

## THE HUMAN ELEMENT AS A FACTOR IN MARINE ACCIDENTS

H. N. Psaraftis, P. Caridis, N. Desypris, G. Panagakos, N. Ventikos<sup>1</sup>

Abstract: *The purpose of this paper is to present a comprehensive analysis of the human element as a factor in marine accidents. This analysis has been part of project SAFECO (for Safety of Shipping in Coastal Waters), sponsored by the European Commission, Directorate General for Transport (DGVII). The analysis investigates relationships between the various probable causes of an accident and the final outcome of the accident.*

Key words: *Maritime safety, human element, accident analysis.*

### 1. Introduction

The purpose of this paper is to present a comprehensive analysis of the human element as a factor in marine accidents. This analysis has been part of project SAFECO (for Safety of Shipping in Coastal Waters), sponsored by the European Commission, Directorate General for Transport (DGVII). The purpose of the project has been to identify technologies and other measures to improve maritime safety, by analyzing the impact of maritime simulators, collision avoidance systems, improved maneuverability, and related technologies, mainly in the context of European waters.

Within the SAFECO project, the objective of the so-called “Historic risks and validation model” has been to assess the overall level of risk, identify statistics for verification of the risk, identify important risk reduction factors, and identify cases for assessment of the

---

<sup>1</sup> Department of Naval Architecture and Marine Engineering, National Technical University of Athens, Greece.

merits (or lack thereof) of specific risk reduction schemes for marine safety in European coastal waters. A two-level hierarchical approach was adopted:

Level I makes a broad and aggregate analysis of a *large* sample of casualty data, so as to identify which factors influence risk. No attempt is made in Level I to go into depth regarding the details of individual accidents, as this information is seldom (if ever) available in the databases on which such an analysis is based. One of the key questions that were addressed was whether one could identify factors such as ship size, type, age, weather, casualty, geographical location, or others that make *a statistically significant difference* on risk. An analysis of statistical significance will generally not prove a cause-and-effect relationship, but it will reveal whether variations in accident rate are systematic or are due to chance alone.

Level II examines *in depth* (and in a case study format) a *limited* sample of accidents for which there is ample investigative information available. Based on this information, the *cause* of each of these accidents has been identified, and an assessment of what a specific risk reduction scheme might accomplish has been made.

This paper focuses on Level II. The results of Level I are reported in other publications (see for instance refs [1,2])). The reader should also be aware that due to space limitations this paper necessarily couldn't go into all the details of the analysis. These can be found in a SAFECO internal report, ref. [3].

## **2. Description of accident data**

The source that we used for Level II was the marine accident records collected by the Greek Ministry of Merchant Marine. In the Ministry, the Coast Guard is tasked by law to investigate each incident or accident that involves a Greek-flagged ship, irrespective of the accident's geographical location. In addition, all events that occur in Greek territorial waters are similarly investigated, irrespective of the flag of the ship involved. The investigative process can be a long one, as it involves depositions under oath of all personnel involved in each accident, the possible use of authors to ascertain technical

matters, and the writing of a report that not only offers the Ministry's official view of what may have occurred, but also assigns civil or even criminal responsibilities to people in the event they prove responsible for the accident. Each investigation is conducted and the corresponding report is written by the so-called "Interrogation Council of Marine Accidents", which is staffed by Coast Guard officers. Depending on the severity or the complexity of the event, a report can be anything from a couple of pages to 60 pages or over.

The Coast Guard was kind enough to provide access to its records for the benefit of the SAFECO project, on the condition that all names of ships, individuals, or shipping companies involved would be blanked out so as to remain confidential. That condition was accepted by the NTUA team, who made several (more than 10) visits to the Coast Guard Headquarters in Piraeus in order to get this information.

Information was collected and processed in several stages. First, the Coast Guard's master log on marine accidents (several large handwritten volumes) was copied. The log included only "headline" information for each accident. By doing this, some 1,355 incidents and accidents involving Greek-flagged ships of 400 GRT or higher from 1978 to 1995 were recorded. Of the events in this database, events that involved fishing vessels or vessels below 1,000 GRT were discarded, and all remaining "serious" events were subsequently put into a separate database. "Serious" was defined as any event involving at least one of the following: Loss of the ship, or major damage to the ship and/or its content, *including* the loss of human life.<sup>2</sup>

Using this process, some 432 events were identified. Of these, we requested copies of the corresponding Coast Guard's reports, starting from year 1994 and moving backwards. Due to time constraints, we stopped at year 1984, and counted a total of 94 cases. These cases were numbered from 1 to 94. Of these 94 cases, we further discarded some cases *during the review process*. In some of them it was evident that the accident

---

<sup>2</sup> Note that according to Lloyds Register a ship accident involving loss of life is not necessarily classified as serious, because "seriousness" involves only what may affect the ship, and not the ship's crew.

cause was an act of war (mostly the Gulf War in 1991) or intentional damage to the ship (sabotage). There were also some cases that turned out to be cases involving small-sized ships. Thus we were left with 75 serious accident cases.

Armed with this inventory of cases, each of the five (5) authors of this paper reviewed each of the cases *independently*, and, for each case, determined the following: (a) his own subjective assessment on what might have been the cause(s) of the accident, and (b) his own subjective assessment of what possible measure would have prevented the accident or have reduced its risk.

In codifying the causes, the codes defined by Det Norske Veritas's "DAMA" database structure (a structure developed for both statistical analysis and fault tree analysis) were used. These codes are listed in Table 2.1 below.

**Table 2.1: DAMA - Casualty cause codes (source: DNV)**

Code	
A	<u>Circumstances not related to the ship</u>
A01	Very heavy weather, natural disaster etc.
A02	Current, wind etc. led to strong drift or other maneuver difficulties.
A03	Collided with floating objects, could not be discovered/avoided in time.
A04	Fault with navigation systems: lights, external electronic systems etc.
A05	Fault with charts or publications.
A06	Technical fault with other ship (also includes towboats and the like).
A07	Operational fault with other ship (wrong maneuver/poor seamanship etc.).
A08	Technical fault with load /unload/bunker construction/quay/sluiice, outside the ship.
A09	Wrong handling of load/unload/bunker construction/quay/sluiice, outside the ship.
A10	Blowout or other extern conditions in connection with oil drilling.
A11	Other conditions outside the ship.
B	<u>Construction of the ship and location of equipment on board</u>
B01	The ship's structural strength not sufficient.
B02	The structural strength weakened by later welding jobs, corrosion etc.
B03	Stability failure caused by the construction of the ship.
B04	The ship had too poor maneuver qualities.
B05	The arrangement of the engine room/location of equipment with danger of leakage/setting on fire.
B06	Unfortunate arrangement or location of load- or storage room.

- B07 Unfortunate location/arrangement of other rooms on board (not bridge).
- B08 Difficult access for cleaning, maintenance and inspection.
- B09 Other conditions concerning the construction and maintenance of the ship.
  
- C Technical conditions concerning equipment on board
- C01 Technical fault with navigation equipment.
- C02 Technical fault with steering systems.
- C03 Technical fault with propulsion systems.
- C04 Technical fault with auxiliary engine.
- C05 Technical fault with anchorage equipment/deck machinery (not load/unload equipment).
- C06 Technical fault with control/remote control/automatic controls/warning equipment.
- C07 Technical fault with loading or unloading device.
- C08 Technical fault with preparedness/safeguarding/inert gas/halogen equipment.
- C09 Technical fault with equipment.
- C10 Other technical conditions concerning equipment on board.
  
- D Conditions concerning use and design of equipment
- D01 Unfortunate design of the bridge, lacking or wrong location of equipment.
- D02 Illogical/wrong design of controls, steering systems etc.
- D03 The equipment was not placed where it was natural to use it.
- D04 Illogical/inappropriate/poor/worn out equipment. More easily accessible.
- D05 Other conditions concerning use/design of equipment. Man/engine problems.
  
- E Cargo, safeguarding and treatment of cargo and bunkers
- E01 Self-ignition in cargo/bunker, also by “sloshing” in tanks.
- E02 Lacked inert gas installation or other safeguarding against explosion/fire.
- E03 Stability not according to regulations (wrong placing of cargo/lacking ballast etc.).
- E04 The cargo was not sufficiently safeguarded against shifting.
- E05 Leakage of liquid cargo in casks, containers, tanks, etc.
- E06 Breaks in loading or bunker pipes.
- E07 Other conditions concerning cargo and safeguarding cargo and bunkers.
  
- F Communication, organization, procedures and routines
- F01 Routines for average control were lacking/were not sufficient.
- F02 Existing routines for average control were not properly known/drilled.
- F03 Routines for safety control lacked/were not sufficient.
- F04 Existing routines for safety control known, but not followed.
- F05 Did not follow the safety regulations for welding.
- F06 Welding led to accident even though the safety regulations were followed.
- F07 Not taken measures concerning testing of rescue instruments etc.
- F08 Did not use protective equipment.
- F09 The general level of organization/routines/qualifications poor.
- F10 Failure of routines for inspection and maintenance on board.

- F11 Stability not known, approved stability calculations were not available.
- F12 Unfortunate management, personal antagonisms or suchlike.
- F13 Too small crew, generally or for the task e.g. helmsman/look-out.
- F14 Command or distribution of responsibility was or was perceived as unclear.
- F15 Not established safety routines in connection with navigation/maneuvering (bridge watch).
- F16 Safety routines in connection with navigation/maneuvering known, but not followed.
- F17 Charts/other documents for the voyage were not amended.
- F18 Failure of procedure/co-operation between vessel/towboat, organization from the shore or suchlike.
- F19 Other conditions concerning routines, procedures, communication or organization.
  
- G Individual on board, situation judgment, reactions
- G01 Insufficient formal competence for the task (courses, exams etc.).
- G02 Insufficient real competence (practice from occupation, waters, with equipment or suchlike).
- G03 Task not well planned (cargo, night voyage, maneuvering, anchoring etc.).
- G04 Available means of warning not sufficiently used.
- G05 Alternative navigation systems not used misjudged lanterns etc.
- G06 Available navigation aids not used (Norwegian Pilot etc.).
- G07 Not adequate observation of own position/not plotted on charts.
- G08 Misjudgment of other vessel's movement or intention.
- G09 Misjudgment of own vessel's movements (current, wind etc.).
- G10 Tried to go through with the operation even though the conditions were not favorable.
- G11 Did not keep to the starboard in the waters.
- G12 Kept up a faster than safe pace.
- G13 Special conditions (illness, little sleep, a lot of work etc.).
- G14 Fell asleep on watch.
- G15 Alcohol or other intoxicant.
- G16 Other conditions concerning individuals.

### 3. Results of the Analysis

Very early in the analysis it became clear that the causes of the accidents studied could not be described in general by a unique DAMA code among those listed in Table 2.1. In fact, among the 75 cases under investigation, only in one case all authors of this paper used the same single code to describe the accident. At the other extreme there was a case where the authors needed collectively as many as *fourteen* (14) different codes to describe it. This was so because of the following reasons:

1) The system of codification of the casualty causes itself. The most critical characteristic of any codification system is the level of detail that is inherent in its codes. The more detailed a system is, the deeper statistical analysis it allows, provided of course that the population of the sample to be analyzed is sufficiently large. Furthermore, it was noted that some of the codes in the DAMA system were more general in nature than others leading to their use even if a more specific code was also applied. For example, the only way that the use of code G02-*Insufficient real competence* can be justified is if one or more of some other causes described by codes like G03-*Task not well planned*, G05-*Alternative navigation systems not used* or G09-*Misjudgment of own vessel's movements* took place. In such cases the authors tended to use a *combination* of codes to describe the cause of the accident.

2) The complexity of the accidents. Although the casualties examined in the case studies are indicative of the multiplicity of things that can go wrong in sailing a ship, in the great majority of the cases it is an unfortunate combination of factors that lead to an accident. The technological vintage that a particular ship belongs to is in fact a decisive factor in this respect as modern design of vessels and equipment tends to provide more safeguards against possible errors, in which case the occurrence of an accident requires an even larger combination of factors.

3) The difference of opinion among the authors of this paper who reviewed the cases. Although at first glance this might have a negative connotation, the difference of

opinion among the five authors who acted independently in reviewing the cases is exactly what makes it possible to describe subjective and qualitative statements such as “what was the cause of an accident” or “what possible measure could have prevented it” in quantitative terms. In fact, this is the reason behind selecting this particular methodology for the analysis.

A first observation from the results was that ship accidents are mainly attributed to *a limited number* of causes. The five more important DAMA causes were (sorted by frequency):

- F04 (8.2%): ‘Existing routines for safety control known, but not followed’
- G02 (7.9%): ‘Insufficient real competence (practice from occupation, waters, with equipment or suchlike)’
- A01 (6.6%): ‘Very heavy weather, natural disaster, etc.’
- G07 (5.0%): ‘Not adequate observation of own position/not plotted on charts’
- G09 (4.0%): ‘Misjudgment of own vessel’s movements (current, wind etc.)’

Within each group, the most important causes were:

Group A - *Circumstances not related to the ship*: cause A01-*Very heavy weather, natural disaster etc* (49.5% of the total), followed by cause A07-*Operational fault with other ship (wrong manoeuvre/poor seamanship etc)* (16.2% of the total) and A02-*Current, wind etc led to strong drift or other manoeuvre difficulties* (7.1% of the total), covering together a percentage of 72.8% of Group A cases;

Group B - *Construction of the ship and location of equipment on board*: cause B01-*The ship’s structural strength not sufficient* (49.1% of the total) and cause B02-*The structural strength weakened by later welding jobs, corrosion etc* (30.9% of the total), together coming to an 80% of Group B cases;



Group C - *Technical conditions concerning equipment on board*: cause C09-*Technical fault with equipment* (34% of the total) only;

Group D - *Conditions concerning use and design of equipment*: there is no statistically significant cause;

Group E - *Cargo, safeguarding and treatment of cargo and bunkers*: cause E01-*Self-ignition in cargo/bunker, also by “sloshing” in tanks* (50% of the total) only;

Group F - *Communication, organization, procedures and routines*: cause F04-*Existing routines for safety control known, but not followed* (31.4% of the total), followed by cause F10-*Failure of routines for inspection and maintenance on board* (11.3% of the total).

Group G - *Individual on board, situation, judgment, reactions*: cause G02-*Insufficient real competence (practice from occupation, waters, with equipment or suchlike)* (22% of the total), followed by cause G07-*Not adequate observation of own position/not plotted on charts* (13.8% of the total), and cause G09-*Misjudgment of own vessel’s movements (current, wind etc)* (11.2% of the total).

It appears that there was a heavy concentration of statistically significant causes in groups F and G. This is not surprising, as these two groups contain basically causes related to human error, which according to the literature constitutes the single most common cause of marine accidents.

The existence of *dependency and correlation* among the seven categories of causes as defined in Table 2.1 was checked next. Based on these distributions, the p-value of chi-square, the p-value of Fisher’s exact test and the correlation have been calculated. From these tests it was observed that:

- Group A is dependent with Group B and G,

- Group B is dependent with group A and G,
- Group C is dependent with group F,
- Group F is dependent with group C and G, and
- Group G is dependent with group A, B, and F.

A detailed discussion on the possible reasons for such dependencies can be found in ref. [3].

#### **4. Discussion and conclusions**

We now discuss what we think are the main points that come out of this analysis.

Human factor: We believe that a central result of this analysis *is the paramount importance of the human factor*. In fact, in the majority of cases reviewed, the incident was due to one or more of the following: Poor crew competence, lack of communication, lack of proper maintenance, lack of application of safety or other procedures, inadequate training, poor judgment of the situation, and so forth. This general conclusion also means that many of the serious accidents reviewed might have been averted if some of the above deficiencies did not exist.

Education and training: It is obvious from the many of the cases reviewed that proper education and training of ship personnel is important. In and of itself, this might constitute one of the most important risk reduction measures. Rigorous national programs that ensure proper implementation of the latest STCW requirements are the only way to proceed toward this goal. Training with marine simulators would further enhance this requirement.

It is impossible to ascertain with a reasonable degree of confidence exactly which of the incidents reviewed might have been averted if the ship's personnel had taken lessons in a marine simulator, or if some other special training program were followed. However,

it is clear that more emphasis on this requirement would reduce the general level of risk on an average basis.

Policies and procedures: Following the procedures that are established for safety and control assumes at least that these procedures exist and are carefully thought of. The problem in many cases is that such procedures are vague, ambiguous, and difficult to apply. This fact places an emphasis on the existence and establishment of proper policies and procedures.

It is believed that the implementation of the ISM Code will be a move in this direction. It is impossible to tell for each of the cases reviewed that the accident would not have occurred if ISM were in place for the ship in question. It is also early to assess the impact of ISM on the safety of the ships on which the Code has been implemented. This will take years to ascertain, and the analysis to do so will not be trivial. However, the very fact that ISM certification implies that all procedures related to the operation of the ship would at least be established, monitored and controlled, means that the risk of a situation getting out of hand would be minimized. Other schemes such as ISO 9002 and various quality certification schemes established by classification societies would achieve similar goals, although again their precise impact is difficult to quantify at this point in time.

External factors: Although several of the accidents reviewed are due to external factors such as bad weather, it is fair to say that in most such cases it was the combination of the external factor and the human factor that led to the accident. For instance, if the Master took the proper measures (such as reduce speed, change course, go to a safe place, send distress signal, etc), the accident might not have occurred, even though the weather was bad.

It is a universal prerogative of the Master to decide whether or not to sail in situations of adverse weather, or how to sail the ship in general. However, the case of Greece, in which there is a policy of banning the sailing of passenger ferries if the weather is

extremely bad is perhaps an example that is worthy of note. The decision of a sailing ban in this case is in the hands of the Central Harbormaster. This policy is equivalent to the closing of an airport in case of a thunderstorm or other bad weather (a policy that is widely practiced). Even though such policy removes power from the hands of the Master, and may be difficult to extend to cargo ships or to deep-sea vessels, it is clear that this policy *is* a risk reduction scheme, and as such should receive due consideration.

Technical factors: The first issue with respect to technical factors relates to the possible role of advanced technology systems that would reduce the risk of accidents if in place. VTMS, ECDIS, and collision avoidance systems are prime examples. In all of the cases reviewed that involved collisions and groundings, it is quite possible that the existence of such systems might have averted some of the accidents. This would not happen automatically just because these systems would exist, but because of the assistance to the human operator that these systems would provide. So again the human factor would be the prevalent factor, but in this case the ability of the human element would be enhanced due to these systems.

The second issue related to technical factors is the central question to what extent accidents might have been averted if the ship had a higher structural strength, a different tank subdivision, or different design characteristics. The central premise behind the new IMO/IACS requirements for bulk carriers and the new IMO/SOLAS requirements for Ro/Ro ferries is that these requirements would enhance safety. Of course, the above question is too general and too difficult to be answered conclusively, however one might wonder looking at the cases reviewed whether such differences might matter.

From the analysis reported (group C), it looks as if technical factors related to the ship are indeed important. However, the correlation of group C with group F (crew competence, etc) should be noted. Given the higher importance of group F as a causal factor, this means that reducing the risk of marine accidents just by “fixing” group C would not be effective if group F (and, by extension, group G) is not “fixed” as well. In fact, we believe that the analysis reported here has demonstrated that *the emphasis in*

*reducing the risk of marine accidents should be placed mostly on the human factor and less on technological solutions.* The importance of the latter should not be overlooked, but only as a means to make the human element perform more effectively.

Final remarks: The main player in the maritime safety international regulatory regime is the IMO, and specifically SOLAS, which is IMO's basic forum dealing with maritime safety. In addition to SOLAS, IMO adopts also other measures that may impact maritime safety, either directly or indirectly. Examples are the STCW Convention and the High Speed Craft Code. Last but not least, a number of other players, such as flag states, port states, and classification societies play key roles in the implementation and enforcement of maritime safety regulations.

Policies currently pursued by the IMO are said to be “proactive” in the sense of an early stage identification of factors that may adversely affect maritime safety and immediate development of regulatory action to prevent undesirable events. Unfortunately, this has not always been the case, as major maritime disasters, including the capsizing of the *Herald of Free Enterprise* in 1987 (193 lives lost), the grounding of the *Exxon Valdez* in 1989 (major pollution), the fire onboard the *Scandinavian Star* in 1990 (158 lives lost), the sinking of the *Estonia* in 1994 (900 lives lost), as well as several major bulk carrier losses, have driven most of IMO's recent regulatory activity.

IMO's policy is also to bridge the gap between new and existing ship standards, emphasize the role of the human element, shift the emphasis from the development of new to the implementation of existing standards, and generally promote a safety culture in all maritime activities.

It is hoped that the methodology and results of R&D such as the SAFECO project, which we think are significant, will assist all the shipping community document more clearly which are the most important factors affecting maritime safety and, as a result, develop and adopt the most appropriate policies and measures for its enhancement.

## References

1. Psaraftis, H.N., G. Panagakos, N. Desypris, N. Ventikos, “ An Analysis of Maritime Transportation Risk Factors”, ISOPE Conference, Montreal, Canada, May 1998.
2. Psaraftis, H.N., G. Panagakos, N. Desypris, N. Ventikos, SAFECO project technical report on WPIII.2.1, NTUA, April 1997.
3. Psaraftis, H.N., P. Caridis, G. Panagakos, N. Desypris, N. Ventikos, SAFECO project technical report on WPIII.2.2/WPIII.2.3, NTUA, January 1998.