KEYS TO SUCCESSFUL INCIDENT INQUIRY[1]

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ABSTRACT

Studies of offshore and maritime incidents (accidents and near-misses) show that the vast majority involve human error(s). 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 what human error is and how it is generally symptomatic of technological, environmental, and organizational factors which are incompatible with optimal human performance. Steps are provided for building a successful human factors incident investigation and analysis program.

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*[2] (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-

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[1] This paper is excerpted from Rothblum, AM, Wheal, D, Withington, S, Shappell, SA, Wiegmann, DA, Boehm, W, and Chaderjian, M. (2002) Human Factors in Incident Investigation and Analysis, prepared for the 2nd International Workshop on Human Factors in Offshore Operations (HFW2002), held in Houston, TX, April 8-10, 2002.

[2] 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).

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 helps us learn how to develop early-warning systems to detect when conditions have become "non-normal" and also shows us what steps were taken that *avoided the accident.*

Incident[3] 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.

Many offshore and maritime companies already have an incident investigation program in place. However, most of these programs fall short 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, in fact, these operator errors account for only a small percentage of the human factors causes of incidents. 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 failing to "drill down" to identify the underlying, organizational causes of that mistake, will not help to prevent reoccurrences of the incident. Because most maritime and 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.

This paper will provide a discussion of how human error contributes to incidents, how to build a successful incident investigation program, and some of the types of human errors most important to the maritime industry. More information, including specific tools for the collection and analysis of incident data and how to use incident investigation results to improve the company's safety program, can be found in Rothblum, Wheal, Withington, Shappell, Wiegmann, Boehm, and Chaderjian (2002). When a focus on human error is incorporated into your existing incident investigation, analysis, and intervention program, 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.

[3] 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).

2.0 HUMAN ERROR

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(s) 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. Incidents 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 incidents happen, it is usually possible to trace the development of an incident 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.

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 improper action, or an improper lack of action (inaction). Probably a better way to explain human error is to provide an example from a real marine casualty: the grounding of the *TORREY CANYON* (Perrow, 1984). This accident occurred during a daylight transit of the English Channel in clear, calm weather.

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

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[5]. 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 this example shows, 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.

[5] This accident occurred years before the *EXXON VALDEZ* catastrophe 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.

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

As was stated earlier, the maritime system is a *people* system (Fig. 1). 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.

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. 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.

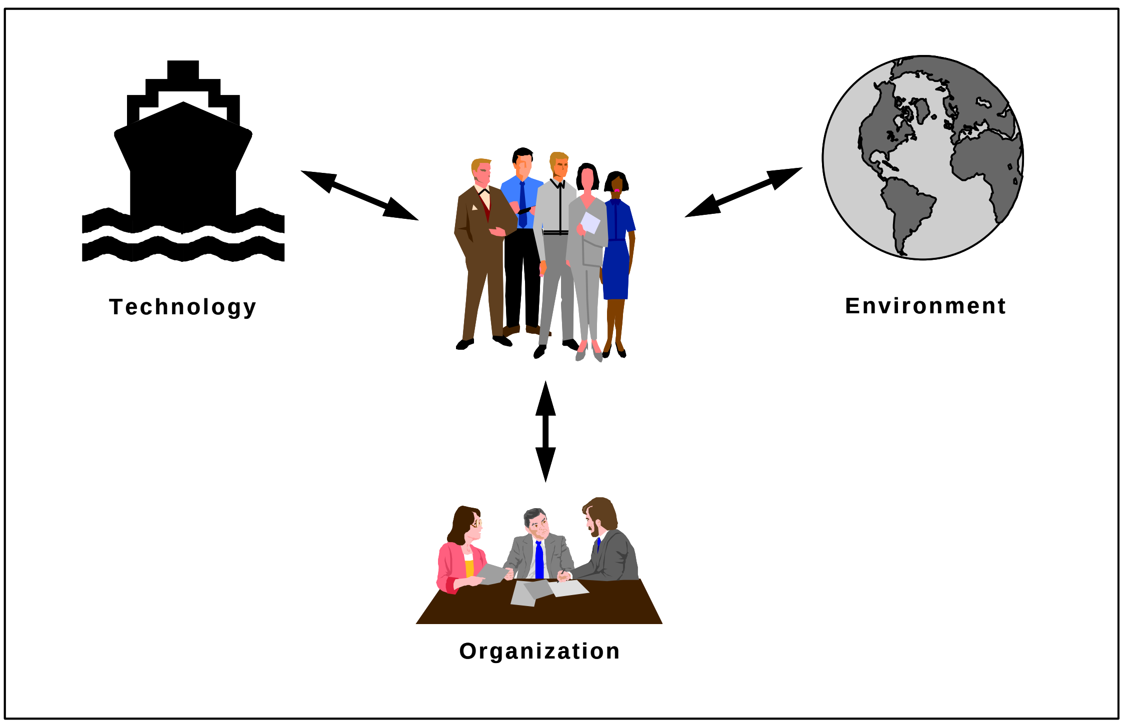

Figure 1. A Human-System Model of Maritime Operations

The design of technology can have a big impact on how people perform. 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.

The environment affects performance, too. By "environment" we are including not only weather and other aspects of the physical work environment (such as lighting, noise, vibration, 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. 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.

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. Including human factors in the incident investigation program can identify the underlying causes of human error. Proper identification of the true contributors to incidents allows a company to establish workable preventive measures.

3.0 BUILDING A HUMAN FACTORS INCIDENT INVESTIGATION PROGRAM

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 further 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.

3.1 How an Incident Evolves

As mentioned earlier, there are usually multiple causes of an incident, with multiple people and events contributing to its evolution. 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] (Fig. 2). 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

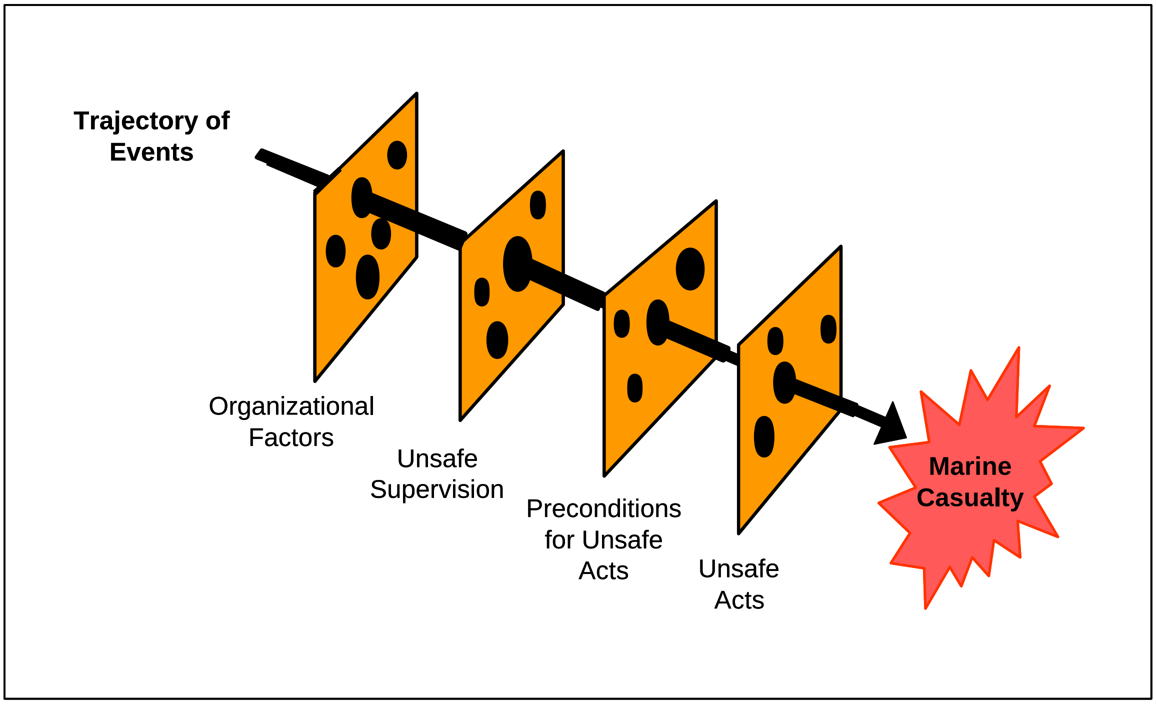

Figure 2. An Accident in the Making
(after Reason, 1990, as adapted by Wiegmann & Shappell, 1999)

[6] Reason's work underscores the fact that "human errors" and "human factors" relate to the *entire system*, not just to an individual operator.

makes. 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 ("Preconditions") 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.

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.
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.

3.2 Investigating for Human Factors Causes

When an incident occurs, the investigator starts with the immediate actions and events surrounding the incident and works backward 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.

Using a tool, such as Events and Causal Factors Charting, can be helpful to represent the factors which led to the incident. For each causal factor, it is necessary to continue asking *why* to uncover the locus of the errors, using the Human-System Model to examine interactions between the people, technology, environment, and organization. Once the specific errors have been identified, it is then useful to use Reason's model[7] to identify the level of the organization (management, line supervisor, or worker) which needs to take action to prevent reoccurrences of these errors. (See Rothblum, et al., 2002 for details.)

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[7] The Human Factors Analysis and Classification System (HFACS; Wiegmann and Shappell, 1999; Rothblum, et al., 2002) is a helpful investigation tool based on Reason's model.

3.3 Keys to a Successful Human Factors Incident Investigation Program

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).

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 above, most incidents are not the "fault" of a given person; rather, they are indicative of deficiencies within the system. 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.

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 injuries 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.). 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. 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.

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. 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.

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. 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).

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. 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.

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.

4.0 IMPROVING SAFETY THROUGH INCIDENT INVESTIGATION AND ANALYSIS

Maritime and offshore operations are inherently risky. Companies 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. 3 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.

4.1 Components of an Incident Investigation and Analysis Program

An incident investigation program consists of five components (Fig. 3). 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. Analysis allows the company to find patterns

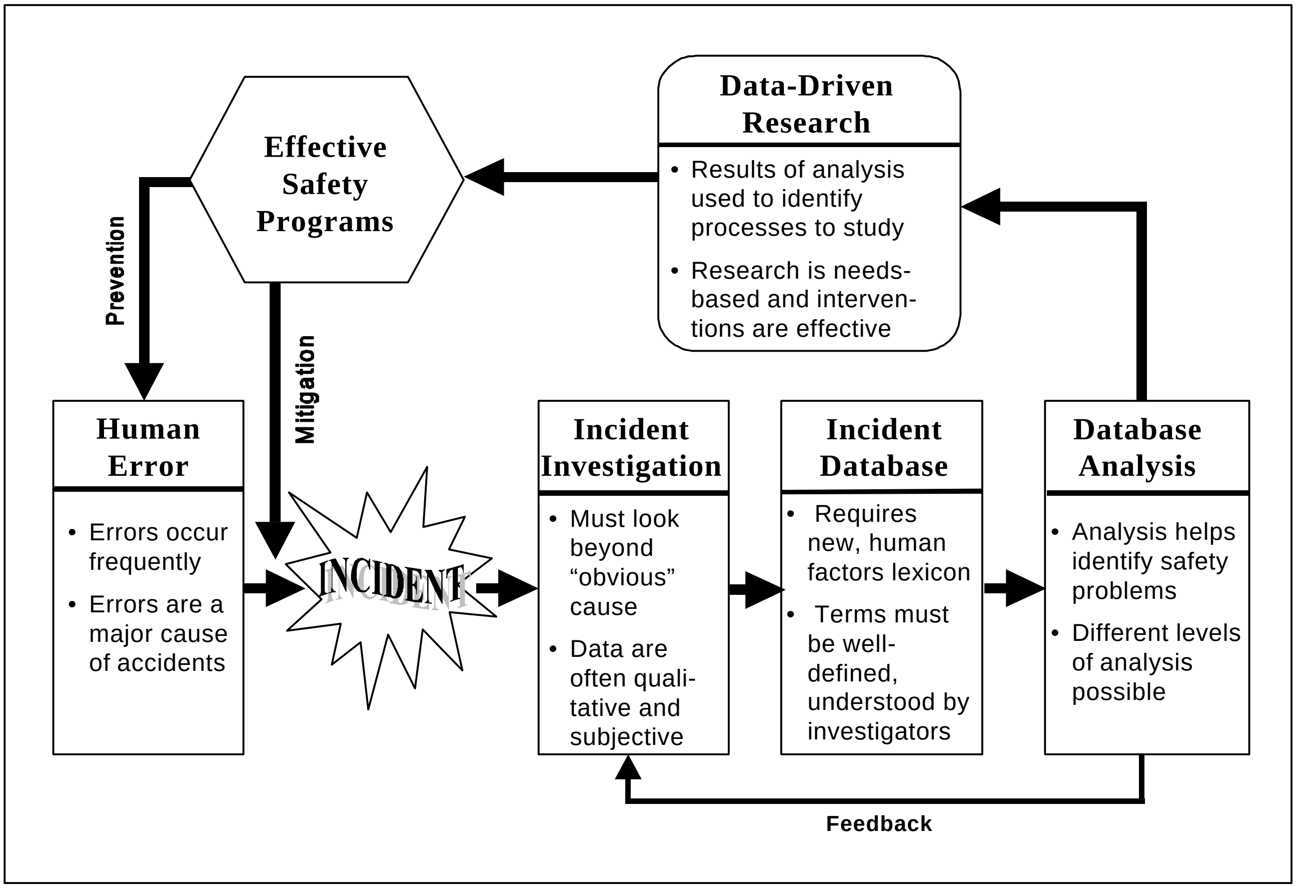

Figure 3. How An Effective Human Factors Incident Investigation Program Can Improve Safety
(Modified from Wiegmann and Shappell, 1999)

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. (For a discussion of data analysis techniques, see Rothblum, et al., 2002.)

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 incident data which has identified underlying causes, it will be effective.

4.2 Human Factors Issues in the Maritime Industry

What types of human errors will be found to underlie your company's incidents? They will likely include some of the human factors challenges that face the maritime industry as a whole. Below is a list of the "top ten" human factors areas that need to be improved in order to prevent marine casualties (U.S. Coast Guard, 1995).

- *Fatigue* – contributes to 16% of the vessel casualties and to 33% of injuries (McCallum, Raby, & Rothblum, 1996).
- *Inadequate Communications* – between shipmates, between masters and pilots, ship-to-ship, and ship-to-VTS.
- *Inadequate General Technical Knowledge* – with respect to 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.
- *Inadequate Knowledge of Own Ship Systems* – crews and pilots are constantly working on ships of different sizes, with different equipment, and carrying different cargoes.
- *Poor Design of 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.
- *Decisions Based on Inadequate Information* – too often mariners rely on either a favored piece of equipment or their memory, and fail to consult available information.

- *Poor Judgement* – risky decisions can lead to accidents.
- *Faulty Standards, Policies, or Practices* – the lack of available, precise, written, and comprehensible operational procedures aboard ship and management policies which encourage risk-taking (like pressure to meet schedules at all costs).
- *Poor Maintenance* – can result in a dangerous work environment, lack of working backup systems, and crew fatigue from the need to make emergency repairs.
- *Hazardous Natural Environment* – 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.

5.0 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 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.

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 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.*

Incident investigation that includes an analysis of human error is needed if we are to prevent these incidents in the future. This conference paper has briefly mentioned some of the concepts important to successful incident inquiry. The interested reader may find Rothblum, et al. (2002) a useful resource: it contains detailed discussions of topics in investigation and analysis, plus it presents tools than can be used to identify human error causes and recommend workable safety interventions.

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, and top-down, human-centered interventions. Indeed, maritime and offshore industries can do the same. 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.

6.0 REFERENCES

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