Human Error and Marine Systems: Current Trends

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Abstract

In the past fifteen years, the maritime industry has suffered from incidents and accidents that have either stemmed directly or indirectly from human error. Some of these, such as the Exxon Valdez, grabbed the world's attention. Others, such as the Sea Empress, raised barely a ripple of public interest. What these events have consistently done, however, is elevate the awareness of issues related to mariner fatigue, human error, and human performance to maritime safety groups. International groups such as the International Maritime Organization (IMO) have put forth new guidance and law, according to international treaty, to address human error. Flag State safety and enforcement agencies (such as national coast guards) have implemented new laws and voluntary programs for their territorial waters. Port States controls have been aimed at identifying potentially high-risk or troublesome vessels. Classification Societies are generating new rules and guidance directed squarely at controlling the factors that influence and induce human error. Ship owners and operators are embracing this new guidance. This paper addresses the issues of human error in the marine industry by presenting an overview of one of the principal factors, crewmember fatigue, which affects or induces errors. The paper also discusses recent trends and initiatives by maritime safety organizations to control those factors in order to reduce the incidence of human error. The paper closes with a short summary of what these initiatives may mean to maritime safety.

Human Performance and Fatigue

It is well established that presence of fatigue greatly influences human performance in any situation. In fact, physiological definitions of fatigue invoke the notion of decreased capacity as a central part of the definition. Recent reports by the International Maritime Organization (IMO) have publicized the fact that crewmember fatigue is increasingly being recognized as a major factor in maritime accidents (MSC/Circ.565).

Crewmember fatigue jeopardizes ship, passenger, and crew safety when it leads to human error. Evidence for the role that human error plays in maritime accidents has been provided by recent submissions to IMO (MSC 71/INF.8, MSC 69/INF.16, MSC 68/INF.15, and MSC 69/INF.15).

With the recognition by the international maritime community that crewmember fatigue can greatly affect ship safety at sea and in port, numerous studies and initiatives have been undertaken to better define the causes and effects of fatigue. In a recent submission to the IMO (MSC 74/15, 2001), Guidelines on Fatigue provided practical information to assist the marine industry in understanding and managing fatigue. Within these guidelines, the potential causes of fatigue were categorized as follows:

- Crew-specific
- Ship-specific
- Physical Environment
- Management

Recognition of categories of causes of fatigue is important because too often it is supposed that individual crewmembers are responsible for their fatigue through poor lifestyle management or personnel habits. Contributing to this limited view was the belief that strong will and stronger coffee would prevail over fatigue. Through the work of many different segments of the maritime industry, the variety of factors which impact crewmember fatigue and its effects on human performance are becoming better recognized.
Crew-Specific Fatigue Factors

In a maritime environment, the symptoms relating to crew-specific fatigue factors have long been recognized. It has also been noted that such symptoms can be a major source of impaired human performance and reliability. Specific symptoms or impairments seen in individuals that can arise due to fatigue, and that can be easily related to human error, are summarized below.

<table>
<thead>
<tr>
<th>Possible Fatigue Symptoms or Impairments</th>
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<tr>
<td>• Feeling tired, muscular weakness</td>
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<td>• Significantly reduced short term memory</td>
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<tr>
<td>• Reduced manual dexterity</td>
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<tr>
<td>• Difficulty recalling information or making decisions</td>
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<tr>
<td>• Increased risk taking behavior</td>
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<td>• Mood swings and changes</td>
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<tr>
<td>• In extreme cases, anxiety, perceptual narrowing, slurred speech, obsession with sleep, hallucination, and incidence of microsleep (microsleep is a period of sleep-like unconsciousness, lasting usually few seconds, without the knowledge or intent of the sufferer).</td>
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The conditions and environment of the sea, in concert with the requirements of the mariner's job, can lead to debilitating fatigue. It is therefore imperative that control be exercised over the accrual of fatigue. Causes of fatigue are many and varied, but generally include combinations of the following.

Conditions of Sleep. Of importance here are the following three conditions:

- **Ability to mass sleep** for a period of at least eight hours. Distributed sleep (for example, four sleep periods of two hours each in a day, summing to eight hours) is not as effective in recovery from fatigue compared to a massed eight hours of sleep.

- **Sleep comfort** of a sort that permits the sleeper to reach deep levels of sleep. Important factors include: light conditions, noise levels, thermal conditions, quality of sleep surfaces, vibration and shock, and air quality.

- **Amount of daily sleep.** Chronic fatigue can be induced over long periods of time by limiting daily sleep periods. When this is the case (for example, allowing only six hours of sleep per day for an individual accustomed to eight), sleep debt accrues, and so does fatigue.

Biological Clocks/Circadian Rhythms. Related to conditions of sleep is the timing of sleep according to endogenous (internal) biological "clocks". Simply put, human sleep-wake cycles, or Circadian Rhythms, generally occur in a reliable, consistent cycle over a 24-hour period. Two consistent factors of circadian rhythms are (1) sleep periods will occur during approximately the same hours of each day and (2) sleep duration for each of these periods is about the same over each 24-hour interval. When these cycles are disrupted (know as circadian de-synchronization), sleep disturbance generally results. These disruptions are usually in the form of the inability to fall to sleep, diminished depth of sleep, and incidents of spontaneous waking (waking from sleep at unplanned times associated with difficulty or inability to regain sleep). Any of these can result in the accrual of sleep debt, waking disturbances, and in the incidence of fatigue. Mariners generally work on a rotating shift basis, and so the presence of circadian de-synchronization, and its consequences, are often the norm.

Workload and Work Duration. These factors concern the physical requirements of the job, in terms of:

- Cognitive and physical energy expended during task performance and over time

- Provision of brief rest periods during the work day

- Length of the workday.
Obviously, demand for high human work output, with few recovery periods, over long workdays will induce fatigue. At-sea, work requirements can be high, and work duration is often around 12-hours per day, seven days a week. In addition, the 12-hours of work are not always continuous. Schedules may be based on rotations of 4-hours on/8-hours off; 6-hours on/6-hours off; or 12-hours on/12-hours off. With the shorter cycles, it is not possible for the mariner to experience the prolonged, uninterrupted period of sleep that is necessary to support high-levels of human performance or to reduce accumulated fatigue.

Crewmember-specific factors. In addition to the factors mentioned above, individual variables effect the susceptibility to the incidence of, and recovery from, fatigue. Among these are personal health status, age, fitness, diet, and substance abuse including beverage/drug consumption. In order to make both the individual crewmember and the industry aware of the impact of these variables, numerous studies, guidelines, and standards have been published by organizations such as the Australian Maritime Safety Authority, Association of Diving Contractors, the United States Coast Guard, and the IMO. The information in these documents can be used not only to inform the industry, but it can also be used to educate mariners, ship owners, and ship operators of steps that can be taken to lessen the likelihood or impact of fatigue.

Ship-Specific Fatigue Factors

Another set of factors which can effect human performance and fatigue is the design of the ship itself. Two of the more influential ship design factors for enhancing human performance and reducing human errors are (1) usable human-machine interfaces and (2) the provision of accommodations that promote reliable human performance.

The quality of design of the spaces where mariners work and rest significantly influences their job performance and fitness for duty. By providing working and living spaces where human factors/ergonomics principles are applied, shipboard conditions can be created that control or avoid fatigue, enhance human performance, and improve mariner's overall health, safety, and welfare. Suitable interface and accommodations design will have the effect of reducing the incidence and severity of human errors afloat. Two major ship-specific factors that can affect human performance and human error in maritime environments are presented below. These are (1) Ergonomics in Design, and (2) Habitability.

Ergonomics in Design. "Ergonomics produces and integrates knowledge from the human sciences to match jobs, systems, products, and environments to the physical and mental abilities and limitations of people. In doing so, it seeks to improve health, safety, well-being, and performance."(ISO/TC 159/SC 1/WG 1, 1997). From this definition, it is clear that ergonomics principles when applied to ships can result in equipment, systems, and overall designs that will support reliable human performance. The ergonomic design of ships, marine structures, and equipment is addressed in numerous handbooks, textbooks, guides, and standards. Such documents include military standards and guidelines, industry documents, national and international standards, and general texts. These specify the design processes and criteria for achieving at-sea control space designs that are ergonomically compatible with humans. The bulk of these present a full array of design guidance for designers of maritime vessels, including design related to:

<table>
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<th>Ergonomics Design Issues</th>
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<tr>
<td>• ambient environment (vibration, noise, etc.)</td>
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<tr>
<td>• computer software interfaces</td>
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<tr>
<td>• equipment design</td>
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<tr>
<td>• written procedures and operations documents</td>
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<tr>
<td>• safety</td>
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<tr>
<td>• training systems</td>
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<tr>
<td>• console profiles, dimensions, and orientations</td>
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<tr>
<td>• maintenance interfaces</td>
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<tr>
<td>• habitability spaces</td>
</tr>
<tr>
<td>• job performance aids (e.g., labels and markings)</td>
</tr>
<tr>
<td>• space layout</td>
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<tr>
<td>• hardware interfaces</td>
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There are also dozens of general-purpose textbooks on ergonomics. These present the philosophies and underpinnings of ergonomics, as well as the science behind it and generalized approaches and processes used to infuse ergonomic data and principles into system design. Some of the recent and more salient documents to maritime control space design are:

- IMO's Guidelines on Ergonomic Criteria for Bridge Equipment and Layout (MSC 73/Circ 982)
- IMO's Navigational Bridge Visibility and Functions (IMO Res.A.708-(17))
- Ship's Bridge Layout and Associated Equipment – Requirements and Guidelines (BS EN ISO 8468)
- IMO's Role of the Human Element in Maritime Casualties - Engine Room Design and Arrangements. (IMO DE 38/20/1)
- IMO's Guidelines for Engine Room Layout, Design and Arrangement (MSC 68/Circ 834)
- IMO's Role of the Human Element in Maritime Casualties - Guidelines for the On Board Application of Computers (IMO DE 38/20/2)
- ABS Guide for Crew Habitability on Ships (2001)

In addition to those documents listed above, in 1998, ABS published the ABS Guidance Notes on the Application of Ergonomics to Marine Systems in order to provide the marine and offshore industries with an easy-to-use general ergonomics design reference. The Guidance Notes were (and are) well-received and many organizations have adopted the Guidance Notes as a design reference. One of the reasons for the wide acceptance was the inclusion of industry-specific ergonomics criteria that could be applied to international populations of mariners. It was intended that by providing detailed direction for the design of human - machine interfaces for an international population, ABS's clients, and industry in general, could use the publication to reduce the likelihood of human error and to reduce the incidence of fatigue. When the Guidance Notes are used in concert with human factors engineering design processes, designs can be achieved that promote better shipboard working and living conditions.

Whether using the ABS Guidance Notes or other ergonomics design resources, ships and their interfaces can be designed in such a way as to improve overall system performance, human productivity, and reliability, and reduce rates of human error. The authors believe that one key to creating well-designed interfaces and workplaces is the application of ergonomics criteria. The result can be work environments that support the mariner with the efficient execution of shipboard tasks, thus reducing job-related stresses and fatigue.

Habitability. Habitability is another ship-specific factor that affects the mariner. Habitability can be defined as the acceptability of a ship as determined by its physical accommodations (design and provision of rest facilities, food services, etc.), as well as by the conditions of the ambient environment (e.g., vibration, noise, thermal, and lighting levels). As stated earlier, the inherent habitability (or "comfort") of a vessel can have direct and significant effects on crew in terms of quality of sleep, speed of onset, and severity of fatigue, and human performance and error. The importance of providing acceptable accommodations was recognized as long ago as the 1940's when the International Labor Organization published both the Food and Catering (Ships Crews) Convention and the revised version of Accommodation of Crews Convention, also known as Convention 68 and Convention 92, respectively.

It is evident that the spaces where a ship's crew work, sleep, dine, and rest will affect their overall safety, health, and sense of well-being. With the passage of time, additional factors outside those specified in ILO Conventions have been recognized as critical to providing sufficient accommodations. However, the information about these factors is distributed among a large number of standards, specifications, and guidelines. Recognizing the potential difficulty in obtaining all relevant information for accommodations design, ABS produced the first comprehensive guide for crew habitability on ships.

The ABS Guide to Crew Habitability on Ships (2001) provides criteria and assessment methodology relating to two major aspects of ship design: accommodations and ambient environment. Accommodations includes all areas on the ship where the crew normally work, eat, sleep, and relax. The way these spaces are designed will influence a mariner's work performance and ability to rest. The overriding design considerations
from the mariner’s perspective are personal comfort and privacy. The ship owner or operator should be concerned with providing accommodations that promote enhanced levels of physical and mental fitness, including alertness. Topics relevant to accommodations design, and that were included in the ABS Guide are:

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<td>Access/Egress</td>
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<td>Sanitary Spaces</td>
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<td>Berthing</td>
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<td>Offices and workstations</td>
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<td>Recreational</td>
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<td>Medical</td>
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Applying accommodations design criteria, based on ergonomics, to a ship will facilitate reliable human performance by reducing the potential for fatigue-related ship design factors. Accommodations can be created that enhance rest, morale, crew retention, and comfort.

**Physical Environment Fatigue Factors**

As mentioned previously, the term “habitability” includes factors related to the ambient environment. The conditions of the ambient environment effect fatigue in several important ways. *First*, working in unfavorable environments facilitates the onset and magnitude of fatigue. Factors such as high or low temperature and high noise and vibration require the human body to use resources to counter those conditions, and resources used to counter the environment are not available to perform the productive work required of the human (until after a rest period). *Second*, slow oscillations of the human body and workspace (for example, ship motions) consume energy resources. These motions present complex, multidirectional g-forces that the human must constantly overcome, and that therefore consume muscular resources. *A third* manner in which the environment effects fatigue is to influence quality of sleep. Extreme conditions can result in lowering of depth and length of sleep thus inhibiting recovery from fatigue.

Many documents exist that provide criteria with regard to the ambient environment aboard ships. Some of the documents are aimed at avoiding extremes (hearing conservation standards) while others provide criteria for optimizing comfort. Within the ABS *Guide to Crew Habitability on Ships*, habitability criteria and measurement methodologies are presented for optimizing conditions of the ambient working and living environment. Relevant information for vibration, noise, indoor climate, and lighting are given in order to allow fatigue-related factors of the physical environment to be controlled.

**Management Fatigue Factors**

The last category of factors discussed in this paper that are recognized to influence mariner fatigue are management policy and practice. These factors range from top-level organizational goals to management decisions relating to vessel operations, schedules, and voyages. The IMO recognized that the way a ship is managed not only affects personnel on board, but also affects the health, safety, and environment of people outside the ship. In order to ensure that shipping owners and operators examine the potential impact of their corporate actions, the IMO passed the International Safety Management Code.

**IMO and the International Safety Management Code.** International Maritime Organization’s International Code, *International Management for Safe Operation of Ships and for Pollution Prevention* (the “ISM Code”) was adopted in November 1993. The ISM Code initially required (Phase I) most ship operators to have a certified safety management system in place by July 1, 1998. The purpose of the Code was to ensure safety-at-sea; prevent human injury or loss of life, and avoid damage to the environment and to property. It also requires companies to establish *specific* safety objectives, based on their sphere of operations, and this includes objectives related to crew fitness-for-duty (which incorporated fatigue factors) and control of human error. Phase II of the ISM Code becomes mandatory on the first of July, 2002 and is be applicable to all vessels above 500 gross tons which were not covered under Phase I.

A safety management system prescribes the management procedures whereby safety and pollution prevention aspects of a ship or offshore structure are managed. It will also set forth policy and practice relating to factors that will directly or indirectly affect crewmembers, their roles and responsibilities, work
hours, reporting schemes, paperwork requirements, etc. The responsible parties are required to provide the resources and support needed to implement and maintain the safety management system. The Code also requires certification of compliance with the requirements of the ISM Code and the safety management system.

**IMO and STCW.** Another area that relates to ship management concerns personnel issues. In 1995, the IMO updated international Standards for Training, Certification, and Watchstanding (STCW) Convention. These agreements (quickly incorporated into many individual Port State systems of law) have been put forth establishing requirements for mariner readiness. Some of the more important provisions of the 1995 amendment include:

- Requires certification of masters, officers, and ratings only when they meet the requirements for service, age, medical fitness, training, qualification, and passing examinations.
- Requires special training for certain types of ships (tankers, Ro-Ro, and passenger ships).
- Requires Flag States establish and enforce rest periods for watchkeeping personnel. Watchstanding personnel must be provided a minimum of ten hours of rest for every 24-hour period (the ten hours may be divided into two periods, but one must be of at least six uninterrupted hours).
- Requires that watch systems be arranged so that watchkeeping personnel are not impaired by fatigue
- Requires instructors and assessors be qualified for the types of training or assessment of competence of seafarers. Those involved in training and/or assessment must be qualified in the task for which the training/assessment is being conducted.

STCW is another initiative of the marine industry that can impact the daily life of crewmembers. Through STCW limits are set for number of hours worked and minimum rest periods for watch-keepers. Other international conventions (such as ILO 180, *Convention concerning seafarers’ hours of work and the manning of ships*, 1996), set limits relating to non-watch-keepers work hours. Both of these regulations are relevant to managing fatigue.

**Other Management Factors.** Other management practices and policies beyond ISM, STCW, and ILO can affect the potential for crewmember fatigue. The IMO’s Guidelines on Fatigue (2001) suggests that ship owners and operators develop fatigue management policies and systems. It is also suggested that practices such as the following be examined as means to counter fatigue:

- scheduling of voyages
- staffing policies
- paperwork requirements
- schedules
- provisions for leave
- communications with families during voyages
- on-board recreation.

These factors, together with those specified in the international regulations, will positively or negatively influence crewmember fatigue and marine safety.

**Summary**

When considering the condition of the mariner, it is apparent that the job can induce fatigue: work hours are long, physical and cognitive demands are high, the physical environment can be challenging, and sleep intervals may be short and de-synchronized. While this is not a new or startling revelation, the recent trend of governments and maritime industries to recognize these problems, and to begin to redress them, is relatively new.

It is further recognized by the maritime industry that human errors, sometimes brought about by crew member fatigue, are a contributing cause to most accidents. It is believed that by controlling fatigue-related factors, benefit can be brought to the mariner, the ship owner/operator, the marine industry, and to society. It should not be forgotten that it is the mariner that often stands as the final link between success and disaster. In a recent address, William O’Neil, Secretary General of IMO (2001), emphasized this point by stating:
On a ship, the human element can provide a weather eye for difficulties ahead, a calm, unruffled response to situations as they develop and those indefinable qualities known as good seamanship: or it can be frail, lacking in competence, ability and concentration. People remain a basic component with all their strengths and weaknesses which can both cause a disaster or prevent it. Our task as members of the Marine Industry is to sort out the issues and to build on the strengths and correct the weaknesses.

The experience of many industries, including the maritime industry, shows that human performance can result in safe and reliable operations. With the combined activities of organizations such as the IMO, Flag States, Port Authorities, and Class societies, the challenges of the job on the mariner are being acknowledged, and a trend towards working together to overcome difficulties is shown. This, united with the continued professionalism of mariner, will result in a far safer marine environment.

References


