout	Fire	Loss of stability
Capsize	Flooding	Material failure
Collision	Fouling	Material failure, diving
Damage to cargo	Grounding	Set adrift
Damage to environment	Implosion	Sinking
Emergency response		Other ________________

Personnel event

Amputation	Drowning	Sprain/strain
Asphyxiation	Electrocution	Struck by object
Broken bone	Fall into water	Other ________________
Burn	Paralysis	
Crush	Severe bleeding	
Cut	Slip/trip/fall	

Type of Vessel: Vessel # 1 (check one)

Tank Vessel
Petroleum
LNG tanker
Chemical
Other tanker ___________

Freight Vessel
Breakbulk
Bulk, Ore
Bulk, Grain
Bulk, Other ___________
Container ship

Tow and Barge
Towing vessel
Tow and barge combo
Barge w/o towboat
Tank barge _________
Freight barge ________
Other barge _________
Tug escort
Composite Unit

Passenger
Passenger, small
Passenger, large
Ferry
Casino boat
Cruise ship

Other Vessels/Platforms
Fishing vessel
Fish processor
Offshore supply vessel
Platform/rig
Workboat (platform)
MODU
OBO
Heavy lift
Dredge
Pilot boat
Other commercial _______
HSC [High speed craft]
Hydrographic survey
Emergency Response

USCG / Military
CG cutter
CG small boat
CG ice breaker
CG buoy tender
CG other _____________
Other military ___________

Recreational
Jet Ski
Sail boat
Powerboat
Other recreational boat ___

(repeat above for vessels #2 and #3)

Type of Facility: Facility # 1 (check one)

Cargo Facilities
Port / pier / dock
Container terminal
Liquid Bulk terminal
Solid Bulk with self loading systems
Bulk cargo facility
Break bulk cargo facility

Oil/chemical facility
Container facility
Other cargo facility _______

Moorings
Single point moorings
Multi buoy moorings
Offshore moorings

Platforms / Drilling
Offshore, Fixed platform
Jack-up rig
Mobile Oil Production Units
Compliant Tower
Tension Leg Platform
Other deep water production/drilling facilities
Lifeboat

Other Facilities
Designated waterfront facility
Shipyard / Dry dock
Marina
VTS
Waterfront Facility

(repeat above for Facility # 2)

Person # 1 (check one)

Crew on Deep Draft Ship
Master

Chief mate

1 Mate
2 Mate
3 Mate
4 Mate
AB
OS
Boatswain
Other Deck ____________
Chief Engineer
1 Asst. Eng.
2 Asst. Eng.
3 Asst. Eng.
QMED/Oiler/Wiper
Maintenance Dept.
Other Eng. ____________

Chief Steward
Steward
Chief Cook
Cook
Purser
Waiter
Other Deep Draft _______
Cadet
Trainee
Pumpman
Entertainer

Crew on Towing Vessel
Captain/Pilot (towing)
1st Class operator
Mate (towing)
2nd Class Operator
Deckhand
Engineer
Cook
Other towing __________

Port / Dock Workers
Dock/Harbor Master
Port Engineer
Port Captain
Port Pilot
Port Safety Rep.
Mooring Master
Line Handlers
Hose Crew (Hook up)
Hose Watch

Terminal Person in Charge
Longshoreman
Dock Worker
Gaugers
Pilot
Docking Pilot
Other Port _____________

Shipyard / Inspections
Shipyard worker
Ship chandler
Government Inspector
Class society inspector
Insurer
Surveyor
Other ____________

Crew on USCG/Military
CG Command (CO,XO,EO)

CG bridge crew

CG engineering
CG other ____________
Other military _________

Waterway Personnel
Lock Master
Bridge Tender
VTS
Federal Pilot
State Pilot
Other Waterway ________

Platform / Rig Crew
Operations supervisor
Logging personnel/contractor
Drilling supervisor/engineer
Platform foreman
Platform crew
Drilling supervisor/engineer
Drill rig personnel
Other _____________

Other Personnel
Vendor
Agent
Visitor
Passenger
Recreational boater
Ship Chandler
Other _______________

Person #1's Activity at Time of Incident (check as many as apply)

On-board Activity
Watch / work / OT
Off duty

Navigation watch
Engineering watch
Eng. Maintenance/repair
Deck maintenance
Handling lines
Make/break tow
Load/discharge cargo
Load/discharge passengers
Meal prep./serve
Other on-board ________

Facility Crew Activity
Describe __________

Platform Crew Activity
Drilling operations
Normal production operations
Crane operations
Maintenance
Testing
Evacuation
Off duty
Other platform _________

Shipyard Crew Activity

Dry dock
Ship repair
Logging
Other shipyard _________

Military Crew Activity
Watch / work
Off duty

Collateral duty
Navigation watch
Engineering watch
Maintenance
CG boarding team

CG helo ops
CG setting ATONs

CG launching small boat
CG other ____________
Other military _________

Other _____________

Person #1's Impairments (check as many as apply to incident)

Fatigue
Suspected alcohol intoxication
Suspected drug intoxication
Rx/OTC medications
Illness
High stress
Chronic health condition: __________________
Psychological condition: __________________
Other ____________________

Hearing impairment
Vision impairment
Impaired mobility
Speech impediment
Poor or no English

(repeat Person, Activity, and Impairments for Persons # 2, 3, and 4)

Equipment Factors (check as many as apply to the incident)

Vessel Equipment which failed:
Steering gear
Engine
Generator
Reefers
Radar/ARPA
Electronic chart
Communications system
Other bridge equipment
Winch
Lines
Crane

Electrical
Piping
Door/hatch
Sanitation
Anchor/chain

Vent system
Pump
Valves
Remote control/monitoring systems
Other vsl equip___________

Platform Equipment which failed:
Drill rig
Drill equipment (tanks)
Pipelines & valves
Crane
Compressors
Safe shut-down equipment
Gas handling units
Hoses
Separators
Fire detection/control
Command & Control equipment
O-ring/gasket
Other platform _________

Safety & Personal Protection Gear
Firefighting equipment
Fire suppression equipment
Life jackets/preservers
Life boats
Cold water immersion suits
Hearing protection
Eye protection
Head protection
Chemical protection gear
Respirators
Other safety ___________

Problem:

Inoperable
Operated incorrectly

Cause:
Lack of maintenance
Improper maintenance
Design/manufacture error
Improper use
Operator error
Inadequate training
Other __________________

Location of equipment
Bridge
Engine room
Deck

Tanks
Other _______________

Waterway Factors (check all that apply)

high/low river stage
strong current
buoy off-station
nav aid not working
poorly marked waterway
bridge not marked
Last Chart Survey of Area
Where charts corrected for latest survey (ship on dock)
Additional permitted activities
Debris in water

dangerous crossing
dangerous traffic scheme
channel width/depth not as charted
Narrow channel
dangerous sandbars/shoals
dangerous port design/layout

Nav aid not available such as DGPS off air

Severe weather/waves
Other:___________

APPENDIX C. EXAMPLES OF HUMAN FACTORS TAXONOMIES
(in alphabetical order by system name)

Incident/Accident System	Agency	Reference
Aviation Safety Reporting System (ASRS)	run by NASA for the FAA; used by commercial aviation (flight crews, ground crews, and air traffic control)	Reynard W.D., Billings C.E., Cheaney E.S., & Hardy R. (1986). *The Development of the NASA Aviation Safety Reporting System.* NASA Reference Publication 1-1-14. National Aeronautics and Space Administration.
Confidential Hazardous Incident Reporting Programme (CHIRP)	Concerted Action Committee on Casualty Analysis (European Commission)	Concerted Action Committee on Casualty Analysis (1998). *Confidential Hazardous Incident Reporting Programme.* FP4 Waterborne Transport Tasks 21 and 36. (draft)
Human Error Root Cause Analysis (HERCA)	U.S. Dept. of Energy	Collopy M.T. & Waters R.M.
Human Factors Analysis and Classification System (HFACS)	US Navy and Marine aviation	Shappell S.A. & Wiegmann D.A. (1997) A human error approach to accident investigation: The taxonomy of unsafe operations. *International J. Aviation Psychology, 7*(4), 269-291.
Human Factors Checklist, and others based on the SHEL-GEMS models	International Civil Aviation Organization (ICAO); Transportation Safety Board (TSB) of Canada; US Coast Guard; International Maritime Organization (IMO)	ICAO (1993). *Investigation of Human Factors in Accidents and Incidents.* Human Factors Digest No. 7, ICAO Circular 240-AN/144. Montreal, Canada: Author. TSB of Canada (1988). *An Integrated Process for Investigating Human Factors.* Montreal: Author. International Maritime Organization (1998). *Role of the Human Element in Maritime Casualties.* Maritime Safety Committee, 69th Session, Agenda Item 13 (MSC/69/13-1). London: Author.

Human Factors Investigation Tool (HFIT)	prototype in testing	Gordon R., Flin R. & Mearns K. (2001). Designing a Human Factors Investigation Tool to Improve the Quality of Safety Reporting. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 1519-1523.
Human Performance Investigation Process (HPIP); TapRooT (a commercial revision of HPIP)	Nuclear Regulatory Commission and various industries	Paradies M., Unger L., Haas P., & Terranova M. (1993) *Development of the NRC's Human Performance Investigation Process, Vol. 1-3.* Report # NUREG/CR-5455. Washington, DC: Nuclear Regulatory Commission. Paradies M., Unger L., & Busch D. (199x). *Root Cause Tree User's Manual,* Revision 3.
Influence Networks	UK Maritime and Coastguard Agency (MCA); UK Health and Safety Executive (HSE); International Maritime Organization (IMO)	Embrey, D (1992) Incorporating Management and Organisational Factors into Probalistic Safety Assessment. *Reliability Engineering, 38*, 199-208. BOMEL Limited (2001) *FSA of Bulk Carriers – Develop-ment and Quantification of Influence Networks* (undertaken for MCA, UK).
International Maritime Information Safety System (IMISS)	prototype system developed by a SNAME working group, sponsored by US Coast Guard and US Maritime Administration	Rothblum A., Chaderjian M., and Mercier K. (2000). Development and Evaluation of the International Maritime Information Safety System (IMISS). Presented at the Society of Naval Architects and Marine Engineers, IMISS Public Meeting, May 2000.
Marine Safety Reporting System (MSRS)	Human Factors Group	Safe Marine Transportation (SMART) Forum of Puget Sound, 1997. *Marine Reporting: The Development of a Northwest Marine Safety Reporting System.* Seattle, WA: Author. (see App. D)

APPENDIX D. HUMAN FACTORS TAXONOMY USED BY THE U.K. MARINE ACCIDENT INVESTIGATION BRANCH

External Bodies Liaison	Non compliance Communication Equipment design - manufacturer Training, skills, knowledge Working environment/workplace Incorrect installation/defective equipment
Company & Organisation	Company standing orders inadequate, insufficient, conflicting Manufacturer's instructions Communication Pressures - organisational Inadequate resources Training, skills, knowledge
Crew Factors	Communication Management and supervision inadequate Allocation of responsibility inappropriate Procedures inadequate Manning (rotation/watches) Training Discipline - crew/passengers Unsafe working practices
Equipment	Equipment misuse Equipment not available as needed Equipment poorly designed for operational use Equipment badly maintained Personnel unfamiliar with equipment/not trained in use Automation means crew not trained in use of manual alternatives
Working Environment	Performance affected by noise Performance affected by vibration Performance affected by temperature Performance affected by humidity Performance affected by visual environment/visibility Performance affected by ship movement/weather effects Poor housekeeping Layout unsuitable for task Accommodation
Individual	Communication

Competence and skill
Training, inexperience, knowledge
Violation of procedures
Health: drugs/alcohol
Health: medical condition
Domestic issues
Fatigue and vigilance
Perceptual abilities
Poor decision making/information use
Perception of risk
Workload

APPENDIX E. ADAPTATION OF HFACS BY THE CALIFORNIA STATE LANDS COMMISSION, MARINE FACILITIES DIVISION

This appendix shows how the Marine Facilities Division (MFD) of the California State Lands Commission has adapted the Human Factors Analysis and Classification System (HFACS) to their specific needs. Below are the guides (job aids) provided to MFD inspectors for their use in investigating the human factors and other causes of oil spills. The job aids contained herein include:

- HFACS Terminology
- HFACS Layer Guides
- HFACS Event Data Form (filled out during a spill investigation)
- Event Data Form Instructions

Note that the term "Layer" refers to the "slice of cheese" being considered: Layer 1 equates to Unsafe Acts; Layer 2 to Preconditions; Layer 3 to Unsafe Supervision; and Layer 4 to Organizational Influences. The term "Tiers" is a short-hand notation for the levels of the taxonomy being considered. For example, Tier 1 is the Layer or top level classification (e.g., unsafe act). Tier 2 would be the next level of classification, such as an "Error" (unintentional) as the type of unsafe act. Tier 3 would be the bottom or most specific level of classification, such as "Skill-based" errors. "Pick-List" refers to the items or types of the Tier 3 factor, such as "omitted step in procedure" under Skill-Based Errors.

As discussed in the report, MFD adapted HFACS to its needs by incorporating non-HF items into the investigation paradigm. For example, in addition to Unsafe Acts under Layer 1, MFD included the category Structural/Mechanical Damage/Failure to help inspectors consider the equipment factors that contributed to the incident and how human factors caused or complemented the equipment factors in the evolving oil spill.

HFACS Terminology

Accident: An unintended event which results in personal injury, illness, property damage, or environmental impairment.

Near Miss: An unintended event which has the potential for causing personal injury, illness, property damage or environmental impairment.

Incident: An unintended event which results in or has the potential for causing personal injury, property damage, or environmental impairment.

Routine Violation (from Reason, 1990): Two factors, in particular appear to be important in shaping habitual violations: (a) the natural human tendency to take the path of least effort; and (b) a relatively indifferent environment (i.e., one that rarely punishes violations or rewards observance). Everyday observation shows that if the quickest and most convenient path between two task-related points involves transgressing an apparently trivial and rarely sanctioned safety procedure, then it will be violated routinely by the operators of the system. Such a principle suggests that routine violations could be minimized by designing systems with human beings in mind at the outset.

Error: a generic term to encompass all those occasions in which a planned sequence of activities fails to achieve its intended outcome, and when these failures and when these failures cannot be attributed to some chance agency.

Slip and lapse: errors which result from some failure in the execution and/or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective. Slips are observable; lapses not.

Mistake: deficiencies or failures in the judgemental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan.

LAYER 1 GUIDE: UNSAFE ACTS

Unsafe Acts

Errors Skill-based	Perceptual	Decision
failed to prioritize attention	misjudged distance/rate/time	improper procedure or maneuver
inadvertent use of controls	misread dial or indicator	misdiagnosed emergency
omitted step in procedure, or executed step out-of-sequence.	failed to see/hear/otherwise sense	wrong response to emergency
omitted checklist item or completed check list item out-of sequence.		poor decision

Violations Routine	Exceptional
(Fill in) Definition: Common or habitual instance of breaking the rules and regulations (taking a shortcut) that is part of a person's behavior pattern and is often tolerated by the organization	*(Fill in)* Definition: Isolated departure from authority, rules and regulations (taking a shortcut) that is typically not condoned by management

Structural/Mechanical Damage/Failure

Vessel Control System	Vessel Structural	Terminal Control System	Terminal Structural
	containment		containment
	flange/gasket		flange/gasket
	hose		hose
	inert gas system		loading arm
	loading arm		pipeline
	pipeline		pump
	piping		shell plating
	pump		valve
	shell plating		
	stern tube		
	valve		

LAYER 2 GUIDE: PRECONDITIONS FOR ADVERSE EVENTS

Preconditions For Adverse Events		
Substandard Conditions of Operators		
Adverse Mental States	**Adverse Physiological States**	**Physical/Mental Limitations**
channelized attention	impaired physiological state	insufficient reaction time
complacency	medical illness	poor vision/hearing
distraction	physiological incapacitation	lack of knowledge
mental fatigue	physical fatigue	incompatible physical capability
haste		
loss of situational awareness		
misplaced motivation		
task saturation		

Substandard Practices of Operators	
Crew Resource Mgt.	**Personal Readiness**
impaired communications due to language difference	self-medicated
interpersonal conflict among crew	inadequate rest
failed to use all available resources	
failure of leadership	
misinterpretation of traffic calls	
failed to conduct adequate brief	
impaired communication/conflict due to cultural difference	

Substandard Work Interface			**Adverse Environmental Conditions**
Substandard Design		**Substandard Maintenance**	low visibility
design inadequate for use	**design inadequate for maintenance**		
ambiguous instrumentation		poorly maintained equipment	storm
inadequate layout or space		poorly maintained workspace	extreme temperature
substandard illumination		poorly maintained communications equipment	extreme sea state
substandard communications equipment			
equipment substandard for job			

Layer 3 Guide: Unsafe Supervision

Unsafe Supervision

Inadequate Supervision	Planned Inappropriate Operations	Failed to Correct a Known Problem	Supervisory Violations
failed to provide guidance	failed to provide correct data	failed to correct document in error	authorized an unnecessary hazard
failed to provide operational doctrine	failed to provide adequate brief time	failed to identify an at-risk behavior	failed to enforce rules and regulations
failed to provide oversight	improper manning	failed to initiate corrective action	authorized unqualified crew
failed to provide training	adequacy of operational procedure or plan	failed to report unsafe tendencies	
failed to track qualifications	provided inadequate opportunity for crew rest		
failed to track performance			

Layer 4 Guide: Organizational Influences

Organizational Influences

Resource Management	Organizational Climate	Organizational Process
inadequate management of human resources	adequacy of organizational structure	adequacy of established conditions of work
inadequate management of monetary resources	adequacy of organizational policies	adequacy of established procedures
inadequate design and maintenance of facilities	adequacy of safety culture	adequacy of oversight

HFACS Event Data Form

Control #:	OES #:	Event Date:	Event Time:
Facility WO #:	Facility Name:		
Vessel Name:		Reviewed by: ____ ____ ____ ____	
Substance:			Quantity : gallons

Event Type

___ Spill
____ Class 3 Violation

Evolution

___ Ballasting/Deballasting
___ Bunkering
___ Fueling
___ Idle
___ Intra-Terminal
___ Intra-Vessel
___ Load/Discharge
___ Maintenance
___ Maneuvering
___ Term/Term
___ Testing
___ Other

Event

___ Arrival
___ Depart
___ Disconnect
___ Hook-up
___ Start-Up
___ Steady
___ Stripping
___ Topping off
___ N/A

Who/What	Incident Causal Factor	Tier 1	Tier 2	Tier 3	Pick-List

Transfer- Related: ___ Yes ___No	**Responsible Party**: ___ Vessel ___ Terminal ___ Other	**Layer Completeness 1: Y N 2: Y N 3: Y N 4: Y N**
Updated Substance:	Quantity: gallons	Date:

Notes (Outside Influences; recommendations; contributors):

Event Data Form Instructions:

<u>Top Sections</u>

1. **Control #:** The control # uniquely identifies the database record for this event. This number gets assigned at the point of computer data entry. It can be left blank by the inspector/specialist/analyst completing the form.
2. **OES#:** This number is assigned by The Office of Emergency Services and can be found on the *Hazardous Materials Spill Report* associated with the spill event. For a class 3 violation, this section should be left blank.
3. **Event Date:** Enter the month, day and year of the spill or violation event in mm-dd-yyyy format.
4. **Event Time:** For spills, enter the time of day that the spill occurred. This time can usually be found on the *Hazardous Materials Spill Report*. For class 3 violations, enter the time of day the violation was noted.
5. **Facility WO #:** Enter the work order number associated with the facility where the event occurred.
6. **Facility Name:** Enter the name of the facility where the event occurred.
7. **Vessel Name:** Enter the name of the vessel, if any, involved in the event.
8. **Reviewed by:** Each staff member that produces or reviews the completed form should initial here. Each form should be produced by and reviewed by a specialist, inspector and human factors analyst at a minimum before it is ready for data entry.
9. **Substance:** Enter the product(s) involved. For a violation, enter the product involved only if the violation occurred during a transfer event.
10. **Quantity:** For a spill event, enter the amount of product spilled, in gallons. For a violation, this section should be left blank .

<u>Left Sections</u>

1. **<u>Event Type</u>:** Check the appropriate blank indicating whether the event is a spill or a class 3 violation.
2. **<u>Evolution</u>:** Check appropriate blank(s) indicating the type of operation that was in progress when the event occurred.
3. **<u>Event:</u>** If the event occurred during a transfer, note the phase of the transfer by checking the appropriate phase.

<u>**Center Grid Sections**</u>

1. **Who/What:** Indicate one of the following:
   - A *person* or *group of persons* associated with the incident causal factor identified identify in column two. Use job titles rather than names; For example, tankerman, dockworker, TPIC, VPIC, chief mate, operations manager, terminal manager, barge company, shipping company, etc.
   - A damaged or malfunctioning *facility structure* or piece of *equipment* associated with the incident causal factor identified in column two.
   - An *environmental condition* or event associated with the incident causal factor identified in column two.
2. **Incident Causal Factor:** a prevailing condition, act, or omission that contributes to bringing about an adverse event.

   Note: For each row in the grid, The "Who/What" (column 1) entry and the "Incident Causal Factor" (column 2) entry should combine to form a sentence.

   Refer to the document *Human Factors Analysis and Classification System – Marine Facilities: Definitions* for a description of each tier & classification in HFACS. You can also use the *HFACS Tier and Layer Chart* for a map of tiers and layers.
3. **Tier 1:** Enter the most general category for the who/what & incident causal factor listed.
4. **Tier 2:** Enter the subcategory for the who/what & incident causal factor listed.
5. **Tier 3:** Enter the subtype for the who/what & incident causal factor listed.
6. **Pick-List:** For subcategories and subtypes that have pick-list items listed in the *HFACS Layer Guides*, select a specific factor from the list that best describes the incident causal factor.

<u>Bottom Sections</u>

1. **Transfer-Related:** Check to indicate whether the spill or class 3 violation is transfer- related.
2. **Responsible Party:** For spills, check to indicate the party responsible for the release.
3. **Layer Completeness:** For each layer, circle yes if you believe all causal factors that contributed to the event were identified as a result of the inquiry. Circle no if you believe other causal factors could have been identified had you been able to get more information during the inquiry.
4. **Updated Substance:** If the product determined to be involved in the event changes over the course of the inquiry, note the change here.
5. **Quantity:** enter the final estimate of the amount of product spilled.
6. **Date:** Enter the date the HFACS EVENT DATA FORM is completed.
7. **Notes (Outside Influences; recommendations)**: If groups outside the terminal-vessel organizations contributed to the event, note it here. Examples of outside influences include government agencies, local public political pressure and economic pressures. Also, specific comments about the event, or recommendations that result from the inquiry should be added here.

APPENDIX F STOLT-NIELSEN ACCIDENT/INCIDENT INVESTIGATION

SHIP:	***DATE, TIME & PLACE OF INCIDENT: CONT***

LOCATION ONBOARD:

LOSS DESCRIPTION: (check all applicable)

___ DAMAGE
- *___ Property Damage*
- *___ System/Equipment Damage*
- *___ Cargo Loss/Damage/Contamination*
- *___ Ship Damage*

___ POLLUTION
- *___ Contained*
- *___ Water Pollution*
- *___ Air Pollution*
- *___ Personnel Exposure*

___ GROUNDING

___ INJURY
- *___ Death*
- *___ Serious*
- *___ Minor*

___ ADMINISTRATIVE
- *___ Operational Delay*

___ Regulatory Violation
- *___ Inspection Deficiency*

___ FIRE/EXPLOSION

___ COLLISION

___ PIRACY/THEFT

____OTHER (describe):____

LOSS SEVERITY: (check) **__ Major __ Serious __ Minor**	**PROBABILITY OF OCCURRENCE: (check)** **__ Frequent __ Occasional __ Seldom**

DESCRIPTION OF THE EVENT:

IMMEDIATE CAUSES: (What substandard actions and conditions caused or could cause the event?)

UNDERLYING CAUSES: (What specific personal or job factors caused or could cause the event?)

REMEDIAL ACTIONS/RECOMMENDED CHANGES: (To control the causes listed)

Rev 9/9/99 **(Cont'd...)**

Page 2:

RESPONSIBILITY (For remedial action/changes):

CODING OF IMMEDIATE CAUSES: (check all applicable)

SUBSTANDARD ACTIONS:
__ 1. Operating equipment without authority
__ 2. Failure to warn
__ 3. Failure to secure
__ 4. Operating at improper speed
__ 5. Making safety devices inoperable
__ 6. Removing safety devices
__ 7. Using defective equipment
__ 8. Using equipment improperly
__ 9. Failing to use proper personal protective equipment
__10. Improper loading
__11. Improper placement
__12. Improper lifting
__13. Improper position for task
__14. Servicing equipment in operation
__15. Horseplay
__16. Drugs/Alcohol
__17. Fatigue
__18. Procedural error

SUBSTANDARD CONDITIONS:
__ 1. Inadequate guards or barriers
__ 2. Inadequate or improper protective equipment
__ 3. Defective tools, equipment or materials
__ 4. Congestion or restricted action
__ 5. Inadequate warning systems
__ 6. Fire or explosion hazards
__ 7. Poor housekeeping; disorder
__ 8. Hazardous environmental conditions
__ 9. Noise exposure
__10. Radiation exposure
__11. High/low temperature exposure
__12. Inadequate or excess illumination
__13. Inadequate ventilation
__14. Installation failure
__15. Equipment failure
__16. System failure

CODING OF UNDERLYING CAUSE: (check all applicable)

PERSONAL FACTORS:
__ 1. Fatigue
__ 2. Inadequate capability
__ 3. Lack of knowledge
__ 4. Lack of skill
__ 5. Stress
__ 6. Improper motivation

JOB FACTORS:
__ 1. Inadequate Leadership/Supervision
__ 2. Inadequate Personnel
__ 3. Inadequate Engineering
__ 4. Inadequate Maintenance
__ 5. Inadequate Tools/Equipment
__ 6. Inadequate Work Standards
__ 7. Wear and Tear
__ 8. Abuse or Misuse

SUBMITTED BY (print name): ______________ **DATE OF REPORT:** ____________

SAFETY COORDINATOR SIGNATURE: ____

SHIPS CAPTAIN CONCURRENCE: ____________________________________

FLEET MANAGERS APPROVAL: ____________________________________

(Please provide any additional comments on additional sheets and attach.)

Appendix G. Sample Taxonomies for Investigating for Fatigue, Communications Problems, and Inadequate Skills and Knowledge

The U.S. Coast Guard Research and Development Center has performed three studies of the roles of specific human errors in marine casualties: fatigue, communications problems, and inadequate skills and knowledge. These studies focused on “critical” casualties, that is, casualties which resulted in significant damage to the vessel, cargo, or the environment, or which resulted in significant injury to personnel.

The first two pages (following this introduction) represent data that were found useful for determining whether or not *fatigue* played a role in the incident (McCallum, Raby, & Rothblum, 1996). Earlier studies (Marine Transportation Research Board, 1976; National Research Council, 1990) had found fatigue to be the “number one” concern of mariners. This study corroborated that concern, finding that fatigue played a role in 16% of critical vessel casualties (groundings, collisions, allisions, etc.) and in 33% of critical personnel injuries (lacerations, amputations, crushings, etc.). The types of data reflected in the Fatigue Information form focus on scientifically validated causes, symptoms, and effects of fatigue. This form is recommended for use by organizations interested in controlling crew fatigue and reducing the casualties fatigue can cause.

As mentioned in Section 6 in the discussion of statistical analysis, the data from the fatigue investigations were submitted to a multiple regression analysis. The analysis showed that the Coast Guard could significantly streamline its initial investigation of fatigue to just three questions: how many hours did the person sleep during the 24-hour period prior to the casualty; how many hours did the person work during the 24-hour period prior to the casualty; and how many fatigue symptoms did the person experience while on duty prior to the casualty? The answers to these questions are put into an equation, as shown on the Fatigue Investigations Worksheet (third page of this Appendix), and the result was found to correctly identify whether fatigue was a causal factor in 80% of the cases. *Please note that the Fatigue Index Score is offered only as an example of the use of statistical analysis of incident data*, and it is *not* recommended for use by anyone other than the Coast Guard. The selection and weightings of the variables in the Fatigue Index equation may well reflect the somewhat guarded atmosphere of a USCG investigation (i.e., since one’s license could be on the line, one is less likely to be open and forthright about one’s condition and everything that occurred). We would anticipate that in the “open, blame-free culture” recommended for safety-conscious companies, a very different set of weighting factors (and maybe a different set of variables altogether) would apply.

Inadequate communications was found to play a role in 18% of critical vessel casualties and in 28% of critical personnel injuries (McCallum, Raby, Rothblum, Forsythe, Slavich, & Smith, 2000, unpublished). The communications investigation procedures provided in this appendix are based on a scientific model of communications (described in the Instructions for Investigating Communications Problems in Marine Casualties). The gist of the procedure is to identify under what types of situations communication is normally required – a list that can easily be modified to suit any company's operations – then to determine whether necessary communications were absent or ineffective and why. As described in Section 6, this investigation protocol was not only sufficient to identify casualties in which inadequate communications were a contributing cause, it also supported a meta-analysis to illuminate underlying causes of the communications failures. In addition, it was found that the five screening questions (Step 1 on the communications investigation form) captured 76% of the casualties in which communications errors were involved, making it a simple and effective way to determine whether the complete communications investigation needs to be performed.

The final set of investigation forms assess whether *skill and knowledge limitations* may have contributed to the incident. A study of skill and knowledge errors showed that they played a role in 22% of critical vessel casualties and in 32% of critical personnel injuries (McCallum, Forsythe, Raby, Barnes, Rothblum, & Smith, 2000, unpublished). Step 4 of the Mariner Skill & Knowledge Limitations Investigation Screening form essentially seeks to distinguish errors of knowledge and skilled performance (Decision Errors in HFACS) from slips and lapses (Skill-based and Perceptual errors in HFACS) and from violations. If it appears that the individual did not intentionally break a rule (violation) and failed to perform an action properly given an honest effort, it is assumed that a lack of knowledge or skill is the cause. The remainder of the skill and knowledge forms provide lists of common skill and knowledge areas relevant to different types of activities (bridge, deck, engineering, and safety & emergency operations) – obviously, these forms can be modified to suit any type of operation. The crux of the forms is to identify the type of error (skill or knowledge that was lacking) and to determine whether the error resulted from a lack of training/experience on the part of the person or from a poorly designed standard operating procedure (SOP) or policy. Note that while this analysis will determine whether insufficient training, experience, or a poor SOP was a contributing cause, that the best solution to such problems may turn out to be other types of interventions, such as a redesign of equipment, tasks, or work environment (see Sec. 8).

Fatigue Investigation Form

*Form should be completed for **each** individual who was directly linked to the casualty.*

Section 1: Casualty Day

1. Experience of involved individual

	year(s)	month(s)
a) in the industry	______	______
b) with this company	______	______
c) in present job or position	______	______
d) on present vessel	______	______

2. Individual's activity at time of casualty

3. Specific location on vessel

4. Number of hours on duty at time of casualty

5. Any break (awake) prior to casualty?
☐ No break
☐ Yes, when ______________

6. Time and last meal (breakfast, lunch, dinner) taken prior to casualty

7. Was the schedule on day of casualty different from usual?
☐ No ☐ Yes
a. What was the difference?______________________________
b. How long had you been on this schedule?______________

8. Did you experience any of these factors during the last 24 hours prior to the casualty? (*Check all that apply.*)

☐ Disruptive ship vibrations
☐ Disruptive ship motion
☐ High noise level
☐ Stormy weather
☐ Cold temperature
☐ Hot temperature
☐ Boredom
☐ None
☐ High stress
☐ Other____________________
☐ Demanding task

9. Did you experience any of the following while you were on duty prior to the casualty? (*Check all that apply.*)

☐ Forgetful
☐ Difficulty keeping eyes opened
☐ Difficulty operating equipment
☐ Sore muscles
☐ Desire to sit or lay down
☐ Distracted
☐ Less motivated
☐ None
☐ Other____

Section 2: Working Schedule

10. Number of days on tour at time of casualty (including shipyard)

11. Please shade the days on which you had 24 hours off in the previous 30 days

30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Day of Casualty

(over)

☐ ☐ ☐ ☐

Fatigue Information - Side 2

12. Normal Schedule	Work / Rec / Sleep — 0000 midnight, 0200, 0400, 0600, 0800, 1000, 1200 noon, 1400 2 pm, 1600 4 pm, 1800 6 pm, 2000 8 pm, 2200 10 pm, 2359	very low … very high 1 2 3 4 5 Workload level ☐ ☐ ☐ ☐ ☐ Fatigue level ☐ ☐ ☐ ☐ ☐ Sleep quality ☐ ☐ ☐ ☐ ☐

*From the time of casualty, trace back the **work, recreation, and sleep** periods for the last 72 hours (3 days) prior to the casualty. Sleep also includes naps. Please mark time of casualty with vertical line.*

13. Day of Casualty	Work / Rec / Sleep — 0000 midnight, 0200, 0400, 0600, 0800, 1000, 1200 noon, 1400 2 pm, 1600 4 pm, 1800 6 pm, 2000 8 pm, 2200 10 pm, 2359	very low … very high 1 2 3 4 5 Workload level ☐ ☐ ☐ ☐ ☐ Fatigue level ☐ ☐ ☐ ☐ ☐ Sleep quality ☐ ☐ ☐ ☐ ☐
14. Day 1 Prior to Casualty	Work / Rec / Sleep — 0000 midnight, 0200, 0400, 0600, 0800, 1000, 1200 noon, 1400 2 pm, 1600 4 pm, 1800 6 pm, 2000 8 pm, 2200 10 pm, 2359	very low … very high 1 2 3 4 5 Workload level ☐ ☐ ☐ ☐ ☐ Fatigue level ☐ ☐ ☐ ☐ ☐ Sleep quality ☐ ☐ ☐ ☐ ☐
15. Day 2 Prior to Casualty	Work / Rec / Sleep — 0000 midnight, 0200, 0400, 0600, 0800, 1000, 1200 noon, 1400 2 pm, 1600 4 pm, 1800 6 pm, 2000 8 pm, 2200 10 pm, 2359	very low … very high 1 2 3 4 5 Workload level ☐ ☐ ☐ ☐ ☐ Fatigue level ☐ ☐ ☐ ☐ ☐ Sleep quality ☐ ☐ ☐ ☐ ☐
16. Day 3 Prior to Casualty	Work / Rec / Sleep — 0000 midnight, 0200, 0400, 0600, 0800, 1000, 1200 noon, 1400 2 pm, 1600 4 pm, 1800 6 pm, 2000 8 pm, 2200 10 pm, 2359	very low … very high 1 2 3 4 5 Workload level ☐ ☐ ☐ ☐ ☐ Fatigue level ☐ ☐ ☐ ☐ ☐ Sleep quality ☐ ☐ ☐ ☐ ☐

17. Are there any company or union policies regarding work hour limits? ☐ No ☐ Yes Maximum hours:_________	18. In the involved individual's opinion, was fatigue a contributing factor to this casualty? ☐ No ☐ Yes Why:____________________

Section 3: For the Investigator Only

19. What was the decision/action that was considered improper given the existing circumstances?

☐ Failure to secure equipment	☐ Failure to recognize code/symbol	☐ Erroneous judgment of situation
☐ Failure to notice something important	☐ Failure to decide on an action	☐ Erroneous calculations
☐ Failure to take action at proper time	☐ Forgetting to accomplish task	☐ Improper procedures
	☐ Prone to take risks	☐ Slow reaction to circumstance
		☐ Other ______________________________

20. a) Was alcohol/drug testing done? ☐ Yes ☐ No b)Was the result: ☐ Positive ☐ Negative ☐ No result	21. In your opinion, was fatigue a contributing factor to this casualty? ☐ No ☐Yes Why__________
22. On a scale of 1 to 5, do you feel that the mariner gave you true and accurate information? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 1 = not at all true & accurate; 5 = extremely true & accurate	Additional Comments

FATIGUE INVESTIGATION WORKSHEET

The formula <u>s(21.4) + wh(6.1) - sh(4.5) = Fatigue Index Score</u> has been established to determine if fatigue may have affected an individual involved in a marine casualty. It should only be used for examining cases in which direct human error contributions are present, i.e., those situations which involve an individual's decisions, actions or inactions as casual factors occurring immediately before the casualty.

<u>Using the Formula</u>

s(21.4) + wh(6.1) - sh(4.5) = Fatigue Index Score

s = total number of fatigue symptoms (0-7) experienced while on duty before the casualty

wh = total number of hours worked in the last 24 hours (to the nearest tenth)

sh = total number of hours slept in the last 24 hours (to the nearest tenth)

1. Interview the individual whose errors directly contributed to the casualty (or another person who can verify the information) to determine the total number of fatigue symptoms (*s*) listed below, if any, that the individual experienced while on duty prior to the casualty.

<u>Fatigue Symptoms (*s*)</u>

- forgetful
- distracted
- sore muscles
- less motivated
- desire to sit or lay down
- difficulty keeping eyes opened
- difficulty operating equipment

2. Obtain the individual's total work hours (*wh*) and sleep hours (*sh*) for the 24 hour period before the casualty. Determine the Fatigue Index Score using the formula.

3. If the Fatigue Index Score is greater than 50, assume that fatigue was a contributing cause of the casualty. Our research has shown that this formula will produce correct results 80% of the time.

Example: At 0130, the F/V SEA MONKEY ran aground while returning to port. The mate on watch reported that he had slept 3.2 hours and worked 18.6 hours in the 24 hours preceding the casualty. He also said that while on watch before the casualty, he had difficulty keeping his eyes opened and felt distracted. The equation for this casualty would then read:

s(21.4) + wh(6.1) - sh(4.5) = Fatigue Index Score

2(21.4) + 18.6(6.1) - 3.2(4.5) = Fatigue Index Score

141.9 = Fatigue Index Score

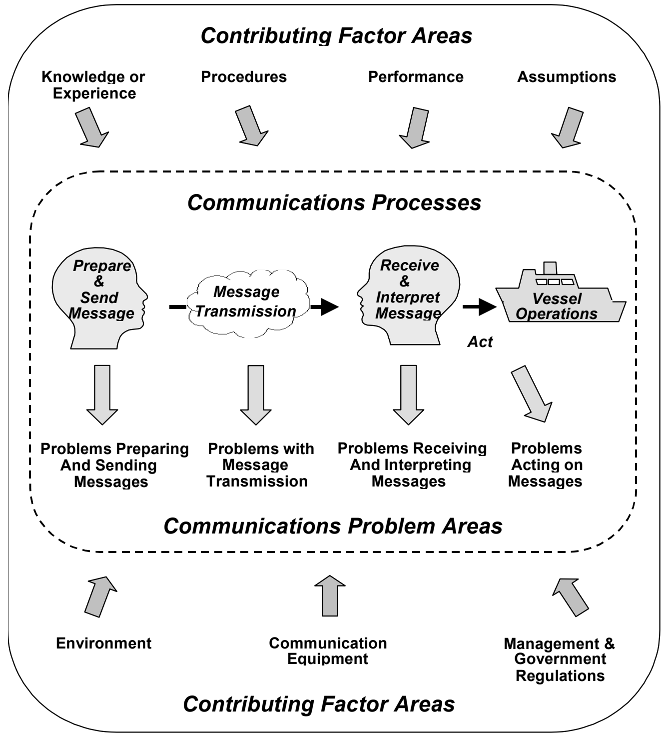
Since the results are greater than 50, fatigue is assumed as a contributing factor to the casualty.

Instructions for Investigating Communications Problems in Marine Casualties

These instructions provide an aid in using the *Communications Problems Screening and Investigation Procedures* to investigate communications problems in vessel and personnel injury casualties.

Background

These procedures were developed as part of a Coast Guard study of how best to investigate and report on communications problems. As part of that study, a general model of communications problems was developed, shown in the adjacent figure. This model divides communications into four *Communications Processes* (prepare and send message, message transmission, receive and interpret message, and act on message) and four corresponding *Communications Problem Areas*. The model further identifies seven *Contributing Factor Areas* that can cause or contribute to communications problems.



Basis

Investigation procedures based on this model were developed and then applied by Investigating Officers as part of the study. During the study, investigators screened casualties to identify those that required effective communications to support safe operations. Of those casualties identified as requiring effective communications, 76 percent were subsequently found to have a communications problem that contributed to the casualty. Following their initial screening of cases, investigators conducted in-depth investigations and analyses of selected casualties to identify specific communications problems and contributing factors. Investigating Officers were able to use the procedures to reliably identify communications problem areas and specific factors contributing to the casualties. Overall, the study found that 18 percent of critical vessel casualties and 28 percent of critical personnel injuries had a communications problem that contributed to the casualty.

Instructions

Step 1 is conducted to identify if there was a potential for a communications problem to have contributed to the casualty. This step identifies casualties where there is a 76 percent probability that ineffective, inappropriate, or a lack of communications contributed to the casualty, according to the results of the research study.

Step 1: Review the five conditions, check any that apply, and identify the type(s) of communications that should be further analyzed (vessel-vessel, bridge-pilot, vessel-shore authority, crew-crew, and vessel-shore worker).

The remaining steps call for a further investigation of the specific communications causes that contributed to the casualty. Complete Step 2 to identify the specific communications causes, if any. Complete Step 3 to document your conclusions regarding the type of communications that contributed to the casualty. Use Step 4 as an aid in investigating and reporting any communication types identified in Step 3.

Step 2: For each communication type identified in Step 1, consider the actions in which ineffective, inappropriate, or a lack of needed communications could have contributed to the casualty.

Step 3: Check the types of communications that likely contributed to this casualty and complete Step 4 for each type checked.

Step 4: For this step, it will typically be necessary to contact individuals involved in the casualty to determine the events leading up to the casualty, specific communications problems that occurred, and the factors that contributed to these problems.

Communications Problem Screening and Investigation Procedures

Please refer to the ***Instructions for Investigating Communications Problems in Marine Casualties*** *for a summary of the background and basis for these procedures, as well as general instructions for their use.*

Step 1: Was there a potential for a communications problem contributing to the casualty?

Review the following casualty conditions, check ☑ all that apply, and note the corresponding communication type(s) for further review in Step 2. If no conditions apply, communications were likely not required in the situation.

Casualty Condition	Communication Type
❑ Two or more vessels were involved in this casualty.	Vessel-Vessel
❑ There was a pilot (other than a member of the vessel's crew) responsible for navigation of the ship.	Bridge-Pilot
❑ The vessel was navigating in an area under the supervision of a VTS operator, a bridge tender, a lockmaster, or a light operator.	Vessel-Shore Authority
❑ Two or more crewmembers who were directly involved in this casualty were working together, or this casualty could have been prevented if someone had shared additional information with another crewmember.	Crew-Crew
❑ The casualty occurred during coordination of activities between the vessel and shore-based personnel (e.g., dock worker, crane operator, or vessel agent).	Vessel-Shore Workers

Step 2: What specific communications actions contributed to the casualty?

Check ☑ all actions in which ineffective, inappropriate, or a lack of needed communications may have contributed to the casualty. Note any other causes not listed. If any potential causes are identified, continue with Steps 3 and 4.

Vessel-Vessel Communication Problems	
❑ Vessel communication using a VHF radio system	❑ Vessel communication using visual signals
❑ Vessel communication using sound signals	❑ Vessel communication using some other means
❑ Other:	
Bridge-Pilot Communication Problems	
❑ Pilot request for vessel and situation information	❑ Pilot brief to bridge crew on operating conditions
❑ Bridge crew warned pilot of equipment malfunction	❑ Pilot update to bridge crew on change in plans
❑ Pilot brief to bridge crew on navigation plan	❑ Crew update to pilot of change in situation
❑ Other:	
Vessel-Shore Authority Communication Problems	
❑ Vessel call to shore authority	❑ Vessel statement of intentions to shore authority
❑ Shore authority advisory to vessel of situation	❑ Shore authority acknowledgement of vsl intentions
❑ Other:	
Crew-Crew Communication Problems	
❑ Use of direct and verbal conversation	❑ Use of communications devices
❑ Use of hand signals	❑ Use of written communications
❑ Other:	
Vessel-Shore Worker Communication Problems	
❑ Use of direct and verbal conversation	❑ Use of communications devices
❑ Use of hand signals	❑ Use of written communications
❑ Other:	
No Potential Communication Problems Identified	
❑ Further investigation failed to support communications as a causal factor	

Step 3: Which of the following types of communication contributed to this casualty?

Based on the response to Step 2, check ☑ the types of communication, if any, that likely contributed to this casualty and complete Step 4 for each type checked.

❑ Vessel-Vessel Communications	❑ Crew-Crew Communications
❑ Bridge-Pilot Communications	❑ Vessel-Shore Worker Communications
❑ Vessel-Shore Authority Communications	❑ N/A--no communication problems identified

Step 4: What specific communications problems and factors contributed to this casualty?

For each type of communication checked in Step 3, check ☑ all communications problems that contributed to the casualty. For each problem identified below, list at least one contributing factor from the list below by indicating its corresponding identification number (#1-41). For example, ☑ Did not request information…3 , 15 , 28.

Communications Process	Communications Problem	Contributing Factor (see 1 – 41 below)
Prepare & Send Message (includes spoken and written communications, hand and sound signals)	❒ Did not communicate	___ ___ ___
	❒ Communicated ambiguous, incorrect, or incomplete information	___ ___ ___
	❒ Did not question others' actions or assert own interpretation of situation	___ ___ ___
	❒ Did not request information	___ ___ ___
	❒ Did not send information in a timely manner	___ ___ ___
	❒ Sent different information than intended	___ ___ ___
Message Transmission	❒ Message was not transmitted	___ ___ ___
	❒ Message was interrupted	___ ___ ___
	❒ Message was incomprehensible	___ ___ ___
Receive & Interpret Message	❒ Did not monitor communications	___ ___ ___
	❒ Did not listen to complete message	___ ___ ___
	❒ Did not acknowledge information reception	___ ___ ___
	❒ Did not interpret the information correctly	___ ___ ___
	❒ Did not verify the validity or accuracy of the information	___ ___ ___
Act on Message	❒ Took no action	___ ___ ___
	❒ Action was not in accordance with agreement	___ ___ ___
Others:		___ ___ ___

Knowledge or Experience

1. Improper use of signaling techniques (hand, light, flag)
2. Improper use of standard marine technical vocabulary
3. Inadequate knowledge of company procedures or policies
4. Inadequate knowledge of correct communications protocol
5. Inadequate knowledge of regulatory requirements
6. Limited English skills or knowledge
7. Language difficulty (e.g., enunciation, strong accent)
8. Lack of common language
9. Other: ____________________

Procedures

10. Did not carry communications equipment on person
11. Did not operate the communications equipment correctly
12. Selected incorrect communications channel or frequency
13. Selected incorrect communications device
14. Other: ____________________

Performance

15. Distracted or interrupted by other tasks (e.g., high workload)
16. Forgot information or intended actions
17. Tired or sleepy
18. Individual not at work station
19. Not willing to challenge authority
20. Not willing to communicate
21. Other: ____________________

Assumptions

22. Assumed that there was no need to communicate
23. Assumed lack of response as implicit (silent) confirmation
24. Assumed incorrectly that other party knew the information
25. Assumed that individual in charge recognized the problem
26. Confusion regarding who was communicating
27. Confusion regarding who was in charge of situation
28. Incorrect interpretation of the situation
29. Other: ____________________

Environment

30. Excessive ambient noise
31. Excessive electronic or atmospheric disruption of signal
32. Excessive traffic (i.e., too many users, too lengthy) on the assigned communications channel
33. Other: ____________________

Communications Equipment

34. Communications equipment malfunction
35. Communications equipment not available
36. Communications equipment turned off
37. Other: ____________________

Management and Government Regulations

38. No regulatory requirement to communicate
39. Not part of individual's job description or responsibilities
40. Inadequate Standard Operating Procedures
41. Other: ____________________

COMMUNICATIONS REPORTING FORM

Section 1. Reference Information

1. Name of Investigator	2. Office	3. Case Number	4. Vessel Name

Section 2. Individuals Contacted

5. Name & Job Position of Individual Name ______________ Job ______________	6. Individual contacted ‘ By phone ‘ By deposition ‘ In person ‘ Unable to contact	7. Individual's Fluency in English Language ‘ a. No English ‘ b. Standard maritime phrases ‘ c. Limited conversation ‘ d. Fluent ‘ e. Unknown
8. Name & Job Position of Individual Name ______________ Job ______________	9. Individual contacted ‘ By phone ‘ By deposition ‘ In person ‘ Unable to contact	10. Individual's Fluency in English Language ‘ a. No English ‘ b. Standard maritime phrases ‘ c. Limited conversation ‘ d. Fluent ‘ e. Unknown
11. Name & Job Position of Individual Name ______________ Job ______________	12. Individual contacted ‘ By phone ‘ By deposition ‘ In person ‘ Unable to contact	13. Individual's Fluency in English Language ‘ a. No English ‘ b. Standard maritime phrases ‘ c. Limited conversation ‘ d. Fluent ‘ e. Unknown

Section 3. Communications Contribution

This form relates to which type of communications problem? *(check only one – use separate form for each type)*

‘ bridge-pilot ‘ vessel-vessel ‘ crew-crew ‘ vessel-shore workers ‘ vessel-shore authority

14. Were communications or coordination between (the groups checked above) advisable during the events leading up to the casualty? ‘ Yes ‘ No If Yes, briefly describe activities (e.g., course change, passing, line handling, cargo transfer, locking) or situation requiring communications:
15. Describe any needed communications that were either not done or done ineffectively.
16. In the Investigator's opinion, were communications a contributing factor to this casualty? ‘ Yes. Describe the specific type of communications problems checked above (i.e., Who? What? How?). ______________________________ ‘ No. Indicate the apparent cause(s) of the casualty______________________________ *If No is checked, proceed with Section 4, but skip Section 5 (Communications Analysis), otherwise complete both sections 4 & 5.*

Section 4. Conclusions and Comments

17. On a scale of 1 to 5, do you feel that the individual(s) gave you true and accurate information?

		Not at all true & accurate				Extremely true & accurate
‘ N/A since nobody was contacted	Individual's initials ______	1. ‘	2. ‘	3. ‘	4. ‘	5. ‘
	Individual's initials ______	1. ‘	2. ‘	3. ‘	4. ‘	5. ‘
	Individual's initials ______	1. ‘	2. ‘	3. ‘	4. ‘	5. ‘

18. To what extent was there a discrepancy in the information received from the various individuals contacted?

	Complete disagreement				Complete agreement
‘ N/A since only 1 individual was contacted	1. ‘	2. ‘	3. ‘	4. ‘	5. ‘

19. Safety recommendations to prevent similar communications-related casualties
20. Additional Comments

Section 5. Communications Analysis

*Please complete this section if **bridge-pilot** communications is a contributing factor to this casualty. Check ☑ all bridge–pilot communications process problems that apply. For each process problem identified, list at least one contributing factor from the list below by indicating its corresponding identification number* (#1-41). *(e.g., ☑ Did not request information _6_, _8_, _11_)*

21. Process Problems		Contributing Factors
Communications Process	Process Problems	(see 1 – 41 below)
Prepare & Send Message	‘ Did not communicate	___ ___ ___ ___
(includes spoken and written communications)	‘ Communicated ambiguous, incorrect, or incomplete information	___ ___ ___ ___
	‘ Did not question others’ actions or assert own interpretation of situation.	___ ___ ___ ___
	‘ Did not request information	___ ___ ___ ___
	‘ Did not send information in a timely manner	___ ___ ___ ___
	‘ Sent different information than intended	___ ___ ___ ___
Message Transmission	‘ Message was not transmitted	___ ___ ___ ___
	‘ Message was interrupted	___ ___ ___ ___
	‘ Message was incomprehensible	___ ___ ___ ___
Receive & Interpret Message	‘ Did not monitor communications	___ ___ ___ ___
	‘ Did not listen to complete message	___ ___ ___ ___
	‘ Did not acknowledge information reception	___ ___ ___ ___
	‘ Did not interpret the information correctly	___ ___ ___ ___
	‘ Did not verify the validity or accuracy of the information	___ ___ ___ ___
Act on Message	‘ Took no action	___ ___ ___ ___
	‘ Action was not in accordance with agreement	___ ___ ___ ___
Others:		___ ___ ___ ___

Contributing Factors

Knowledge or Experience

1. Improper use of signaling techniques (hand, light, flag, Morse)
2. Improper use of standard marine technical vocabulary
3. Inadequate knowledge of company procedures or policies
4. Inadequate knowledge of correct communications protocol
5. Inadequate knowledge of regulatory requirements
6. Limited English skills or knowledge
7. Language difficulty (e.g., enunciation, strong accent)
8. Lack of common language
9. Other:____________________

Procedures

10. Did not carry communications equipment on person
11. Did not operate the communications equipment correctly
12. Selected incorrect communications channel or frequency
13. Selected incorrect communications device
14. Other: ____________________

Performance

15. Distracted or interrupted by other tasks (e.g., high workload)
16. Forgot information or intended actions
17. Tired or sleepy
18. Individual not at work station
19. Not willing to challenge authority
20. Not willing to communicate
21. Other: ____________________

Assumptions

22. Assumed that there was no need to communicate
23. Assumed lack of response as implicit (silent) confirmation
24. Assumed incorrectly that other party knew the information
25. Assumed that individual in charge recognized the problem
26. Confusion regarding who was communicating
27. Confusion regarding who was in charge of situation
28. Incorrect interpretation of the situation
29. Other: ____________________

Environment

30. Excessive ambient noise
31. Excessive electronic or atmospheric disruption of signal
32. Excessive traffic (i.e., too many users, too lengthy) on the assigned communications channel
33. Other: ____________________

Communications Equipment

34. Communications equipment malfunction
35. Communications equipment not available
36. Communications equipment turned off
37. Other: ____________________

Management and Government Regulations

38. No regulatory requirement to communicate

41\. Not part of individual’s job description or responsibilities

42\. Inadequate Standard Operating Procedures

41\. Other: ____________________

MARINER SKILL & KNOWLEDGE LIMITATIONS INVESTIGATION SCREENING

Step 1: Human Factors Involvement

Did at least one person's actions, inaction, or decisions directly contributed to the casualty or its severity?
☐YES – Go to Step 2.
☐NO – Human factors are likely not involved and further investigation of mariner skill and knowledge limitations is unwarranted.

Step 2: Contributing Individuals

List the names and job positions of up to three persons whose actions, inaction, or decisions most directly contributed to the casualty. For each person, identify the general area(s) of vessel operations that contributed to the casualty, then go to Step 3.

Mariner's Name	**Job Position**	**Vessel Operations Contributing to Casualty** *(Bridge, Deck, Engineering, Safety & Emergency)*
1.		
2.		
3.		

Step 3: Contributing Activities

Briefly describe each person's actions, inaction, and/or decisions that contributed to the casualty.

Mariner 1:
Mariner 2:
Mariner 3:

Step 4: Potential for Skill and Knowledge Limitations

For each mariner, respond to the following questions. If possible, interview the mariner(s) in-person or by telephone to address these questions.	**Mariner 1**	**Mariner 2**	**Mariner 3**
a. Did this person's action or inaction result in their **knowing** violation of an applicable law, rule, policy or standard operating procedure? ***If NO for any involved mariner, go to b.*** *If YES for all involved mariners, end report. This casualty is likely a **violation**, not the result of skill and knowledge limitations.*	☐YES ☐NO	☐YES ☐NO	☐YES ☐NO
b. Has each person successfully demonstrated the contributing activities many times before under similar circumstances and within the last five years? ***If NO for any involved mariner, go to Step 5.*** *If YES for all involved mariners, end report. This casualty is likely either a **slip** or a **lapse**, not the result of skill and knowledge limitations.*	☐YES ☐NO	☐YES ☐NO	☐YES ☐NO

Step 5: Completion of Operations Form(s)

*Complete applicable operational area investigation form(s) for **Bridge, Deck, Engineering, and/or Safety & Emergency Operations**, for each mariner with **NO** answers to Questions 4a and 4b.*

Bridge Operations – Mariner Skill & Knowledge Limitations

Please complete a separate copy of this form for each person whose bridge activities contributed to the casualty.

Step 5.1: Maritime Work History of Contributing Mariner

1. Mariner's name:	2. Job position at time of casualty:
3. _____ years _____ months in this industry.	4. _____ years _____ months with this company.
5. _____ years _____ months in present position.	6. _____ years _____ months on present vessel or facility.
7. _____ years _____ months on present route.	8. Current licenses/documents (N/A if not applicable):

Step 5.2: Mariner's Actions, Inaction, or Decisions Contributing to the Casualty

9. Briefly describe how this person's specific **bridge** actions, inaction, or decisions contributed to the casualty:

Now, check ☑ all bridge activities (10-17) that directly contributed to the casualty.

10. Did **changing bridge watch** activities contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 11.*
    - ❑ a. Check and acknowledge passage plan, orders, and special information
    - ❑ b. Assess traffic and weather conditions
    - ❑ c. Check status of ship's equipment
    - ❑ d. Ensure that watch is relieved

11. Did **visual monitoring and lookout** activities contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 12.*
    - ❑ a. Instruct Lookout as to duties and ensure Lookout is prepared to assume the watch
    - ❑ b. Maintain lookout to detect objects, traffic, or navigational aids and assess visibility
    - ❑ c. Determine type, aspect, and relative motion of other vessels
    - ❑ d. Receive and verify reports of visual contact

12. Did **collision avoidance** activities contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 13.*
    - ❑ a. Adjust and operate radar/ARPA
    - ❑ b. Monitor radar/ARPA and radar contacts
    - ❑ c. Assess collision threat and determine avoidance maneuver
    - ❑ d. Recognize and apply COLREGS

13. Did **grounding avoidance and navigation** contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 14.*
    - ❑ a. Establish a passage plan based on navigation information and knowledge of are
    - ❑ b Determine vessel position using available systems
    - ❑ c. Calculate course changes based on navigation information, local conditions, and local regulation
    - ❑ d. Check and update navigation charts and publications

14. Did **shiphandling** activities contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 15.*
    - ❑ a. Maneuver in accordance with sea/river/weather conditions
    - ❑ b. Maneuver in accordance with vessel and/or tow handling characteristics
    - ❑ c. Maneuver vessel in accordance with conning orders
    - ❑ d. Maneuver vessel during docking, anchoring, and mooring
    - ❑ e. Manage and coordinate assist vessels

15. Did **bridge communications** contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 16.*
    - ❑ a. Communicate and coordinate effectively among the vessel's crew (Bridge, Engine, and Deck)
    - ❑ b. Communicate and coordinate between the bridge watch team and the federal/state pilot
    - ❑ c. Interpret and reply to signals (flag signals, flashing light, and ship's whistle)
    - ❑ d. Establish and maintain VHF radio communications with other vessels and appropriate shore authorities

16. Did **port or anchor watch** activities contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 17.*
    - ❑ a. Inspect for leaks, loose or weak mooring lines, and smoke or fire
    - ❑ b. Monitor vessel position to determine if anchor is dragging

17. Did a **bridge activity not listed above** contribute? ☐ YES *Briefly describe activity below.* ☐ NO *Go to 18.*

(Bridge Operations – Mariner Skill & Knowledge Limitations, cont.)

Step 5.3: Training and Procedures

Write the identification numbers of up to three bridge activities checked in Step 5.2 that most contributed to the casualty. (Example: Activity 1: 10a, Activity 2: 13b, Activity 3: 16a.) Then, complete the remaining items under each listed activity.

18. Activity 1:	23. Activity 2:	28. Activity 3:
19. What training has the mariner had to prepare for **Activity 1**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	24. What training has the mariner had to prepare for **Activity 2**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	29. What training has the mariner had to prepare for **Activity 3**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training
20. Briefly describe the mariner's most relevant training for **Activity 1**.	25. Briefly describe the mariner's most relevant training for **Activity 2**.	30. Briefly describe the mariner's most relevant training for **Activity 3**.
21. How long has it been since the mariner received this **Activity 1** training? _____ years and _____ months	26. How long has it been since the mariner received this **Activity 2** training? _____ years and _____ months	31. How long has it been since the mariner received this **Activity 3** training? _____ years and _____ months
22. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 1**. Are procedures adequate? □YES □NO	27. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 2**. Are procedures adequate? □YES □NO	32. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 3**. Are procedures adequate? □YES □NO

Step 5.4: Conclusions and Recommendations

*Respond to items 33-34 **after** completing Step 5.3.*

33. If the mariner lacks skill or knowledge in any activity (1 to 3), complete *33* and *34*; otherwise, end this report (NOT skill or knowledge related).	**Activity 1**	**Activity 2**	**Activity 3**
a. The mariner most likely lacks **skill** in this activity.	□ TRUE □ FALSE	□ TRUE □ FALSE	□ TRUE □ FALSE
b. The mariner most likely lacks **knowledge** in this activity.	□ TRUE □ FALSE	□ TRUE □ FALSE	□ TRUE □ FALSE
34. What could be done to improve this mariner's skill and/or knowledge, or to improve established procedures and reduce casualties? *Minimum:*			
Ideal:			

Deck Operations – Mariner Skill & Knowledge Limitations

Step 5.1: Maritime Work History of Contributing Mariner

1. Mariner's name:	2. Job position at time of casualty:
3. _____ years _____ months in this industry.	4. _____ years _____ months with this company.
5. _____ years _____ months in present position.	6. _____ years _____ months on present vessel or facility.
7. _____ years _____ months on present route.	8. Current licenses/documents (N/A if not applicable):

Step 5.2: Mariner's Actions, Inaction, or Decisions Contributing to the Casualty

9. Briefly describe how this person's specific **deck** actions, inaction, or decisions contributed to the casualty: **Now, check ☑ all deck activities (10-21)) that directly contributed to the casualty.**	
10. Did **vessel stability and integrity management** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 11.*
❑ a. Load and unload a vessel taking into account load lines, stability, trim, and stress principles and calculations	❑ b. Adjust ballast as required to maintain stability ❑ c. Operate vessel in compliance with Stability Letter ❑ d. Ensure vessel's water tight integrity
11. Did **deck equipment operations** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 12.*
❑ a. Board pilot ❑ b. Conduct docking, anchoring, and mooring operations	❑ c. Assist in tug/escort vessel tie-up operations ❑ d. Prepare and stow cargo handling equipment
12. Did **container cargo operations** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 13.*
❑ a. Establish container stowage plan ❑ b. Load and unload containers	❑ c. Lash all containers ❑ d. Monitor and maintain cargo security
13. Did **bulk cargo operations** contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 14.*
❑ a. Establish bulk cargo loading plan ❑ b. Load and unload bulk cargo	❑ c. Monitor and maintain cargo security ❑ d. Handle dangerous and hazardous cargo
14. Did **petroleum cargo** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 15.*
❑ a. Operate pumping equipment ❑ b. Monitor piping and pumping systems	❑ c. Clean petroleum cargo tanks ❑ d. Conduct inert gas and gas-free operations
15. Did **towing and fleeting operations** contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 16.*
❑ a. Establish a tow diagram ❑ b. Make up, check, and tighten towlines and headwires	❑ c. Check tow for water and pump barges ❑ d. Conduct locking and lock assist operations
16. Did **fishing operations** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 17.*
❑ a. Set, retrieve, and handle fishing gear ❑ b. Bring aboard and load catch	❑ c. Unload or transfer catch ❑ d. Process catch
17. Did **deck communications** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 18.*
❑ a. Communicate effectively between deck and bridge ❑ b. Communicate effectively among deck crew	❑ c. Coordinate between deck and assist vessels ❑ d. Coordinate between deck and dock crew
18. Did **deck maintenance** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 19.*
❑ a. Perform deck, hull, and surface chipping, painting ❑ b. Maintain deck equipment	❑ c. Work in confined spaces ❑ d. Perform hot work
19. Did **general activities on deck** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 20.*
❑ a. Embarking or disembarking vessel ❑ b. Moving around the vessel	❑ c. General off-duty activities onboard vessel
20. Did **passenger safety** activities contribute?	☐ YES *Check all activities that apply.* ☐ NO *Go to 21.*
❑ a. Ensure the safety of passengers during embarkation and disembarkation ❑ b. Ensure the safety of passengers when underway and during ship operations	❑ c. Inspect passenger spaces for hazards and take appropriate action ❑ d. Confine passenger access to safe vessel spaces only
21. Did a **deck activity not listed above** contribute?	☐ YES *Briefly describe activity below.* ☐ NO *Go to 22.*

(Deck Operations – Mariner Skill & Knowledge Limitations, cont.)

Step 5.3: Training and Procedures

Write the identification numbers of up to three deck activities checked in Step 5.2 that most contributed to the casualty. (Example: Activity 1: 10a, Activity 2: 13b, Activity 3: 16a.) Then, complete the remaining items under each listed activity.

22. Activity 1:	27. Activity 2:	32. Activity 3:
23. What training has the mariner had to prepare for **Activity 1**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	28. What training has the mariner had to prepare for **Activity 2**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	33. What training has the mariner had to prepare for **Activity 3**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training
24. Briefly describe the mariner's most relevant training for **Activity 1**.	29. Briefly describe the mariner's most relevant training for **Activity 2**.	34. Briefly describe the mariner's most relevant training for **Activity 3**.
25. How long has it been since the mariner received this **Activity 1** training? _____ years and _____ months	30. How long has it been since the mariner received this **Activity 2** training? _____ years and _____ months	35. How long has it been since the mariner received this **Activity 3** training? _____ years and _____ months
26. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 1**. Are procedures adequate? ☐YES ☐NO	31. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 2**. Are procedures adequate? ☐YES ☐NO	36. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 3**. Are procedures adequate? ☐YES ☐NO

Step 5.4: Conclusions and Recommendations

*Respond to items 37-38 **after** completing Step 5.3.*

37. If the mariner lacks skill or knowledge in any activity (1 to 3), complete *37* and *38*; otherwise, end this report (NOT skill or knowledge related).	**Activity 1**	**Activity 2**	**Activity 3**
a. The mariner most likely lacks **skill** in this activity.	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE
b. The mariner most likely lacks **knowledge** in this activity.	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE

38. What could be done to improve this mariner's skill and/or knowledge, or to improve established procedures and reduce casualties?

Minimum:

Ideal:

Engineering Operations – Mariner Skill & Knowledge Limitations

Please complete this form separately for each person whose engineering activities contributed to the casualty.

Step 5.1: Maritime Work History of Contributing Mariner

1. Mariner's name:	2. Job position at time of casualty:
3. _____ years _____ months in this industry.	4. _____ years _____ months with this company.
5. _____ years _____ months in present position.	6. _____ years _____ months on present vessel or facility.
7. _____ years _____ months on present route.	8. Current licenses/documents (N/A if not applicable):

Step 5.2: Mariner's Actions, Inaction, or Decisions Contributing to the Casualty

9. Briefly describe how this person's specific **engineering** actions, inaction, or decisions contributed to the casualty:

Now, check ☑ all engineering activities (10-16)) that directly contributed to the casualty.

10. Did **changing engineering watch** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 11.*
   - ❑ a. Check and acknowledge standing orders, night orders, and special information
   - ❑ b. Check status of ship's equipment
   - ❑ c. Assess traffic and weather conditions
   - ❑ d. Ensure that watch is relieved

11. Did **engineering systems operations** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 12.*
   - ❑ a. Operate main propulsion system (engines, boilers, fuel and steering
   - ❑ b. Operate generating and electrical systems
   - ❑ c. Operate motors, pumps, and lubrication systems
   - ❑ d. Operate service equipment (evaporators, refrigeration, heating, AC, sewage, and garbage treatment)
   - ❑ e. Load, discharge, or transfer fuel between tanks

12. Did **engineering systems inspection and testing** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 13.*
   - ❑ a. Inspect and test main propulsion system (engines, boilers, fuel, and steering)
   - ❑ b. Inspect and test generating and electrical systems
   - ❑ c. Inspect and test motors, pumps, and lubrication systems
   - ❑ d. Inspect and test service equipment (evaporators, refrigeration, heating, AC, sewage, and garbage treatment)

13. Did **routine, scheduled, and preventive maintenance** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 14.*
   - ❑ a. Maintain main propulsion system (engines, boilers, fuel, and steering)
   - ❑ b. Maintain generating and electrical systems
   - ❑ c. Maintain motors, pumps, and lubrication systems
   - ❑ d. Maintain service equipment (evaporators, refrigeration, heating, AC, sewage, and garbage treatment)

14. Did **unscheduled, corrective repair** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 15.*
   - ❑ a. Repair main propulsion system (engines, boilers, fuel, and steering)
   - ❑ b. Repair generating and electrical systems
   - ❑ c. Repair motors, pumps, and lubrication systems
   - ❑ d. Repair service equipment (evaporators, refrigeration, heating, AC, sewage, and garbage treatment)

15. Did **engineering communications** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 16.*
   - ❑ a. Communicate and coordinate effectively among the vessel's crew (Bridge, Engine, and Deck)
   - ❑ b. Communicate and coordinate effectively among the engineering crew

16. Did **engineering activity not listed above** contribute to casualty? ☐ YES *Briefly describe activity below.* ☐ NO *Go to 17.*

(Engineering Operations – Mariner Skill & Knowledge Limitations, cont.)

Step 5.3: Training and Procedures

Write the identification numbers of up to three engineering activities checked in Step 5.2 that most contributed to the casualty. (Example: Activity 1: 10a, Activity 2: 13b, Activity 3: 16a.) Then, complete the remaining items under each listed activity.

17. Activity 1:	22. Activity 2:	27. Activity 3:
18. What training has the mariner had to prepare for **Activity 1**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	23. What training has the mariner had to prepare for **Activity 2**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	28. What training has the mariner had to prepare for **Activity 3**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training
19. Briefly describe the mariner's most relevant training for **Activity 1**.	24. Briefly describe the mariner's most relevant training for **Activity 2**.	29. Briefly describe the mariner's most relevant training for **Activity 3**.
20. How long has it been since the mariner received this **Activity 1** training? _____ years and _____ months	25. How long has it been since the mariner received this **Activity 2** training? _____ years and _____ months	30. How long has it been since the mariner received this **Activity 3** training? _____ years and _____ months
21. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 1**. Are procedures adequate? ☐YES ☐NO	26. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 2**. Are procedures adequate? ☐YES ☐NO	31. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 3**. Are procedures adequate? ☐YES ☐NO

Step 5.4: Conclusions and Recommendations

*Respond to items 32-33 **after** completing Step 5.3.*

32. If the mariner lacks skill or knowledge in any activity (1 to 3), complete *32* and *33*; otherwise, end this report (NOT skill or knowledge related).	**Activity 1**	**Activity 2**	**Activity 3**
a. The mariner most likely lacks **skill** in this activity.	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE
b. The mariner most likely lacks **knowledge** in this activity.	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE

33. What could be done to improve this mariner's skill and/or knowledge, or to improve established procedures and reduce casualties? *Minimum:*
Ideal:

Safety & Emergency Operations – Mariner Skill & Knowledge Limitations

Please complete this form separately for each person whose safety and emergency activities contributed to the casualty.

Step 5.1: Maritime Work History of Contributing Mariner

1. Mariner's name:	2. Job position at time of casualty:
3. _____ years _____ months in this industry.	4. _____ years _____ months with this company.
5. _____ years _____ months in present position.	6. _____ years _____ months on present vessel or facility.
7. _____ years _____ months on present route.	8. Current licenses/documents (N/A if not applicable):

Step 5.2: Mariner's Actions, Inaction, or Decisions Contributing to the Casualty

9. Briefly describe how this person's specific **safety and emergency** actions, inaction, or decisions contributed to the casualty:

Now, check ☑ all safety and emergency activities (10-18)) that directly contributed to the casualty.

10. Did **general safety** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 11.*
- ❑ a. Embark and disembark vessel safely
- ❑ b. Walk about vessel safely
- ❑ c. Perform off-duty activities safely

11. Did **safety equipment inspection and service** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 12.*
- ❑ a. Inspect and service fire detection equipment
- ❑ b. Inspect and service fire extinguishing equipment
- ❑ c. Inspect and service lifesaving equipment, locating devices, and flotation devices
- ❑ d. Inspect and service survival craft
- ❑ e. Inspect and service emergency generator, batteries, etc.

12. Did **controlling and fighting fires** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 13.*
- ❑ a. Establish and maintain a Fire Safety Plan
- ❑ b. Organize and conduct fire drills
- ❑ c. Identify the type of fire
- ❑ d. Use fire-fighting equipment and procedures
- ❑ e. Maintain escape routes

13. Did **confined space rescue** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 14.*
- ❑ a. Locate individual(s)
- ❑ b. Establish a rescue plan
- ❑ c. Use breathing apparatus and other required equipment
- ❑ d. Maintain back-up personnel and escape routes

14. Did **person overboard procedures** contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 15.*
- ❑ a. Initiate warning
- ❑ b. Locate person overboard
- ❑ c. Maneuver vessel
- ❑ d. Bring person aboard

15. Did **abandon vessel operations** contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 16.*
- ❑ a. Don survival suits and personal flotation devices
- ❑ b. Launch, load, and maneuver lifeboats and life rafts
- ❑ c. Employ locating devices properly

16. Did **emergency medical and life-saving procedures** activities contribute to casualty? ☐ YES *Check all activities that apply.* ☐ NO *Go to 17.*
- ❑ a. Use medical chest and first aid items
- ❑ b. Apply First Aid/CPR

17. Did **emergency communications** activities contribute? ☐ YES *Check all activities that apply.* ☐ NO *Go to 18.*
- ❑ a. Establish and maintain communications with crew
- ❑ b. Establish and maintain communications with passengers
- ❑ c. Establish and maintain emergency communications with other vessels
- ❑ d. Establish emergency communications with shore authorities
- ❑ e. Monitor GMDSS and other emergency frequencies as required

18. Did **safety and emergency activity not listed above** contribute to casualty? ☐ YES *Briefly describe activity below.* ☐ NO *Go to 19.*

(Safety & Emergency Operations – Mariner Skill & Knowledge Limitations, cont.)

Step 5.3: Training and Procedures

Write the identification numbers of up to three safety and emergency activities checked in Step 5.2 that most contributed to the casualty. (Example: Activity 1: 10a, Activity 2: 13b, Activity 3: 16a.) Then, complete the items under each listed activity.

19. Activity 1:	24. Activity 2:	29. Activity 3:
20. What training has the mariner had to prepare for **Activity 1**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	25. What training has the mariner had to prepare for **Activity 2**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training	30. What training has the mariner had to prepare for **Activity 3**? *(Check all that apply.)* ❑ No training of any kind ❑ Informal on-the-job training ❑ Formal, structured on-the-job training and supervision ❑ Coast Guard-approved course ❑ Maritime trade school training ❑ Maritime college or academy training ❑ Other training
21. Briefly describe the mariner's most relevant training for **Activity 1**.	26. Briefly describe the mariner's most relevant training for **Activity 2**.	31. Briefly describe the mariner's most relevant training for **Activity 3**.
22. How long has it been since the mariner received this **Activity 1** training? _____ years and _____ months	27. How long has it been since the mariner received this **Activity 2** training? _____ years and _____ months	32. How long has it been since the mariner received this **Activity 3** training? _____ years and _____ months
23. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 1**. Are procedures adequate? ☐YES ☐NO	28. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 2**. Are procedures adequate? ☐YES ☐NO	33. Briefly describe established vessel procedures, regulations, or common practices that guide mariner performance of **Activity 3**. Are procedures adequate? ☐YES ☐NO

Step 5.4: Conclusions and Recommendations

*Respond to items 34-35 **after** completing Step 5.3.*

34. If the mariner lacks skill or knowledge in any activity (1 to 3), complete *34* and *35*; otherwise, end this report (NOT skill or knowledge related).	**Activity 1**	**Activity 2**	**Activity 3**
a. The mariner most likely lacks **skill** in this activity.	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE
b. The mariner most likely lacks **knowledge** in this activity.	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE	☐ TRUE ☐ FALSE
35. What could be done to improve this mariner's skill and/or knowledge, or to improve established procedures and reduce casualties? *Minimum:*			
Ideal:			

Appendix H. Human Factors Investigation Questions

The following is taken from "Role of the Human Element in Maritime Casualties," by the Joint ILO/IMO adhoc Working Group on Investigation of Human Factors in Maritime Casualties, Maritime Safety Committee, MSC 69/13/1 ([MSC], 1998, Annex 4, Appendix 2). These are questions designed to help the casualty investigator ask questions appropriate to discovering human errors which may have contributed to an incident. While no list of questions can be comprehensive, this one provides a good set of initial inquiries into the events and underlying causes. Investigators can use these to explore many facets surrounding the incident, choosing relevant areas for follow-up. Even though the questions below assume an accident to a commercial ship, the questions can easily be tailored to investigate incidents on any type of facility or vessel. The text of the MSC document is provided below.

Note: The following questions are designed to aid the investigator while investigating for human factors, particularly fatigue. Skilful [sic] questioning can help the investigator eliminate irrelevant lines of inquiry and focus on areas of greater potential significance.

The order in which the questions should be asked will depend on who is being interviewed and on his or her willingness and ability to describe personal behaviour and personal impressions. Also, it may be necessary to verify, cross-check or augment information received from one person by interviewing others on the same points.

These areas of inquiry can be used in training investigators as well as in planning interviews. The following questions are not intended as a checklist, and some may not be relevant in the investigation of a particular accident.

1 **Safety Policy**

.1 Does the company have a written safety policy?
.2 Is there a designated person for shipboard safety matters in the company?
.3 When did a company Representative last visit the vessel or when were you last in contact with the company?
.4 When were you last provided safety training? What was the training and how was it provided?
.5 When was the last emergency drill (e.g., fire, abandon ship, man-overboard, pollution response, etc) and what did you do during the drill?
.6 Was appropriate personal protective equipment provided and did you use it?
.7 Are you aware of any personal accidents which occurred on board in the period prior to the accident?

2 **Activities prior to incident**

.1 (If the ship was leaving port at the time of the accident) In general, how did you spend your time while the ship was in port?
.2 (If the ship was approaching port or at sea at the time of the accident) How long has the ship been on passage since its last port or terminal operation?

.3 What were you doing immediately prior to coming on watch or reporting for duty, and for how long? Recreational activity? Physical exercise? Sleeping? Reading? Watching T.V.? Eating? Paperwork? Travelling to vessel?
.4 Specifically what were you doing approximately 4 hours .... 1 hour .... 30 minutes .... before the accident?
.5 What evolution was the ship involved in when the accident occurred? What was your role during that evolution?
.6 Immediately prior to the accident, what were you thinking about?
.7 At any time before the accident, did you have any indication that anyone was tired or unable to perform their duty?

3 **Duties at the time of accident**

.1 Where were you on the ship when the accident occurred?
.2 What specific job or duty were you assigned at the time? By whom? Did you understand your assignment? Did you receive any conflicting orders?
.3 How often have you performed this job in the past (on the specific ship involved in the accident)?

4 **Actual behaviour at time of accident**

.1 Precisely where were you located at the time of the accident?
.2 What specific task were you performing at the time of the accident?
.3 Had you at any time since reporting for duty found that you could not concentrate (focus your attention/keep your mind) on a task you were trying to perform?

5 **Training/Education/Certification/Professional Experience**

.1 How long have you been assigned to this ship? Have you requested that your assignment be lengthened or shortened?
.2 How long have you filled your crew position? What other crew positions have you held on this ship?
.3 How long have you held the certificate indicating your qualifications?
.4 Before being assigned to this ship, did you work on other ships? If so, what crew positions have you held?
.5 What is the longest time you have been to sea in a single voyage? How long have you been at sea on this passage? What was your longest single passage?

6 **Physical condition**

.1 Were you feeling ill or sick at any time in the 24 hours immediately before the accident? If so, what symptoms did you have? Did you have a fever, vomit, feel dizzy, other? Also, did you tell anyone? What do you believe the cause was?
.2 When was the last meal you had prior [to] the accident? What did you eat? Was it adequate?
.3 Do you exercise regularly while onboard? When did you last exercise (before the accident)? How long was the session?

7 **Psychological, emotional, mental condition and employment conditions**

.1 When was the last time you felt cheerful or elated onboard the ship, and what were the circumstances that generated this emotion?
.2 When was the last time you were sad or depressed or dejected, on board the ship? Why? Did you talk about it with anyone else?
.3 Have you had to make any difficult personal decisions recently? Have you had any financial or family worries on your mind recently?
.4 Have you been criticized for how you are doing your work lately? By whom? Was it justified?
.5 What was the most stressful situation you had to deal with on the voyage (prior to the accident)? When did the situation occur? How was it resolved?
.6 What are the contractual arrangements for all crewmembers?
.7 Have there been any complaints or industrial action in the last (12) months?

8 **Workload/Complexity of Tasks**

.1 What is the shipboard organization?
.2 Is the shipboard organization effective?
.3 What is your position in the shipboard organization (i.e., who do you work for, report to or assign duties to)?
.4 What is the nature of your work? Sedentary? Physically demanding?
.5 Was anyone involved in the accident impaired due to heavy workload?

9 **Work-period/rest-period/recreation pattern**

.1 What is your normal duty schedule?
.2 Are you a day worker or a watchstander?
.3 What was your duty schedule on the day before the accident and during the week before the accident?
.4 Were you on overtime at the time of the accident?
.5 How long had you been on duty, or awake performing other work, at the time of the accident?
.6 When was your lat period of sleep? How long did it last? How often did you awaken during your last sleep period? Did you awaken refreshed? If not, what would have made your sleep period more restful?
.7 How do you normally spend your off-duty time while on board? Play cars? Read? Listen to music? Watch T.V.? Other?
.8 When was your last extended period of off duty time when you were able to rest?

10 **Relationship with other crewmembers and superiors/subordinates**

.1 Who among the crew would you consider to be a friend?
.2 Do you find any members of the crew unpleasant to be with?
.3 Do you have difficulty talking with any of the crewmembers because of language barriers?
.4 Have any new crewmembers recently joined the ship? Have you had a chance to get acquainted with them?
.5 Did you have any argument recently with another crewmember?
.6 In an emergency, would you trust your fellow crewmembers to come to your assistance?

.7 Has another crewmember ever offered to take your place on watch or perform a duty for you to let you get some extra rest?
.8 What was the subject of your last conversation with another crewmember before reporting for duty (when the accident occurred)?
.9 Have you talked with any other crewmembers since the accident? If so, what was the subject of your conversation? Have you talked with anyone else about the accident prior to being interviewed?

11 **Living conditions and shipboard environment**

.1 Do you consider your personal area on board the ship to be comfortable? If not, how would you like it to [be] improved?
.2 Prior to the accident, did you have any difficulty resting as a result of sever weather, noise levels, heat/cold, ship's motion, etc.?

12 **Manning levels**

.1 Is the manning level sufficient in your opinion for the operation of the vessel?

13 **Master's standing orders**

.1 Are there written standing orders to the whole crew complement from the Master?
.2 Did the Master/Chief Engineer provide written or verbal standing orders to the watchkeeping personnel?
.3 Were the orders in conflict with the company safety policy?

14 **Level of automation/reliability of equipment**

.1 In your opinion, was the system reliable?
.2 Were there earlier failures in the system?
.3 Were the failures repaired by the crew or shore-based workers?

15 **Ship design, motion/cargo characteristics**

.1 Did you observe anything out of the ordinary on this passage concerning the ship design, or motion or cargo characteristics?

Questions 16-24 [25] are EXAMPLES OF QUESTIONS THAT MAY BE DIRECTED TO SHORESIDE MANAGEMENT

16 **Scheduling of work and rest periods**

.1 What is the company's work schedule and relief policy?

17 **Manning level**

.1 How is the manning level determined for your fleet?

18 **Watchkeeping practices**

.1 Do you require the Master to stand watch?

.2 Do you leave the watchkeeping practices to the discretion of the Master?

19 **Assignment of duties**

.1 Do you leave this matter to the Master?

20 **Shore-ship-shore support and communications**

.1 How do you support the vessel's Master?

21 **Management policies**

.1 Does the company have a written safety policy?

22 **Voyage planning and port call schedules**

.1 How does the Master plan the voyages?

23 **Recreational facilities**

.1 Are welfare/recreational services and facilities provided on board?

24 **Contractual and/or industrial arrangements and agreements**

.1 What are the contractual agreements for all crewmembers?
.2 Have there been any complaints or industrial action in the last (12) months?

25 **National/international requirements**

.1 Are the management/Master complying with the requirements and recommendations of the applicable international conventions and Flag State regulations?

Appendix I. Norwegian Petroleum Directorate Near-Miss System

In 2000, Norway instituted a near-miss database to assess risk levels in the continental shelf offshore industry. The database contains reports on major hazards, occupational injuries, occupational disease, cultural risk factors, and perceived risks. The focus is on preventing risk to personnel on offshore facilities, such as production installations, mobile drilling units, and flotels. A report, "Trends in Risk Levels on the Norwegian Continental Shelf," gives an overview of the near-miss system and findings to date. The report can be found on the Norwegian Petroleum Directorate (NPD) web site (http://www.npd.no ; click on the British flag for English, then go to the Health, Environment & Safety (HSE) page). This appendix gives a brief presentation of the near-miss system and a couple examples of the data, courtesy of Professor Jan Erik Vinnem.

The near-miss database is limited to incidents that may have the potential to cause major accidents, if multiple barrier failures occur. Some other incidents that are essential for emergency preparedness planning are also covered. The operators on the Norwegian Continental Shelf have a duty (enforced by NPD through regulations) to notify NPD about injuries, accidents and near-misses within a short time after the occurrence of these events. (For the most serious incidents, further investigation reports will be required for submission.) The cut-off limits for which incidents to report are somewhat loosely defined, and there are significant differences between the companies, with respect to reporting practices. The database is based on a subset of these mandatory reports, and includes those which have been extensively reviewed and verified to ensure consistency and which have established exposure data (activity levels).

The NPD classifies major hazards into eleven types (or DFUs), shown below. Each DFU presents a specific, potentially-serious hazardous situation.

DFU	Event Scenario
1	Unignited hydrocarbon leak
2	Ignited hydrocarbon leak
3	Kick/loss of well control
4	Fire/explosion, excluding DFU#2
5	Vessel on collision course
6	Drifting object/vessel on collision course
7	collision with field related traffic
8	Structural damage
9	Leak from subsea installation
10	Damage to subsea installation
11	Evacuation (precautionary/emergency)

Although the near-miss database was not formally brought on-line until 2000, the NPD had incident data from several prior years. The NPD has analyzed yearly incident data in terms of the DFUs, as shown in the trend analysis presented in Figure I-1 (see Sec. 6.3 for information on trend analysis). It is clear from the figure that unignited hydrocarbon leaks are a primary source of potential accidents. These data have been further analyzed by size of leak in Figure I-2. The NPD system demonstrates how near-miss data can be used to identify potential hazardous situations so that the industry can seek safety solutions before a significant accident results.

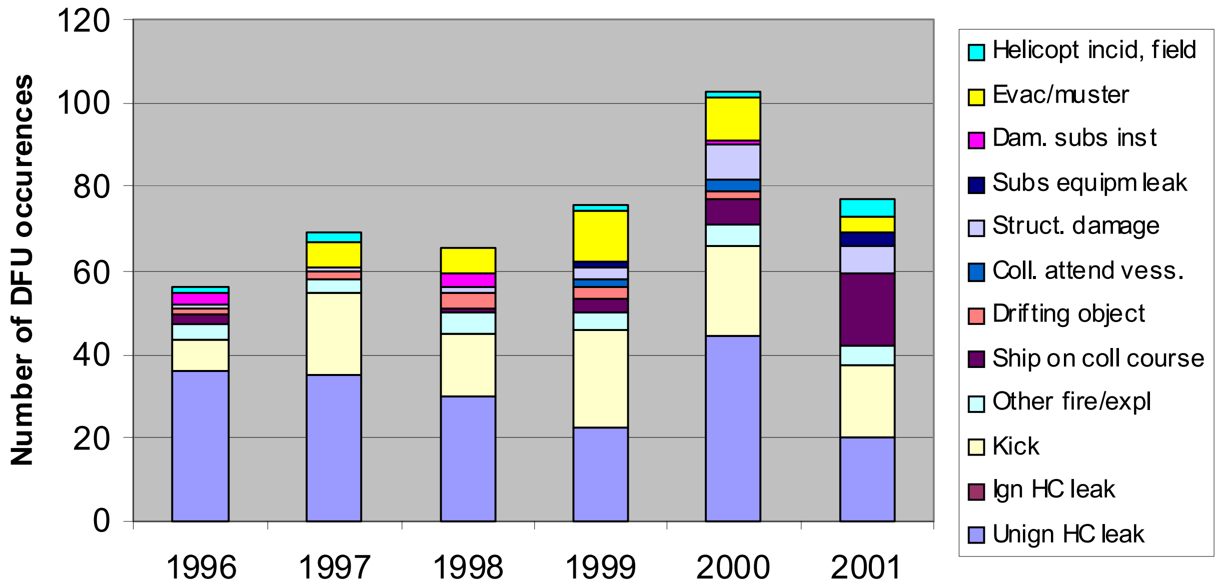


Figure I-1. Norwegian Petroleum Directorate Near-Miss Data. Six years of incident data for all major hazard DFUs, representing near-misses at all continental shelf offshore installations.

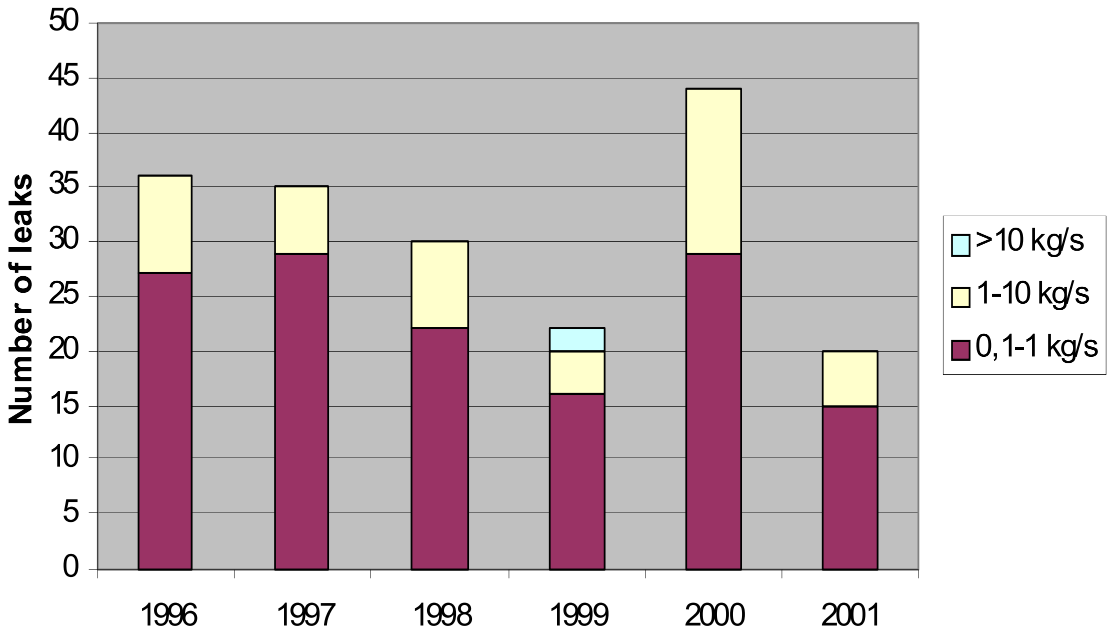


Figure I-2. NPD Data on Unignited Hydrocarbon Leaks. Data are segmented by size of the leak.