7

Human Error in Shipping

7.1 Introduction

Humans have relied on oceans, lakes , and rivers to ship goods from one end to another throughout the recorded history. Today, over 90% of the world's cargo is transported by merchant ships due to various reasons, including that it is the cheapest form of transportation. In fact, from the early 1920s through the end of the century, the total number of merchant ships in the world increased from under 30,000 to about 90,000 [1, 2]. Also, today a large number of ships are being used for various military purposes throughout the world.

A modern ship is comprised of many elements (systems), each of which has a varying degree of effect on the overall performance of that ship. Although many of these systems may be fully automated, they still require a degree of human intervention (*e.g.*, set initial tolerances or respond to alarms). Also, the nonautomated systems may require direct human inputs for their operation and maintenance, humans to interact with other humans, *etc.* Needless to say, as humans are not one hundred percent reliable, the past experiences indicate that in the shipping industry around 80% of all accidents are rooted in human error [3].

This chapter presents various important aspects of human error in shipping.

7.2 Facts, Figures, and Examples

Some of the facts, figures, and examples directly or indirectly related to human error in shipping are as follows:

- Human error costs the maritime industry $541 million per year, as per the findings of the United Kingdom Protection and Indemnity (UK P&I) Club [4].
- A study of 6091 major accident claims (*i.e.*, over $100,000) associated with all classes of commercial ships, conducted over a period of 15 years by the UK P & I Club, revealed that 62% of the claims were attributable to human error [4–6].
- Human error contributes to 84–88% of tanker accidents [7, 8].

- Human error contributes to 79% of towing vessel groundings [7, 9].
- Over 80% of marine accidents are caused or influenced by human and organization factors [10, 11].
- Around 60% of all US Naval Aviation-Class A accidents (*i.e.*, the ones that result in death, permanent disability, or loss of $1 million) were due to various human and organization factors [10, 12].
- Human error contributes to 89–96% of ship collisions [7, 13].
- A Dutch study of 100 marine casualties found that human error contributed to 96 of the 100 accidents [7, 14].
- In February 2004, a chemical/product tanker, the *Bow Mariner* sunk because of an on-board explosion due to a human error and 18 crew members died [15].
- The collision of the MV Santa Cruz II and the USCGC Cuyahoga due to a human error resulted in the death of 11 Coast Guardsmen [7, 16].
- The grounding of the ship *Torrey Canyon* due to various human errors resulted in the spilling of 100,000 tons of oil [7, 16].

7.3 Human Factors Issues Facing the Marine Industry

Today, there are many human factors issues facing the marine industry that directly or indirectly influence the occurrence of human error. Some of the important ones are shown in Figure 7.1 [7, 17–21]. These are poor communications, fatigue, poor automation design, poor general technical knowledge, poor maintenance, decisions based on inadequate information, faulty policies, practices, or standards, poor knowledge of own ship systems, and hazardous natural environment.

The issue of “poor communication” is concerned with communications between shipmates, between masters and pilots, ship to ship, *etc.* Around 70% of all major

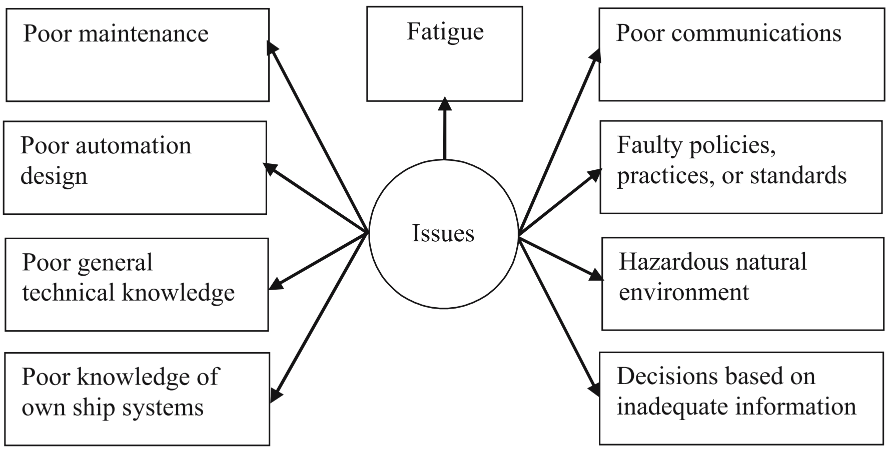

Figure 7.1. Important human factor issues facing the marine industry

marine allisions and collisions took place when a State or federal pilot was directing one or both vessels [20]. In this regard, better training and procedures can help to promote better communications and coordination on and between vessels. Fatigue has been pointed out as the "pressing issue" of mariners in two different studies [17, 18], and another study revealed that fatigue contributed to 33% of the vessel injuries and 16% of the casualties [21]. Poor automation design is a challenging issue because poor equipment design pervades almost all shipboard automation, and as per Reference [14] poor equipment design was a causal factor in one-third of major marine casualties [14]. In this regard, a proper consideration by equipment designers to factors such as how a given piece of equipment will support the mariner's tasks and how it will integrate into the entire equipment "suite" used by the mariner can be a very helpful step.

The issue of "poor general technical knowledge" is concerned with the poor understanding of mariners of how the automation works or under what conditions it was designed to work effectively. Consequently, mariners sometimes commit errors in using the equipment, and, in fact, according to one study, this problem alone was responsible for 35% of casualties [14].

Poor maintenance is another important issue because poor maintenance of ships can lead to situations such as dangerous work environments, lack of functional backup systems, and crew fatigue from the need to carry out emergency repairs. In fact, the past experiences indicate that poor maintenance is a leading cause of fires and explosions in ships [13]. The issue of "decisions based on inadequate information" is concerned with mariners making navigation-related decisions on inadequate information. They often tend to rely on either a favoured piece of equipment or their memory and in other cases, critical information could be lacking or incorrect altogether. Situations such as these can lead to navigation errors.

The issue of faulty policies, practices, or procedures covers a variety of problems including the lack of available precisely written and comprehensible operational procedures aboard ship, management policies that encourage risk-taking, and the lack of standard traffic rules from port to port.

Poor knowledge of the ships' systems is a frequent contributing factor to marine casualties because of various difficulties encountered by crews and pilots working on ships of different sizes, with different types of equipment and carrying different cargoes. Furthermore, 78% of the mariners surveyed cited the lack of ship-specific knowledge an important problem [17]. Nonetheless, actions such as better training, standardized equipment design, and an effective method of assigning crew to ships can be quite useful to overcome this problem.

The issue of hazardous natural environment is concerned with currents, winds, and fog that can make treacherous working conditions; thus a greater risk for casualties. This problem could be overcome by considering these three factors (*i.e.*, currents, winds, and fog) into ships and equipment design as well as adjusting ship associated operations on the basis of hazardous environmental conditions.

7.4 Risk Analysis Methods for Application in Marine Systems

There are many sources of risk to marine systems including human error, external events, equipment failure, and institutional error [22]. Risk analysis or assessment helps to answer basically three questions, as shown in Figure 7.2. Over the years, in areas such as reliability and safety, many methods and techniques have been developed to perform various types of analysis. Many of these methods can be used to perform risk analysis in marine systems. Nine of these methods are shown in Figure 7.3 [22–26]. Each of these methods with respect to risk assessment, is briefly discussed below [22]:

- **Fault tree analysis (FTA).** This is a qualitative/quantitative and an inductive modeling approach, and is quite useful to identify combinations of equipment failures and human errors that can lead to an accident. An application of FTA to oil tanker grounding is presented in a subsequent section and additional information on FTA is available in Reference [27].
- **Failure modes and effect analysis (FMEA).** This is a qualitative/quantitative and an inductive modeling approach that identifies equipment (components) failure modes and their impacts on the surrounding components and the system. Additional information on the method is available in Reference [28].
- **Checklists.** This is a qualitative approach, and it insures that organizations are complying with standard practices. Additional information on the method is available in Reference [29].
- **Safety/review audits.** This is a qualitative approach and is quite useful to identify equipment conditions or operating procedures that could result in a casualty or lead to property damage or environmental impacts. Additional information on the method is available in References [22, 25].
- **Hazard and operability study (HAZOP.** This is a qualitative approach that was developed in the chemical industry and is a form of FMEA. The method is quite useful to identify system deviations and their associated causes that can result in undesirable consequences and to determine recommended actions for reducing the frequency/deviation consequences. Additional information on the method is available in References [26, 30].
- **Probabilistic risk analysis (PRA).** This quantitative methodology was developed by the nuclear engineering community to assess risk. PRA may use a combination of risk assessment approaches and is described in detail in Reference [31].
- **"What-if" analysis.** This is a qualitative approach that identifies hazards, hazardous conditions, or specific accident events that could lead to undesirable consequences. Additional information on the method is available in References [22, 25, 32, 33].

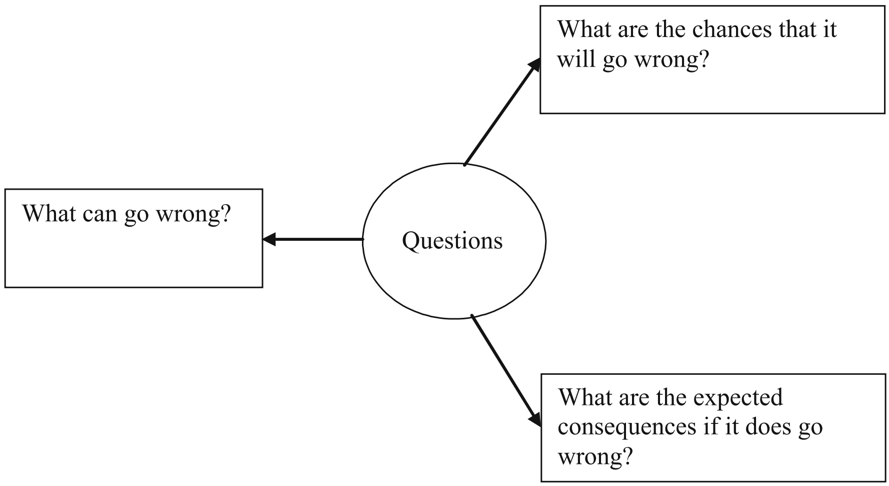

Figure 7.2. Questions answered by risk assessment or analysis

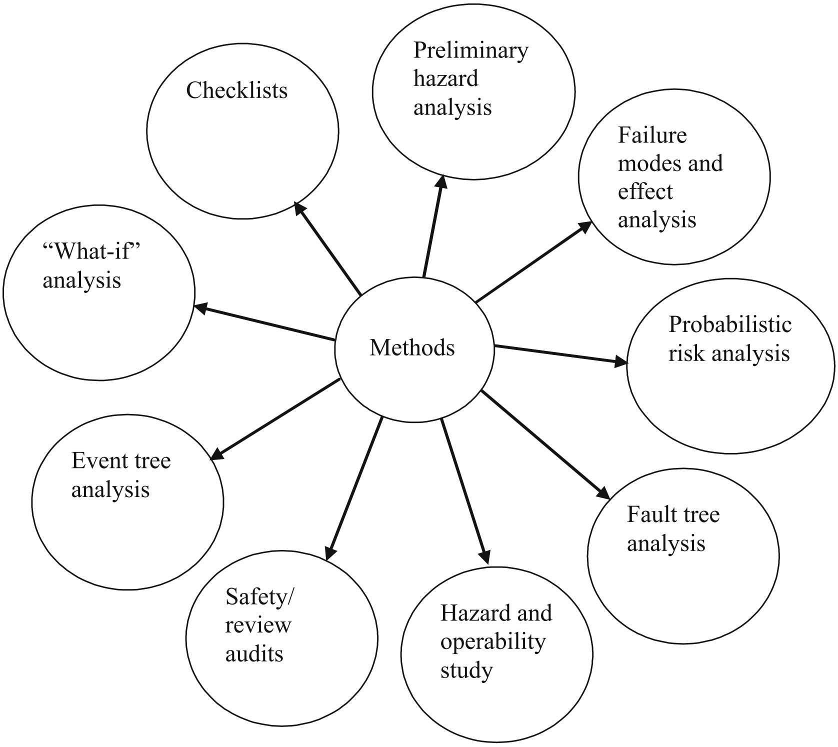

Figure 7.3. Methods for performing risk analysis in marine systems

- **Preliminary hazard analysis.** This is a qualitative and an inductive modeling approach, and is quite useful to identify and prioritize hazards leading to undesirable consequences early in the system life cycle. In addition, it evaluates recommended actions for reducing the frequency/consequences of the prioritized hazards. Additional information on the method is available in References [22, 25, 26].
- **Event tree analysis (ETA).** This is a quantitative and an inductive modeling approach that identifies various consequences of events, both successes and failures that can result in an accident. Additional information on ETA is available in References [22, 26, 34].

7.5 Fault Tree Analysis of Oil Tanker Groundings

Over the years, as oil tankers have become bigger, the tolerance for error has decreased with an increase in consequences. The United States Coast Guard (USCG)

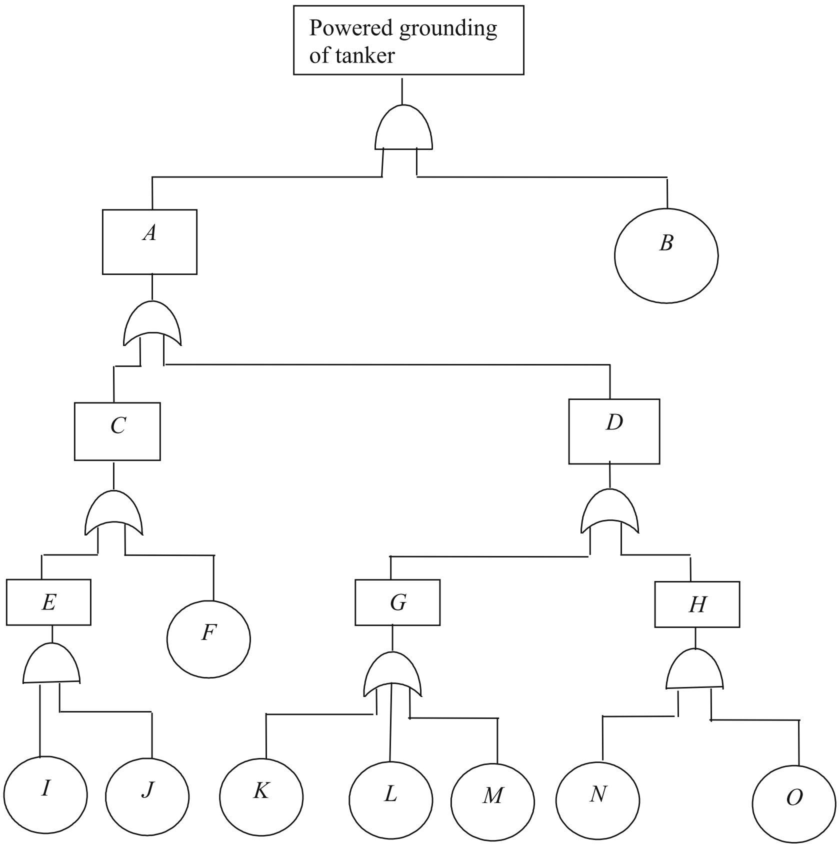

Figure 7.4. A fault tree for the top event: powered grounding of tanker

has identified the tanker industry as a high-risk industry with a high potential for improvement [35]. Thus, it means that a systematic approach must be undertaken to identify all tanker associated possible accidents and their consequences, so that they can be reduced to a minimum level through appropriate safety-related measures. Fault tree analysis is a useful tool to perform various types of tanker safety-related analysis, directly or indirectly, concerning human error.

Using the fault tree symbols defined in Chapter 5, a simple fault tree for the top event, powered grounding of tanker, is shown in Figure 7.4 [35]. This top event may be described as an event that occurs when a tanker collides with the shoreline while underway because of lack of crew vigilance and navigational error. The capital letters in rectangles and circles of Figure 7.4 diagram denote intermediate and basic fault events associated with the tanker, respectively. Each of these capital letters is defined below [35].

- ***A***: The actual tanker course proceeds down a hazardous track.
- ***B***: Able to follow a safe track.
- ***C***: The tanker course deviates from a safe and desired path or track.
- ***D***: The desired tanker track is unsafe or hazardous.
- ***E***: Inadequate action to eliminate error and difference error is detected.
- ***F***: No difference error detected.
- ***G***: Errors committed in planning track.
- ***H***: Planning information is incorrect and no errors in planning.
- ***I***: Inadequate action to eradicate error.
- ***J***: Difference error is detected.
- ***K***: Incorrect information is used.
- ***L***: Information is used incorrectly.
- ***M***: Inadequate amount of information is used.
- ***N***: No errors committed in planning.
- ***O***: Planning information is incorrect.

Example 7.1

Assume that in Figure 7.4, the probabilities of occurrence of independent events, B, F, I, J, K, L, M, N, and O are 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, and 0.09, respectively. Calculate the probability of occurrence of the top event: Powered grounding of tanker, by using equations presented in Chapter 5.

Thus, from Chapter 5 the probability of occurrence of event G is

$$P(G)=1-[1-P(K)][1-P(L)][1-P(M)] \tag{7.1}$$

where

$P(K)$ is the probability of occurrence of event K.
$P(L)$ is the probability of occurrence of event L.
$P(M)$ is the probability of occurrence of event M.

For the specified values of $P(K)$, $P(L)$, and $P(M)$, Equation (7.1) yields

$$P(G) = 1 - [1 - 0.05][1 - 0.06][1 - 0.07],$$
$$= 0.1695.$$

Similarly, from Chapter 5 the probability of occurrence of event H is

$$P(H) = P(N)P(O), \tag{7.2}$$

where
$P(N)$ is the probability of occurrence of event N.
$P(O)$ is the probability of occurrence of event O.

For the given values of $P(N)$ and $P(O)$, from Equation (7.2), we get

$$P(H) = (0.08)\,(0.09),$$
$$= 0.0072.$$

Similarly, the probability of occurrence of event E is

$$P(E) = P(I)\,P(J), \tag{7.3}$$

where
$P(I)$ is the probability of occurrence of event I.
$P(J)$ is the probability of occurrence of event J.

For the specified values of $P(I)$ and $P(J)$, Equation (7.3) yields

$$P(E) = (0.03)(0.04),$$
$$= 0.0012.$$

In a similar manner to Equation (7.1), the probability of occurrence of event C is

$$P(C) = 1 - [1 - P(E)][1 - P(F)], \tag{7.4}$$

where
$P(F)$ is the probability of occurrence of event F.

For the above calculated and given values of $P(E)$ and $P(F)$, respectively, from Equation (7.4), we get

$$P(C) = 1 - [1 - 0.0012][1 - 0.02],$$
$$= 0.0212.$$

Similarly, the probability of occurrence of event D is given by

$$P(D) = 1 - [1 - P(G)][1 - P(H)]. \tag{7.5}$$

For the calculated values of $P(G)$ and $P(H)$, Equation (7.5) yields

$$P(D) = 1 - [1 - 0.1695][1 - 0.0072],$$
$$= 0.1755.$$

Similarly, the probability of occurrence of event A is

$$P(A)=1-\left[1-P(C)\right]\left[1-P(D)\right]. \tag{7.6}$$

For the calculated values of *P*(*C*) and *P*(*D*), from Equation (7.6), we get

$$\begin{aligned} P(A) &= 1-[1-0.0212][1-0.1755], \\ &= 0.1930. \end{aligned}$$

Thus, for the above calculated and given values of *P*(*A*) and *P*(*B*), respectively, the probability of occurrence of the top event: Powered grounding of tanker, is given by

$$\begin{aligned} &= P(A)P(B), \\ &= (0.1930)(0.01), \\ &= 0.0019. \end{aligned}$$

7.6 Safety Management Assessment System to Identify and Evaluate Human and Organizational Factors in Marine Systems

Past experiences indicate that a very high percentage of major marine accidents are either caused or influenced by humans and organizations (errors). The safety management assessment system (SMAS) is a useful tool to reduce such accidents [36]. In fact, it was developed specifically to assess marine systems such as ships and marine terminals with respect to human and organization factors. SMAS may simply be described as a screening approach that chooses and trains operators of the system under consideration for conducting a self-assessment. SMAS is composed of three main components as shown in Figure 7.5 [36].

The assessment process consists of three phases: in-office evaluation of information (*i.e.*, at the on-shore office), system visits (*i.e.*, at the actual facility), and final review and assessment (*i.e.*, at the on-shore office). The time required for the process is about five days.

Assessors make comparisons and evaluate human and organization factors by choosing appropriate ranges and providing appropriate comments to capture the element of certainty. Instruments (*i.e.*, computer programs) assist the assessment process by performing appropriate calculations, placing them in a database, and using pre-programmed reports to display the assessment results.

A filed test of SMAS at a marine terminal in California concluded the following [36]:

- A facilitator is required in using SMAS.
- It is possible to accomplish, an assessment of a system for human and organization factors, within five days.

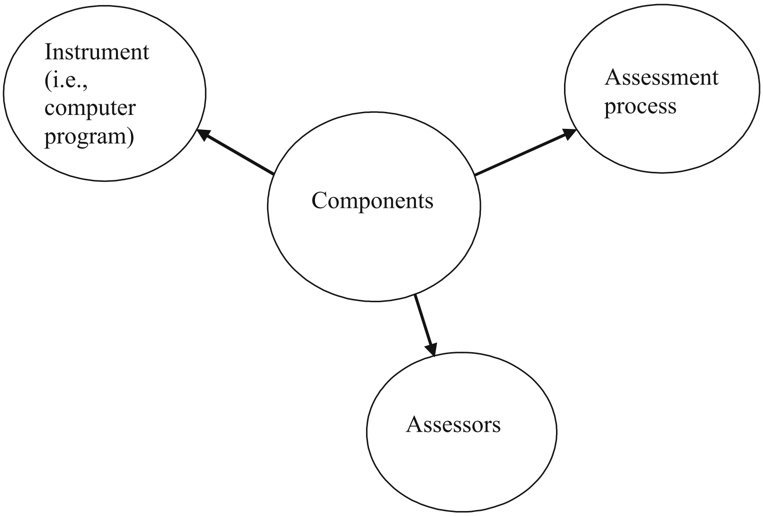

Figure 7.5. Safety management assessment system (SMAS) main components

- The existence of the computer program is crucial in performing the assessment.
- A careful selection and proper training of operators as assessors is critical to produce consistant results.
- The use of operators as assessors is important because they are the best people to provide insight into their system.

Additional information on SMAS is available in Reference [36].

7.7 Reducing the Manning Impact on Shipping System Reliability

In a reduced manning environment, the overall shipping system reliability is impacted both negatively and positively. For example, with the human as an element of the system, the lesser number of humans could very well equate to reduced operating capacity. In contrast, the system operates better when machines or automatic software comprise the critical operating parameters of the system [37]. Nonetheless, the expected impacts of a reduced manning design on shipping system reliability can be described with respect to human systems integration approaches, for improving human reliability. Three of these approaches are as follows [37]:

- Reduce the occurrence of human error incidence
- Eliminate or minimize human error impacts
- Improve mean time between failures (MTBF) under the reduced manning environment

In the case of the first approach, *i.e.*, reduce the occurrence of human error incidence, human error rates are reduced through means such as application of human engineering design principles, job task simplification, and error likelihood modeling or analysis.

In the case of the second approach, *i.e.*, eliminate or minimize human error impacts, human error impacts are eliminated or minimized through actions such as designing the system to be error tolerant, and designing the system that enables the human/system to recognize that an error has occurred as well as to correct the error prior to any damage.

In the case of the third approach, *i.e.*, improve MTBF) under the reduced manning environment, one typical method for improving MTBF) is to design or choose highly reliable system parts as well as design the interfaces to optimize the use of these parts.

7.8 Problems

1. Write an essay on human error in shipping.
2. List at least seven facts and figures concerned with human error in shipping.
3. Discuss five most important human factors issues facing the marine industry.
4. What are the typical questions answered by risk assessment?
5. Discuss the following two methods that can be used to perform risk analysis in marine systems:
   - Failure modes and effect analysis
   - Event tree analysis
6. Assume that in Figure 7.4, the probability of occurrence of independent events *B*, *F*, *I*, *J*, *K*, *L*, *M*, *N*, and *O* is 0.05. Calculate the probability of occurrence of the top event: Powered grounding of tanker.
7. Describe safety management assessment system.
8. Discuss the term "reducing the manning impact on shipping system reliability."
9. Compare hazard and operability study with failure modes and effect analysis in regard to marine systems.
10. List four methods that can be used to perform quantitative risk analysis in marine systems.

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