HUMAN FACTORS ON THE SHIP'S BRIDGE

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ABSTRACT

The shipping industry has long acknowledged that more than 80% of all accidents at sea are caused by 'human error'. Thus far the underlying causes have attracted less attention than in other industries.

This research focuses on the role of the human element in preventing collisions and groundings. The intention is not to shift the blame from one cause to another, but to explore the underlying human factors which may induce an error on the ship's bridge. The navigating officer works within a unique environment which differs in many aspects from other industries.

'Human error' in the marine environment is explored and the framework of the working environment of the ship's bridge is examined. The organisational framework is provided by the International Maritime Organization and implemented by the Member States. The physical environment of the ship's bridge encompasses the physical layout of the bridge and the exterior environment that the ship may encounter during its passage from one port to another.

Traditionally, research in the marine environment has been based on causal classification systems that provide limited information related to the particular working environment. A review of published accident reports and voluntary incident reports suggested that additional useful detail could be extracted by focusing on problem/activity areas.

This resulted in the development of a marine human factor's classification system. Problem areas were defined as 'Catalysts' and they provide an additional layer of information characteristics to the ship's bridge. These were selected in preference to 'errors' to move away from a blame seeking strategy for examining collisions and groundings.

It is expected that a more detailed classification system will improve future analysis of collisions and groundings. The increased understanding of human factors on the ship's bridge can also, for example, be applied to examine 'human error' and improve the IMO rule making process. The principle of the marine human factors classification system can be adopted to analyse accidents in other working environments, e.g., personal injury.

This study also provides a basic guide to human factors on the ship's bridge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Finally, I would like to thank my husband Chris, for his support and encouragement.

To Chris

Human factors are rarely pure, and never simple.

Oscar Wilde paraphrased*

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* The Importance of Being Earnest (1895)

CHAPTER 1

INTRODUCTION

1.1 Objectives and scope

Safe sailing is not something to wish for but something to plan for. Navigating officers are not born with an inherent aptitude for safety; recognising danger is a learned skill. Abell (1933) acknowledged that an increased understanding of danger would allow measures to be developed that would help to avoid it and reduce the probability of making mistakes.

This thesis examines the need to understand human factors on the ship's bridge, their effect on navigation safety, and how such knowledge is necessary when developing technology or regulations to ensure that the outcome is as intended.

Accidents at sea generally result in some form of loss, e.g., hull damage, loss of lives. There are two ways to reduce these losses, i.e., through preventing an accident and improving the survival rate. This research focuses on the prevention of accidents but does not aim to shift the blame from one cause to another. It considers the use and contribution of cognitive psychology and engineering as agents to examine accidents attributed to errors on the ship's bridge.

The importance of human factors has long been recognised in other industries, resulting in many different definitions. This study adopts a broad definition and assumes the term human factors to include the perceptual, mental and physical capabilities of individuals, their interactions with their work and working environment and the influence of equipment and system design on human performance within the organisational characteristics that influence safe navigation (derived from Health and Safety Executive, 1989).

Other industries have carried out extensive research into human factors within the working environment of their respective industry, e.g., the cockpit. The navigating officer, however, works within a unique environment which differs in many aspects from other industries (see Chapter 3 and Chapter 4).

There are several excellent general human factors' textbooks (see e.g., Booth, 1989; Chapanis, 1996; Salvendy, 1995) and industry specific textbooks (see e.g., Hawkins, 1993; Beaty, 1995). At present, the shipping industry lacks specific textbooks focusing on human factors on the ship's bridge. This thesis should therefore be considered exploratory in nature.

The aim is to establish a basis for the collection of human factors' related data, its presentation, interpretation and practical utilisation in the marine environment.

From the outset it became clear that existing studies and classification schemes (see further tables 2, 3 (pages 20 and 21) and 17 (page 134) would not provide sufficient detail of human factors within the specific working environment of the ship's bridge. They provide broad categories such as Human Behaviour, Poor Planning or Negligent/Inappropriate handling (see further table 25, page 151) that do not afford sufficient detail to develop preventive measures to reduce collisions and groundings.

Although safety at sea has attracted much attention from researchers, particularly in the wake of major accidents (e.g., the collision between the *Andrea Doria* and the *Stockholm*[1]) few studies have centred specifically on the ship's bridge. The aim of this research was to explore whether systematic examination of readily available data sources could provide additional information.

Besides the examination of a pre-classified database, data derived from official accident investigation reports and published voluntary incident reports will be explored. A brief review of published accident reports and voluntary incident reports suggested that additional useful detail could be extracted by focusing on problem/activity areas. In addition, it was decided to explore whether a survey using a questionnaire would increase the existing understanding of the working environment on the ship's bridge.

This research focuses on collisions and groundings, i.e., accidents traditionally attributed to an error made by navigating officers engaged primarily on ships in the merchant navy. The symbol of the ship's bridge, shown in figure 1, and used throughout this thesis, is derived from the outline of an existing ship with a modern integrated bridge. It illustrates the working environment, and provides a mental aid to the core areas of human factors on the ship's bridge.

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[1] The Swedish liner *Stockholm* struck the Italian passenger ship *Andrea Doria* broadside off Nantucket Island on July 25, 1956 resulting in the loss of 52 people

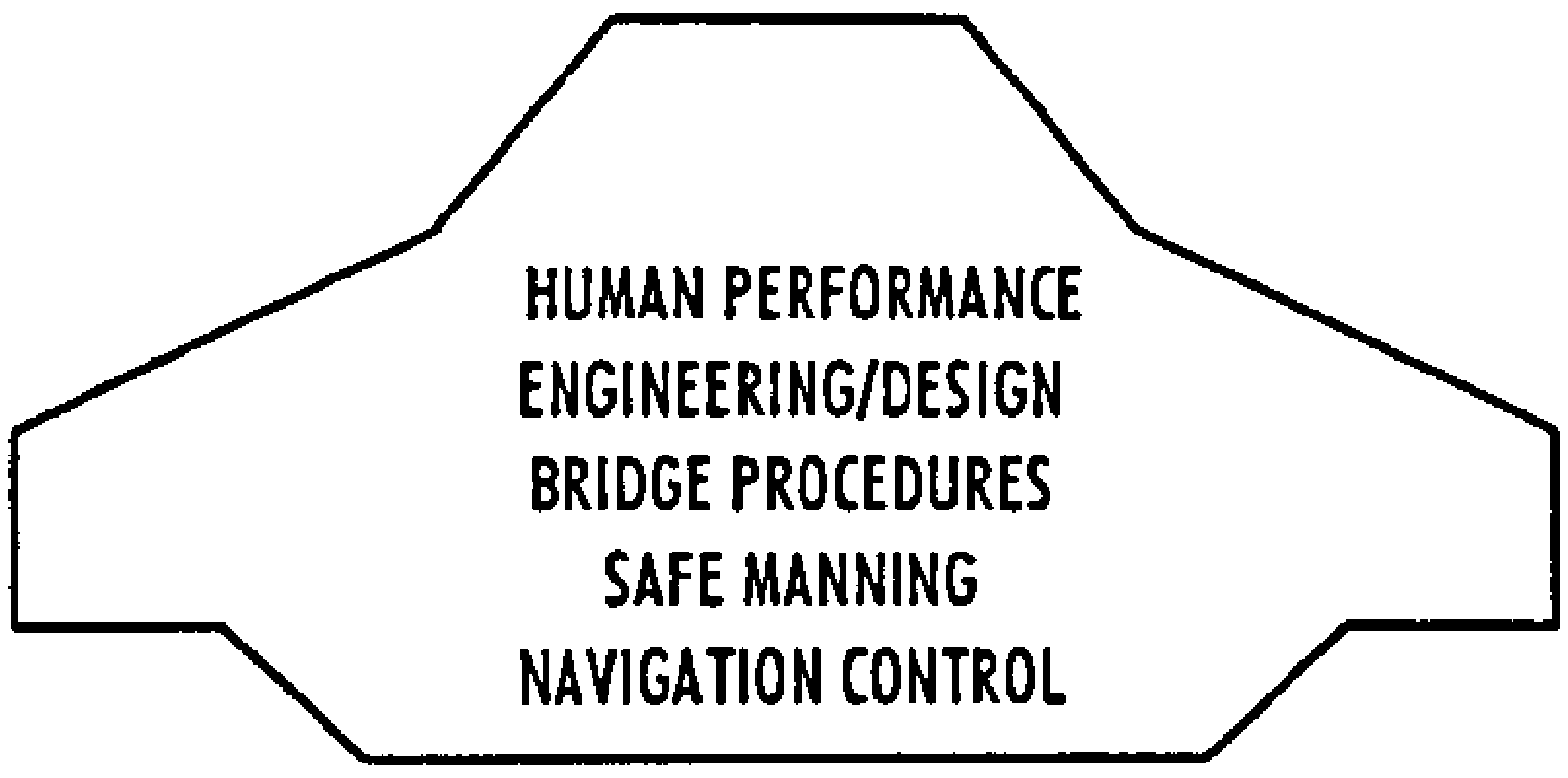

Figure 1 Symbol for a mental aid to the core areas of human factors on the ship's bridge

1.2 Human factors and accidents at sea

1.2.1 What are human factors?

Originally human factors were considered as a discipline focused on optimising the relationship between technology and the human (Kantowitz & Sorkin, 1983). As the general understanding of human factors increased this interpretation has progressively expanded. Dowell and Long (1989), for example, suggested three approaches to human factors:

1) As a craft it evaluates design by comparing with the previous design. Practitioners apply their experience as rough 'rules-of-thumb'. This obviously represents a highly-skilled, but largely unstructured approach (both in content and methodology).

2) As an applied science it draws on research from many interrelated subject areas, from psychology and physiology to computer science and engineering. It is concerned with the design of systems that can enhance human performance.

3) As an engineering discipline it seeks to develop adequate design specifications and focuses on cost-benefit analysis.

The above approaches, with Stanton's (1994) additional four approaches to human factors, are also applicable to safety at sea:

1) a discipline that seeks to apply natural laws of human behaviour to the design of the working environment (e.g., to the design of the ship's bridge);

2) a multi-disciplinary approach to issues surrounding the operator (e.g., the navigating officers on the ship's bridge);

3) a discipline that seeks to maximise safety, efficiency and comfort by developing the working environment to match the physical and psychological capabilities of the operator (e.g., the navigating officer);

4) an idea - looking at the behaviour of operators in their working environment (e.g., the behaviour of the navigating officer on the ship's bridge).

All the above definitions confirm that a multi-disciplinary approach to human factors' research should be adopted, including:

- Theories and models of human performance and behaviour
- Methods for evaluating man-machine systems
- Techniques and principles for the application of a human factor's methodology.

1.2.2 Review of Accidents at Sea

More than 90% of international trade (by weight) is carried by ships (Goss, 1993). Statistics of shipping economics, e.g., value and types of cargo are readily available (see e.g., Singh, 1995; UK P&I Club, 1992) and thus are not considered in detail within this study. Seaborne trade, nevertheless, is increasing steadily and it has been suggested that the shipping industry faces a severe shortage of skilled seafarers within the next 5-10 years (Grey, 1997). These factors are likely to have an impact on safety at sea.

Accidents at sea are typically categorised according to accident type, i.e., collision/contact (allision), grounding, fire & explosion, mechanical breakdown, weather and misc./unknown. Despite efforts to reduce accidents at sea, collisions and groundings continue to occur. For example the World Maritime News reported, on July 18, 1997, the following accidents (Schultz, 1997) (table 1).

TYPE OF ACCIDENT	NO OF ACCIDENTS
Capsizing/Sinking	10
Fire	4
Collision/Allison	2
Grounding	5

Table 1 Number and type of accidents reported for the week ending July 18, 1997 (derived from Schultz, 1997)

No readily available sources detail the total costs resulting from navigation related accidents. Figures published by the UK P&I Club (1992) show that most claims are individually less than US$100,000. Nevertheless, 1444 major claims (over US$100,000) were paid out during the period from 1987 to 1991. Of these, 78 were individually more than US$1,600,000. PCL, the operators of *Star Princess* have estimated that the grounding of their ship resulted in a total cost of US$27.16 million (NTSB, 1997). It has also been reported that Exxon has paid out approximately US$1.2bn in fines and settlements after the grounding of *Exxon Valdez* (Jensen, 1998).

Figures published by the UK P&I Club show that number of claims arising from collisions are about 8% of all risk types. The graph shown in figure 2 suggests that, apart from a sudden increase between 1989 and 1991, the overall trend has remained remarkably unchanged. These figures include claim investigations costing more than US$100,000. Club membership accounts for approximately 20% of the world's deep-water fleet (UK P&I Club, 1999 a/b).

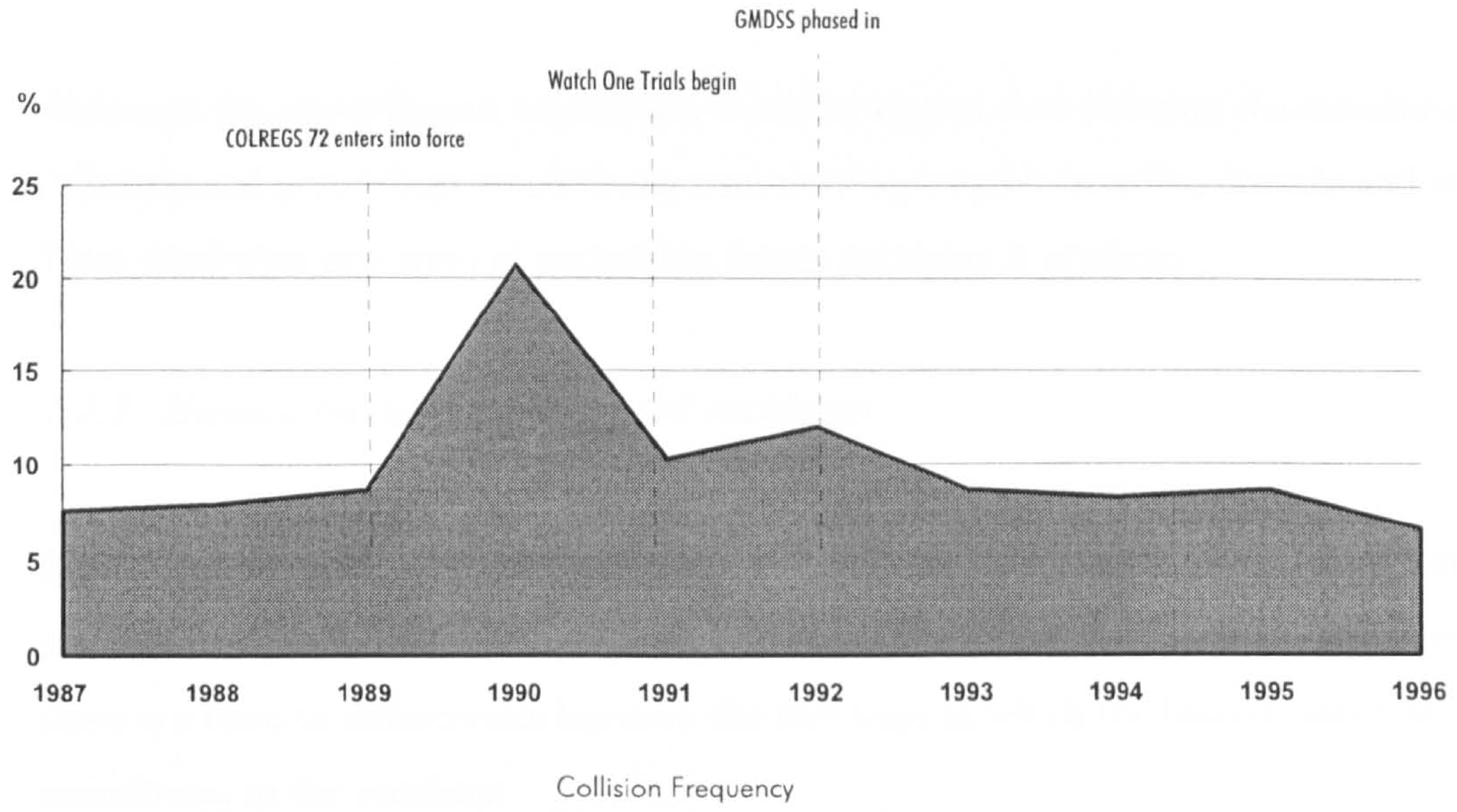

Figure 2 Collision frequency 1987-1996 (derived from UK P&I, 1999a)

It has been suggested that the ratio of hidden to direct costs can be more than 4:1 as illustrated in figure 3 (Heinrich, Petersen & Roos, 1980).

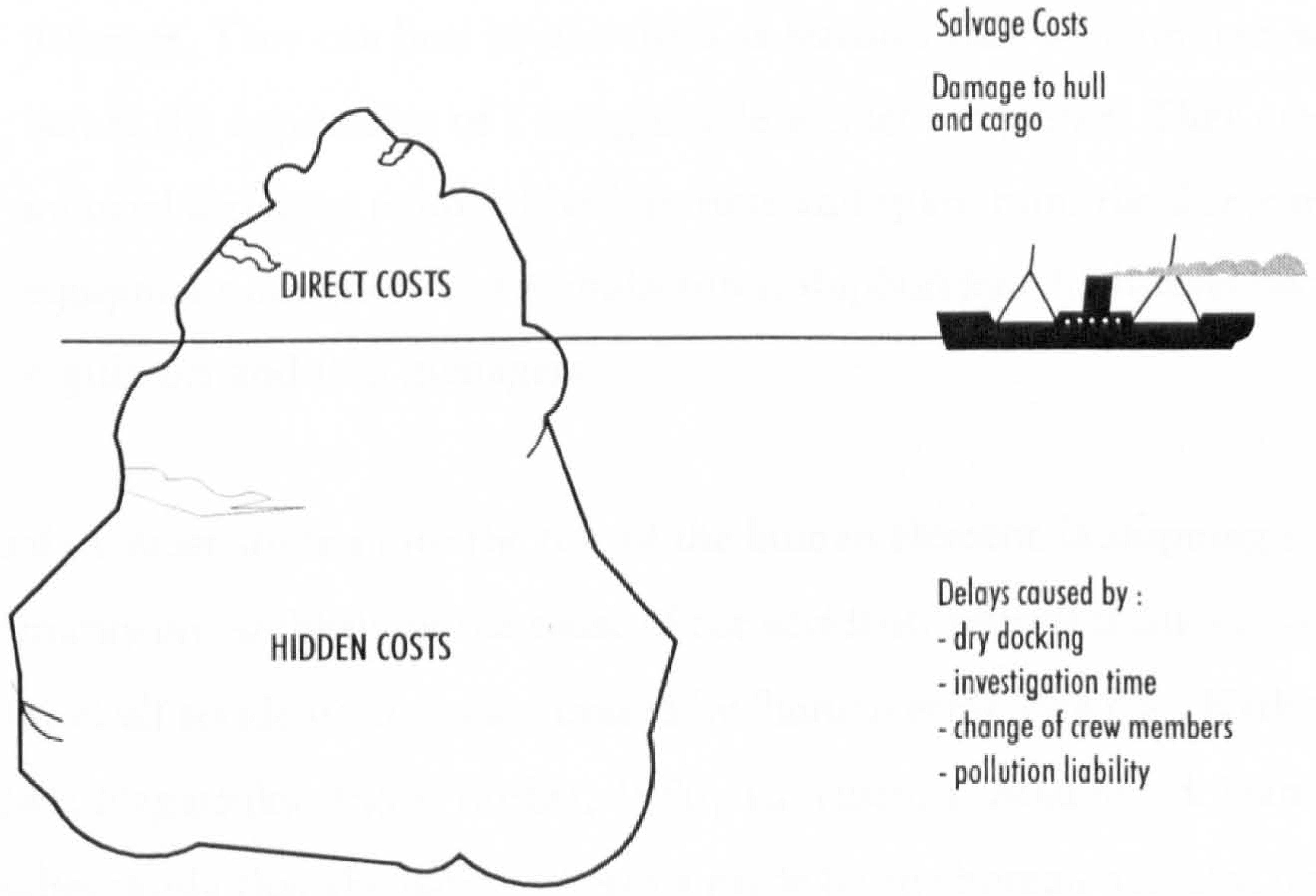

Figure 3 Hidden costs can be likened to the iceberg principle where 2/3 of the mass is invisible below the water line (adapted from Heinrich et al., 1980)

Although the above figures are inexact, it can be argued that reducing the number of collisions and groundings would bring considerable tangible benefits, directly and indirectly. Thus, exploring new ways of preventing future accidents is prudent.

1.2.3 Human factors and causes of accidents

Most accidents result in some form of investigation into the causes. Traditionally post-accident analysis has focused on finding someone to blame. Reason (1990a) suggests that there is a need to differentiate between the two ways in which the human operator contributes to the accident:

1) Active failures are errors and violations that have a direct adverse effect and are generally associated with the activities of 'front-line' operators, e.g., the Master and/or the navigating officer.

2) Latent failures are decisions or actions, where the damaging effects may lie dormant for a long time. These only become apparent when they combine with local triggering factors (i.e., active failures, technical faults, atypical system conditions) to breach the system's defences. They can best be described as features that were present within the system well before the appearance of a recognisable accident sequence. They are most likely to be induced activities removed both in time and space from the direct man-machine interface: equipment designers and manufactures, shipbuilders, high-level decision makers, regulators and ship managers.

To date most studies into the role of the human element in shipping accidents have focused primarily on establishing the cause of the accident. Several studies have concluded that some 80% of all accidents at sea are caused by 'human error' (see e.g., Karlsen & Kristiansen, 1981; Nagatsuka, 1993; Rother, 1980; Tuovinen, Kostilainen & Hämäläinen, 1984). These studies imply that the nature of errors made by the human operator on the ship's bridge is perhaps somehow distinct from errors made elsewhere in the chain of events.

However, when an accident occurs, as noted by Reason (1990a), human involvement is evident on many other levels, including during the design and manufacturing of bridge equipment, training, inspections and the development of rules and regulations (shown in figure 4).

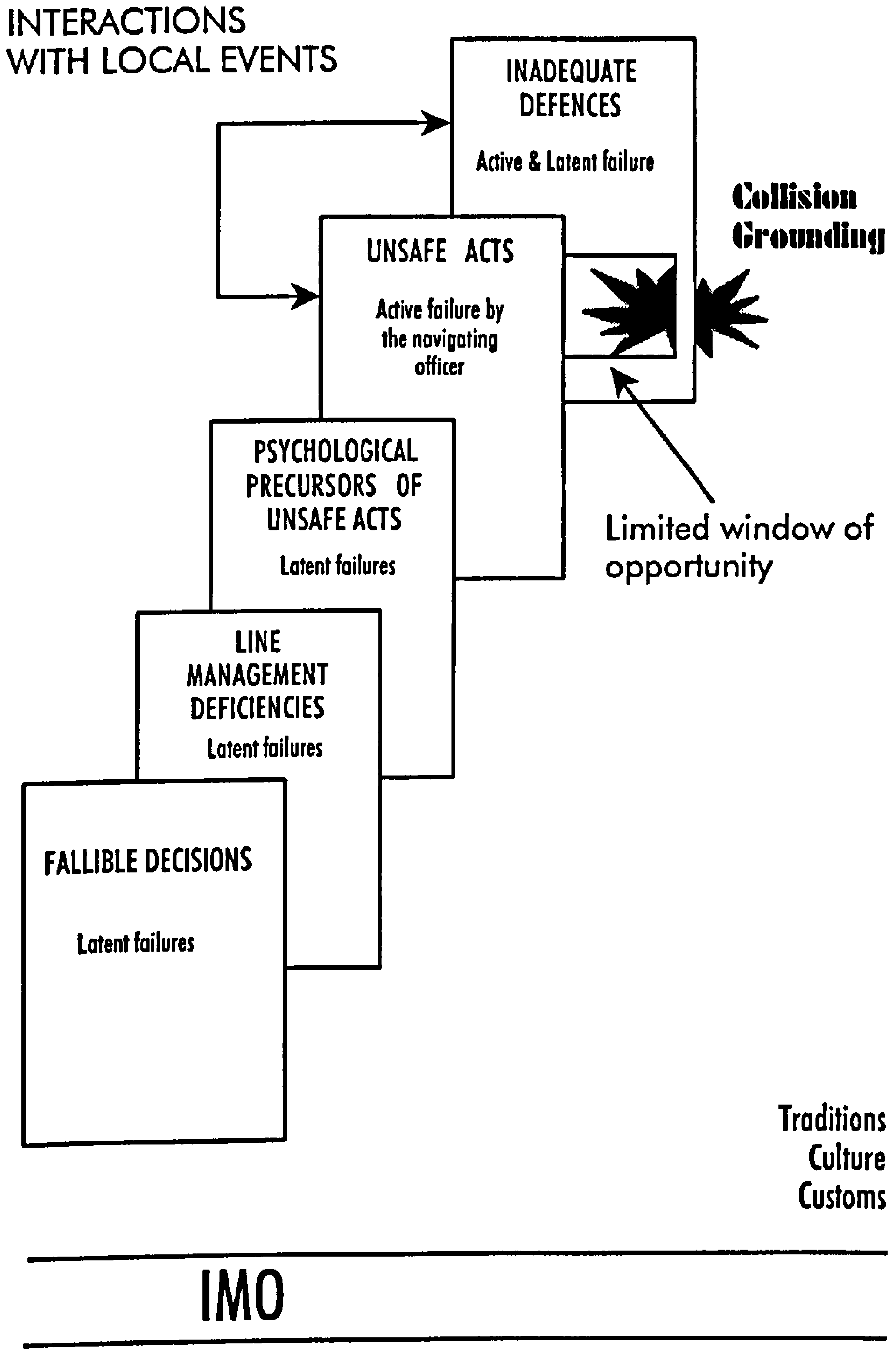

Figure 4 **The different human contributions to the breakdown of the navigational system as mapped on the basic elements of production (derived from Reason, 1990a).**

Figure 4 shows that an accident may be caused by a fallible decision made by top-level decision-makers, e.g., government departments, shipowners, shipbuilders and so on. The

International Maritime Organization (IMO) has no enforcing powers and is therefore considered outside the ultimate decision making process.

In illustration, the ferry the *Woodside I*, with some 20 passengers onboard, departed the Halifax Ferry terminal for Woodside in reduced visibility without first determining the position and intentions of other shipping. The OOW was unaware of the position of the tug the *Tussle* until the near collision. The *Woodside I* had not been informed of the presence of the other vessel by the VTS. Neither vessel attempted to communicate with the other and neither vessel made any significant reduction in speed. Thus the report into the dangerous occurrence between these two vessels shows the following latent and active failures (Transportation Safety Board of Canada, 1993a):

1. The city of Dartmouth had no defined policy for minimum operating standards for navigation equipment to help ferry masters in making informed decisions.	FALLIBLE DECISIONS BY TOP-LEVEL DECISION MAKERS
2. Contrary to its operations manual Vessel Traffic Services advised only one vessel of the other vessel's departure.	LINE MANAGEMENT DEFICIENCY
3. Neither officer in charge had completed a radar observer's course. Together with a familiarity of the harbour area this may have resulted in a false sense of security.	PSYCHOLOGICAL PRECURSORS OF UNSAFE ACTS
4. Did not report to the Vessel Traffic Services before leaving the port. Neither vessel attempted to establish timely contact with the other vessel	UNSAFE ACTS BY NAVIGATING OFFICERS

The nature of shipping today is such that accidents at sea rarely attract attention from the general media unless it results in a major loss of life (e.g., the *Herald of Free Enterprise*[2], the *Estonia*[3]) or extensive pollution (e.g., the *Exxon Valdez*[4]).

Technological advances or changes in regulations may not always have the intended effect for preventing accidents. For example, air-bags in cars were considered one of the greatest automotive safety devices in decades. Iacocca (Iacocca & Novak, 1985), the then Chairman of Chrysler, noted at an early stage that air-bags would only be effective when used with seat-belts.

In 1996 air-bags were being blamed for nearly 50 deaths in the USA in the previous three years. This is in part because in the USA barely 60% habitually fasten their seat belts. In Canada, Britain, Germany and Scandinavia, where nearly everyone wears their seat-belts, fewer deaths have been associated with air-bags (Anon., 1996). This suggests that human behaviour may have a significant effect on whether a preventive measure will have the intended effect.

1.3 Measuring safe navigation

Although 'human error' has been generally accepted by the shipping industry as a major cause of collisions and groundings, there appears to be a lack of systematic research to identify the specific human factors that contribute to accidents at sea. Human factors in the marine environment have, in the past, attracted less attention from research workers. Research is generally carried out within the realms of individual nautical colleges or maritime organisations.

Useful research into human factors has been carried out in other industries such as in the aviation, nuclear processing and the automobile industries (see e.g., Rosekind et al., 1994; Reason, 1990b; Davies, Parasuram & Toh, 1984). It appears that the majority of research

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[2] The UK registered ro-ro passenger/car ferry the *Herald of Free Enterprise* capsized on March 6, 1987 in Zeebrugge with the loss of 192 lives

[3] The Estonian registered ro-ro passenger/car ferry the *Estonia* foundered on September 28, 1994 resulting in the greatest loss of life in the Baltic Sea in times of peace

[4] The U.S. registered oil tanker *Exxon Valdez* grounded on Bligh Reef in Prince William Sound, near Valdez, Alaska on March 24, 1989 rupturing eight cargo tanks resulting in catastrophic damage to the environment

effort into safety at sea has been spent in relatively few areas possibly exceeding their relative importance on the whole, e.g., researchers have focused on post-accident investigations and collision avoidance (see e.g., Karlsen & Kristiansen, 1981; Nagatsuka, 1993; Rother 1980; Tuovinen et al., 1984).

Where does the human element fit into the concept of safe navigation? Some theories that have been put forward as measures of safe navigation are: (1) encounter rates based on the ship domain theory (see e.g., Goodwin, Lamb & Kemp, 1983), (2) collision risk indexes based on the assumption that some encountered situations are more dangerous than others (see e.g., Gonin, 1993) and (3) navigator work loads measured as potential encounters in a given area or accuracy of track keeping (see e.g., Schuffel, Boer & Breda van, 1989; Hammell & Puglisi, 1980). From a human factor's point of view, the above examples of ways to measure safe navigation are considered limited because of the complexity of the working environment which is affected by regulations, technology and human behaviour.

1.3.1 The relationship between safety and danger

Navigation is a learned skill the same way as driving a car. Thus the navigating officer must be taught how to avoid dangerous situations. Some learned skills become automatic with time, involving no conscious control. In contrast, controlled processes require conscious effort. They are performed sequentially and generally take much longer to execute than automatic processes (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977).

Norman (1976) has emphasised the importance of automatic processes for various safety practices especially in high-risk complex occupations, including navigation. For example, the navigating officer of the *River Embley*, on the request of the pilot, sounded the whistle automatically, when they realised that the HMAS *Freemantle* was bearing down on an immediate collision course. It should be noted, that after the event, the officer could not recollect whether or not he had managed to complete the whistle signal (Marine Incident Investigation Unit, 1997).

However, in some situations automated behaviour may also increase the risk of an accident. The role of the cockpit checklists is to ensure that all required pre-flight checks are carried out. Unintentionally this standard operation may, with time, become automated to the extent that, if distracted, the pilot may routinely mark off the list without checking visually or physically the indicated controls. Barley (1991) cites several aviation accidents where a contributory factor was the failure of the crew to complete the checklist. Thus man's ability to acquire automatic behaviour is both a weakness and a strength.

To avoid a dangerous situation the navigating officer must know what the danger is, (e.g., the draft of the ship and minimum underkeel clearance) and where the danger is, (e.g., shallow waters). The basic concept of draft and underkeel clearance is the same for all ships. However, in practical terms there is a vast difference between the manoeuverability of, for example, a car ferry with a draft of 5 m (16 ft) and a fully laden VLCC with a draft of more than 15 m (49 ft).

The knowledge required to avoid dangerous situations and navigate safely is extensive and stretches from basic seamanship and pure navigation skills to awareness of human behaviour, limitations of technology and communication skills.

1.4 Basis for this study

The number of collisions and groundings occurring each week is relatively small in comparison with the worldwide number of ship movements. Nevertheless, as discussed above, they continue to occur and the costS of such accidents are significant. Research into safety at sea has generally concentrated on the results of the weaknesses of the navigating officer by focusing on WHAT went wrong. Consequently, changes in regulations or new technology have been introduced with the aim of preventing him from committing unsafe acts.

Andersen and Fredriksson (1995) examined whether collisions make you smarter, i.e., whether the maritime community overall learns from collisions at sea. They suggest that the lack of benefits from collision investigations are mainly due to the difficulty of measuring the effect of safety improvements.

The working environment of the ship's bridge has changed because of recent advances in electronics. The development of bridge aids appears to have moved the navigating officer almost imperceptibly from a controlling to a monitoring position. Generally, navigating officers are trained to a certain standard according to the International Maritime Organization regulations. In theory, they operate similar bridge equipment under similar oceanographic and atmospheric conditions and according to specific rules and regulations. However, in practice this is not the case (see further Chapter 3).

1.5 Value of this study

Considering the lack of recorded basic human factors data in the marine environment, the next logical step was to consider data sources that would individually or collectively provide additional knowledge of human factors specifically on the ship's bridge. Readily available sources are:

1. Pre-classified databases of collisions and groundings. Such databases could provide the basis for a simple analysis of factors that may have contributed to the accident.

2. Officially published accident reports of groundings and collisions. Examining such reports in detail employing a non-blame seeking strategy could provide additional detail that would add to the existing human factors knowledge in the marine environment.

3. Voluntary Incident Reports could provide similar situational data as accident reports. If they could be examined using the same method, they could provide a useful complement to the above data.

4. A survey using a questionnaire could provide supplementary data. Such a method could, e.g., confirm whether navigating officers would be willing to participate in more comprehensive human factors research and ascertain the diversity of ship types and trading patterns.

It was anticipated that the systematic examination of each data source individually would provide enhanced knowledge of specific human factors on the ship's bridge. In addition, it was anticipated that some form of collective examination of the selected data sources could be carried out, thus improving the existing human factors' knowledge base in the marine environment.

The enhanced knowledge would also assist the maritime community at large by providing information that:

- Would ensure that relevant human factors could be considered when developing new technology or rules/regulations.

- Assists in focusing on specific human factors which can be used to improve the design of ships' bridges and user-interfaces of navigation aids.

1.6 Guide to this study

Chapter 2 will examine briefly the concept of 'human error' and its past, present and future role in accidents at sea. In the absence of industry specific research it will draw heavily on human factors research carried out in other industries.

Chapter 3 will outline the framework of the working environment on the ship's bridge, how the human element is affected by the organisational framework provided by the IMO, and the physical environment of the ship's bridge.

Chapter 4 will explore the SHELL concept (Edwards, 1972) where Software, Hardware, Environment and Liveware represent the components with which human factors on the aircraft flight deck can be addressed. Human factors in general will be examined focusing on those affecting the navigating officer on the ship's bridge in particular. These include the design of hardware and related information processing, learning processes and training, communication in the marine environment and a brief overview of health and safety at sea. It is intended that this Chapter could provide practical guidelines to human factors on the ship's bridge.

Chapter 5 will examine data collection techniques and describe the data sources used in this study in detail. The limitations of the current coding systems in the analysis of accidents will be discussed. A marine human factor's classification scheme based on the idea of 'Catalysts' will be presented and discussed.

Chapter 6 will examine data processing and presentation. Chapter 5 introduced a marine human factor's classification system and the associated data will be presented in table format followed by a brief examination of the data. The four sources provide comparable and supporting information which is presented in a tabular form. It is intended to be viewed as descriptive, rather than analytical, i.e., to show patterns of 'catalysis'.

Chapter 7 will discuss the application of the marine human factors classification system presented in this research. It will be shown that the classification system can provide a recording technique that describes human factors in a more functional manner thus presenting information that can be used to test theories of accident causation. To illustrate the advantages of the marine human factors' classification system the groundings of the *Exxon Valdez* and the *Sea Empress* will be examined as case studies.

Chapter 8 will review the outcome of the previous chapters, suggest recommendations and show how objectives have been achieved.

Appendix A provides a general classification scheme or taxonomy of different human factors' methodologies. Appendix B provides a selection of human factors studies applicable to the marine environment and appendix C provides a selection of studies related to auditory warnings. These have been arranged in table format which are cross referenced to the source of the study arranged at the end of the table. Appendix D includes a copy of the questionnaire into human factors relating to navigation.

A glossary of more frequently used acronyms, abbreviations and terminology is included to assist in the examination of this study. In addition a brief list of useful Web Sites is provided.

Bibliographic references to the work cited are given in parentheses in the text. The references are provided in a list at the end of the thesis, set out in alphabetical order. References to court cases and similar documents are shown throughout the thesis as footnotes.

It is recognised that many seafarers today are female but, in the interest of brevity the convention of third person masculine will be used to refer to navigating officers throughout this work.

CHAPTER 2

'HUMAN ERROR' IN THE MARINE ENVIRONMENT

2.1 Introduction

Whenever an accident at sea has occurred, seafarers worldwide sigh in despair "no doubt it will be attributed to 'human error'". To a certain degree this has become the norm in the shipping industry, if all else fails attributing the cause to the actions of an unknown individual is an easy option.

This chapter considers the evolution and role of 'human error' in accidents at sea. The IMO has acknowledged the role of 'human error' in shipping accidents and as a result has proposed a working definition (IMO, 1996a):

> "A departure from acceptable or desirable practice on the part of an individual or group of individuals that can result in unacceptable or undesirable results."

The concept of human error is outlined and a current study is explored in this Chapter. Human error identification techniques and relevant human factors' studies in the marine environment are examined.

2.2 The evolution of 'human error' in accidents at sea

Statistics of accidents at sea have been collected since the last century. Some of these led to a growing concern over the number of collisions that seemed to have resulted from the lack of common rules for overtaking, crossing and meeting end-on (Gray, 1867).

The origin of the statement "80% of all accidents at sea are caused by 'human error' can be traced back to the late 1970's (Gray, 1978) and has been discussed elsewhere in detail (Barnett, 1989). These early studies suggest that researchers tried to find solutions to human factors' problems by employing the same methodology utilised for problems resulting from situational factors. Consequently the human element in casualty reports was examined in detail. The most significant group was labelled 'human error' and in the beginning little further analysis, other than stating this all-encompassing category, was carried out. It soon became apparent that to prevent future accidents required a deeper analysis of the factors that induced 'human error'. Throughout the 80's and early 90's statistics of accidents at sea were compiled and analysed resulting in the publication of several studies utilising different definitions for the causes of the accidents. A few studies illustrating this diversity are shown in Table 2 and Table 3. The researchers used various sources of data attempting to identify causal factors.

Tables 2 and 3 are intended as an illustration and should not be viewed as especially authoritative because of the miscellany of terms used in grouping the accidents. The tables show clearly that the lack of uniform classification of the data renders it difficult to compare the studies. It should also be noted that although it has become generally accepted that 'human error' causes more than 80% of all accidents at sea (see e.g., Department of Transportation, 1995) the figures shown in the tables range from 15.3% to more than 92%.

Published By	Time Span	No of Casualties Analysed	Type of Accident Data	% 'Human Error' in collision when stated	Time of Day when stated	Source of Data
Det Norske Veritas, Norway(i)	1970-1978	2742	Collisions & Groundings	61.6%		Reported collisions and groundings involving Norwegian ships
Helsinki Commission, Finland(ii)	1979-1981	471	All	17%	23% between 0400-0800	Ship casualties in the Baltic
UK P&I Club, UK(iii)	1987-1991	123	All	90%	32% between 0400-0800	Major claims
JAMRI, Japan(iv)	1985-1991	2491	All	>90%		Maritime casualties in Japan that required outside assistance
ISE, Brehmen, Germany(v)	1977-1978	1528	All	88%	ca 22% between 0400-0800	United States Coast Guard
Tavistock, UK(vi)	year ending 1970	415	All	> 92%		Casualties to British Merchant Ships
Jordbruksdepartementet, Sweden(vii)	1975-1977	54	Collisions	ca. 90%		Accidents reported to the Swedish Maritime Administration
Wagenaar & Groeneweg, Holland(viii)	1982 -1985	100	All	15.3%		Accidents reported to the Dutch Shipping Council

i) Karlsen J.E., (1980), "Analysis of causal factors and situation dependent factors, Project: Cause Relationships of Collisions and Groundings, Det Norske Veritas Report No: 80-1144

ii) Tuovinen P., Kostilainen V. & Hämäläinen A., (1984), "Studies on Ship Casualties in the Baltic Sea 1979-1981, Baltic Sea Environment Proceedings, Helsinki Commission, Report No: 11

iii) UK P&I Club, (1992), Analysis of Major Claims

iv) Nagatsuka S., (1993), "Analysis of World/Japan's Shipping Casualties and Future Prospects Thereof, Japan Maritime Research Institute, Report No: 47

v) Rother D., (1980), "Ship Casualties - An Analysis of Causes and Circumstances", The Institute of Shipping Economics, Brehmen, Germany

vi) Quinn P.T. & Scott S.M., (1982), "The Human Element in Shipping Casualties", The Tavistock Institute of Human Relations, London, UK

vii) Komittén för miljörisker vid sjötransporter, (1979), Ren Tur - program för miljösäkra sjötransporter - Annex 6, Statens offentliga utredningar, 1979:43, Jordbruksdepartementet, Sweden

viii) Wagenaar W.A. & Groeneweg J., (1987), "Accidents at Sea: Multiple causes and impossible consequences", International Journal of Man-Machine Studies, 27, 587-598

Table 2 Summary of eight studies into the causes of accidents at sea

Det Norske Veritas(i)	Helsinki Commission(ii)	UK P&I Club(iii)	JAMRI(iv)	ISE(v)	Tavistock(vi)	Jordbruks-departementet(vii)	Wagenaar & Groeneweg(viii)
External conditions; Technical failure; Inadequate navigational factors; Navigational error; Non-compliance; Other ship	Environmental conditions; Technical deficiencies and their reasons; Human factors and actions	Officer error; Eng officer error; Crew error; Shore error; Pilot error; Structural failure; Mechanical failure; Equipment failure; Under investigation; Other;	Substandard ship operation control; Substandard ship handling; Noncompliance with navigation rules; Lack of attention to weather conditions; Imperfections of equipment and instruments; Improper handling of machinery and tools; Inadequate operation by seamen; Force majeure	Personnel fault; Calculated risk; Restricted manoeuvring room; Storms-adverse weather; Unusual currents; Sheer-suction-bank suction; Depth of water less than expected; Failure of equipment; Unseaworthy-lack of maintenance; Floating debris-submerged object; Inadequate tug assistance; Fault on part of other vessel or person; Unknown-insufficient information;	Knowledge; Experience; Judgement; Communication; Rule violation; Use of equipment; Organisation; Uncertain; Other;	Officer error; Pilot error; Influence of alcohol; Inadequate watchkeeping; Failure of navigation equipment; Violation of navigation rules	Cognitive system; Social System; Situational System

i) Karlsen J.E., (1980), "Analysis of causal factors and situation dependent factors, Project: Cause Relationships of Collisions and Groundings, Det Norske Veritas Report No: 80-1144

ii) Tuovinen P., Kostilainen V. & Hämäläinen A., (1984), "Studies on Ship Casualties in the Baltic Sea 1979-1981, Baltic Sea Environment Proceedings, Helsinki Commission, Report No: 11

iii) UK P&I Club, (1992), Analysis of Major Claims

iv) Nagatsuka S., (1993), "Analysis of World/Japan's Shipping Casualties and Future Prospects Thereof, Japan Maritime Research Institute, Report No: 47

v) Rother D., (1980), "Ship Casualties - An Analysis of Causes and Circumstances", The Institute of Shipping Economics, Brehmen, Germany

vi) Quinn P.T. & Scott S.M., (1982), "The Human Element in Shipping Casualties", The Tavistock Institute of Human Relations, London, UK

vii) Komittén för miljörisker vid sjötransporter, (1979), Ren Tur - program för miljösäkra sjötransporter - Annex 6, Statens offentliga utredningar, 1979:43, Jordbruksdepartementet, Sweden

viii) Wagenaar W.A. & Groeneweg J., (1987), "Accidents at Sea: Multiple causes and impossible consequences", International Journal of Man-Machine Studies, 27, 587-598

Table 3 Grouping of major causes of accidents

Another major disadvantage is the lack of worldwide annual statistics of the number of collisions and groundings. The main source of worldwide statistics accessible to the public are published by Lloyd's Register of Shipping. These, however, include only ships that are declared a Total Loss or a Total Constructive Loss[5]. Figures derived from different sources for the number of collisions and groundings can vary significantly as shown in table 4.

Source	No of ships involved in Collisions	No of Ships Grounded or Wrecked/Stranded
Lloyd's Register of Shipping(i)	36	45
Danish Maritime Administration(ii)	32	35
Swedish Maritime Administration(iii)	39	57

(i) Lloyd's Register of Shipping Casualty Return 1991
(ii) Dansk Søulykkesstatistikk for 1991 og 1992, Søfartsstyrelsen, December 1993
(iii) Extracted from data provided by the Swedish Maritime Administration

Table 4 No of ships involved in collisions and groundings in 1991

The figures were obtained from published sources and have not been cross-referenced. Therefore it is possible that the same ship is represented in more than one source. This is particularly likely for the data published by the Swedish and Danish authorities because of the geographical proximity of the two countries. Thus because of a possible overlap these figures cannot be aggregated to provide an accurate figure for the total number of collisions or groundings in 1991.

2.3 The role of 'human error' in accidents at sea

A significant weakness of the studies shown in tables 2 and 3 and other similar studies is that they do not provide sufficient detail to provide clear or specific action. For example, inattention may be remedied by increased vigilance but the question remains how. This general categorisation of the causes has perhaps led to some, largely, unsubstantiated

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[5] Costs of repairs are higher than the value of the ship

presumptions. Over the years these have been discussed informally in nautical journals and the maritime press (see e.g., Lloyd's List, Seaways). They can be summarised broadly as follows:

2.3.1 Competence and Certification of Seafarers

The competence of seafarers depends on many factors, notably the quality of their initial training, length of sea-time and experience. There is a general belief that the competence of seafarers has declined in the last decades (see e.g., letters to the editor in Seaways, Lloyd's List). This is attributed in part, to the decreasing employment of seafarers from so called 'traditional maritime countries' and subsequent increasing employment of crew members from so called 'developing maritime countries'. There is a general belief that navigating officers from 'developing maritime countries' are less competent but there appears to be no published studies confirming these assumptions.

2.3.2 Fatigue

The role of fatigue as a direct or primary cause is, as yet, not clear from published studies. There is a strong feeling among many active seafarers that fatigue is a major problem. The purpose of IMO's Safe Manning certificate is to provide guidelines to ensure that ships carry sufficient numbers of crew members to navigate safely, e.g., preventing them from suffering from fatigue.

2.3.3 Lack of common language

Communication is typically assumed to involve a common language but, as will be explained in Chapter 4, this is a simplistic view of communication at sea. The employment of mixed crews onboard ships is not a new concept. Nevertheless, ships increasingly carry mixed departments, i.e., a complement of Master and deck officers with no common native language. Existing research does not clearly show the role of a common native language in preventing accidents.

2.3.4 Bridge Resource Management

During the last few years it has emerged that many accidents resulted from poor interaction between the bridge team members (Transportation Safety Board of Canada, 1995). In the aviation industry most commercial planes are piloted by two persons, a pilot and a copilot. On the ship's bridge the navigation team may include members from outside the ship, i.e., a marine pilot. Conversely, there may at times be only one person on the bridge. Additionally the bridge team may need to coordinate with members outside the physical environment of the bridge, e.g., with mooring parties or tug Masters.

2.3.5 User-Interfaces

As navigation aids have become more computer based, it has been suggested that poor design of user-interfaces and inadequate attention to the ergonomics of the ship's bridge may result in errors that cause accidents (Merenkulkulaitos, 1997).

For example, the passenger ferry the *Sally Albatross* went aground due to the navigating officer failing to fully understand the operation of a new radar system equipped with superimposed charts and connected to a Differential Global Positioning System (DGPS) (Oikeusministeriö, 1994). Concerns over such problems have also been expressed by active seafarers in nautical publications such as Seaways, Sjömannen, Schiff und Hafen and Merimies.

2.4 The concept of 'human error'

The concept of 'human error' has been researched in depth employing different Human Error Identification Techniques (HEI), see further e.g., Rasmussen (1990), Reason (1990b) Zapf & Reason, (1994), Wagenaar & Groeneweg, (1987), Pedrali & Cojazzi (1995), Stanton (1997), Leplat (1987) and Kirwan (1992a/b).

As a result of the above and other studies several HEI techniques have been proposed and a selection is shown in table 5. Notwithstanding the attention the HEI techniques have attracted, Kirwan (1995) suggests that there is no single 'best' technique available. The HEI techniques can be used:

- to evaluate interface design, workload or other human factors
- for Human Reliability Assessment

The basis for HEI techniques is to examine tasks and identify possible errors that may occur, perhaps as a result of poor interface design, inadequate training or other human factors. HEI techniques can be model based (e.g., Skill-Rule-Knowledge (SKR), Generic Error Modelling Systems (GEMS)) or non model based (resulting in simple error taxonomies). A selection of Human Error Identification Techniques are shown in table 5.

It appears that the SRK model proposed by Rasmussen (1983) has become a dominant HEI model. There has been a trend towards modifications of this model, e.g., GEMS (Reason, 1990b). This model focuses on different types of 'human error' and the factors that promote errors. It shows that different types of errors occur in different parts of the system and thus require different remedies. In this model errors have thus been categorised into slips, lapses, mistakes and violations as illustrated in figure 5.

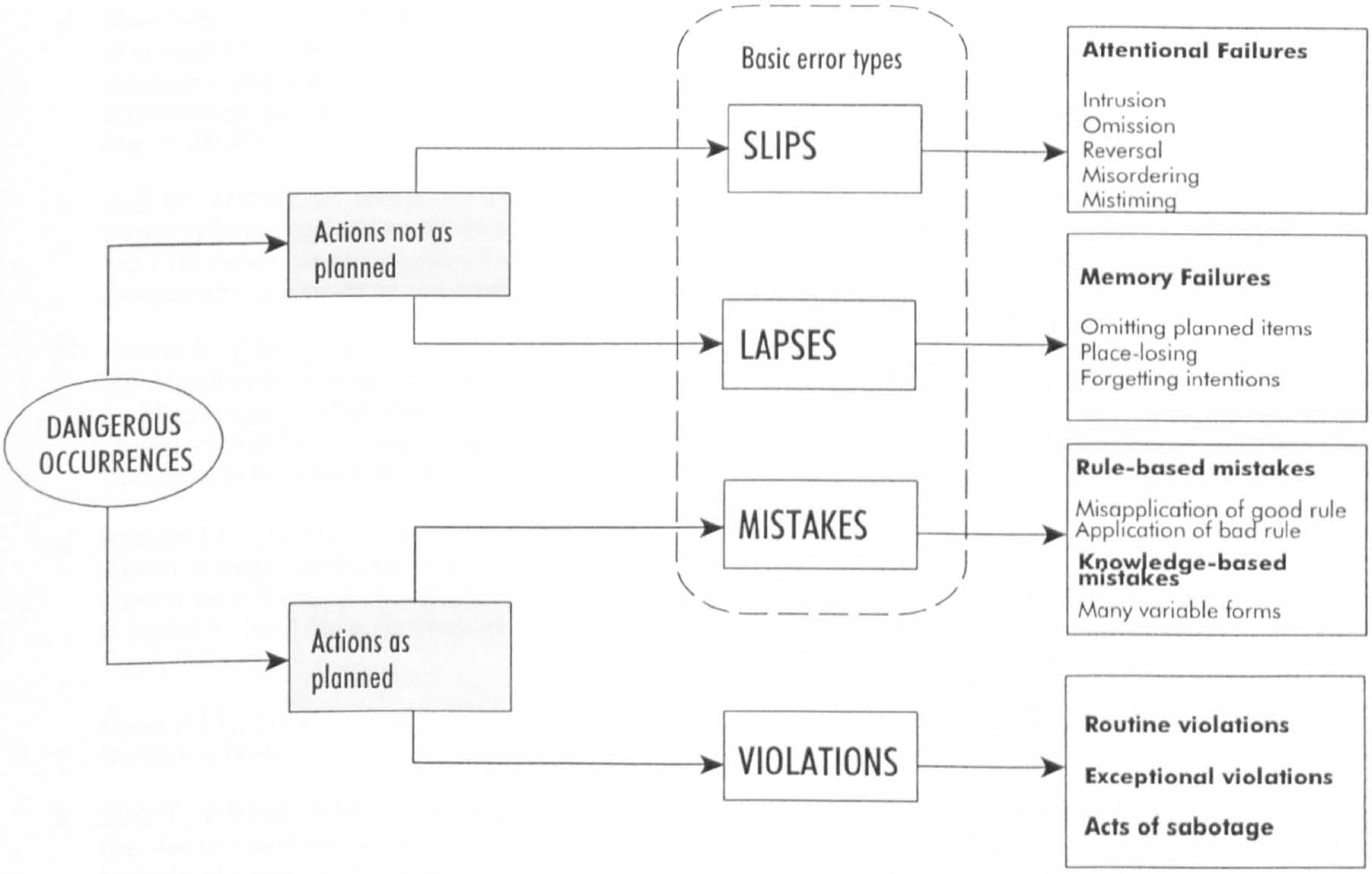


Figure 5 Summary of error types (derived from Reason, 1990b)

Accident Dynamic Sequence Analysis (ADSA)[a]
Cognitive Environment Simulation (CES)[b]
Confusion Matrix Analysis (CMA)[c]
CREW PROblem solving simulation (CREWPRO)[d]
Critical Action and Decision Approach (CADA)[e]
Error of Commission Analysis (EOCA)[f]
Generic Error Modelling System (GEMS)[g]
HAZard and Operability Study Technique (HAZOP)[h]
Human Reliability Management System (HRMS)[i]
Influence Modelling and Assessment System (IMAS)[j]
INTENT[k]
Murphy Diagrams[l]
Potential Human Error Causes Analysis (PHECA)[m]
Skill, Rule and Knowledge-based behaviour model (SRK)[n]
SNEAK[o]
Systematic Human Error Reduction and Prediction Approach (SHERPA)[p]
Technique for Human Error Rate Prediction (THERP)[q]

[a] Hsueh K-S., Soth L. & Mosleh A., (1994), A simulation study of errors of commission in nuclear power accidents, in PSAM-II Proceedings, pp 066-1 - 066-6, San Diego, CA, March 20-25

[b] Woods DD., Pople H.E. & Roth E.M., (1990), The cognitive environment simulation as a tool for modelling human performance and reliability, Nureg/CR-5213, USNRC, Washington DC

[c] Potash L., et al., (1981), Experience in integrating the operator contribution in the PRA of actual operating plants, Proceedings of ANS/ENS Topical Meeting on PRA, New York, American Nuclear Society

[d] Shen S-H., Smidts C. & Mosleh A., (1994), Elements of a model for operator problem solving and decision making in abnormal conditions, in PSAM-II proceedings, pp 060-7 - 060-12, San Diego, CA, March 20-25

[e] Gall W., (1990), An analysis of nuclear incidents resulting from cognitive error' Paper presented at the 11th Advances in Reliability Technology Symposium, University of Liverpool, April 1990

[f] Kirwan B., (1995), Review of Human Error Identification techniques for use in Nuclear Power and Reprocessing HRA/PSA: Volume II, IMC GNSR Project HF/GNSR/22, Industrial Ergonomics Group, University of Birmingham, March

[g] Reason J.T., (1987), Generic error modelling system: a cognitive framework for locating common human error forms, in Rasmussen J., Duncan K.D. & Leplat J., (eds) New Technology and Human Error, Wiley

Reason J.T., (1990), Human Error, Cambridge University Press

[h] Kletz T., (1974), 'HAZOP and HAZAN - notes on the identification and assessment of hazards', Institute of Chemical Engineers, Rugby

[i] Kirwan B., (1990), Human reliability assessment, in Wilson J.R. & Corlett N., (eds) Evaluation of human work, Taylor & Francis, London, pp 706-754

[j] Embrey D.E., (1986), Approaches to aiding and training operators' diagnoses in abnormal situations, Chem Ind., July 7, pp 454-459

[k] Gertman D.I., (1991), INTENT: a method for calculating HEP estimates for decision-based errors, Proceedings of the 35th Annual Human Factors Meeting, San Francisco, September 2-6, pp 1090-1094

[l] Pew R.W., Miller D.C. & Feehrer C.S., (1981), Evaluation of proposed control room improvements through analysis of critical operator decisions, NP 1982, Electric Power Research Institute, Palo Alto, CA

[m] Whalley S.P., (1988), Minimising the cause of human error, in Libberton G.P., (ed), 10th Advances in Reliability Technology Symposium, Elsevier

[n] Rasmussen J., Pedersen O.M., Carnino A., Griffon M., Mancini C. & Cagnolet P., (1981), Classification system for reporting events involving human malfunction, Riso-M-2240, DK-4000, Riso National Laboratories, Denmark

[o] Hahn H.A. & deVries J.A., (1991), Identification of human errors of commission using Sneak Analysis, Proceedings of the Human Factors Society 35th Annual Meeting, San Francisco, September 2-6, pp 1080-1084

[p] Embrey D.E., (1986), SHERPA: a systematic human error reduction and prediction approach, paper presented at the International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxwill, Tennessee, April 1986

[q] Swain A.D. & Guttman H.E., (1983), A handbook of human reliability analysis with emphasis on nuclear power plant applications, USNR-Nureg/CR-1278, Washington, DC 20555

Table 5 Human Error Identification (HEI) Techniques (extracted from Kirwan 1995 and Kirwan 1992 a/b)

Grouping errors within taxonomies and determining underlying psychological mechanisms has resulted in the following classification of 'human error' (Stanton, 1997):

- Different error forms, e.g., capture error, description error, data driven errors, association and activation errors and loss of activation errors.

- Psychological mechanisms, e.g., failure of memory retrieval in lapses, poor perception and decision making in mistakes and motor execution problems in slips.

2.5 'Human error' in the marine environment

Traditional approaches to investigating 'human error' in accidents at sea have typically followed general 'human error' research, frequently concluding that an individual, i.e., generally the Master, was ultimately responsible for the accident.

The approach of focusing on 'human error' is highlighted by a recent a study carried out by the Maritime Administration of Finland (Merenkulkulaitos, 1997). The value of examining this study closer here is that: (1) it focuses on shipping accidents and is based on accident investigation reports, (2) it is detailed and the methodology is based on an accepted 'human error' model, and (3) it is current.

2.5.1 The Merenkulkulaitos Study

The Merenkulkulaitos study examined 8 major accidents involving Finnish ships (Merenkulkulaitos, 1997) and is based on Reason's model (Reason,1990b) referred to previously in this Chapter.

The methodology of the study is summarised in tables 6 to 8. Error types are defined as slips, mistakes and violations as shown in table 6. The researchers considered that errors may occur within three different operational categories, i.e., during the planning of the operation, assessment of the situation and decision making or when performing an activity as defined in table 7. The task/category was then related to the operational environment of ships (shown in table 8).

Type	Definition of Type	Examples
Slip	Actions-not-as planned. Typical errors made by experienced people. Slips occur to all humans on a daily basis. For instance a person realises that he is doing something else than intended or realises that he has forgotten what he intended to do.	* Slips of the tongue and gestures * Memory lapses * Incorrect performance of activity * Learning a new activity
Mistake	Planned actions do not achieve their desired result. In this case the objective or the actions have been incorrectly chosen or performed. Mistakes can be either rule or skill-based.	Wrong decision. An error made when trying to solve a familiar problem Mistake in decision making. A mistake relating to solving a problem in a new or unknown environment. When assessing the familiarity of the situation experience must be regarded from all aspects, e.g. experience in ship handling, ship management, ship in general, operation of the equipment, weather and sea conditions and geographical area.
Violation	Violations are deliberate deviations against the rules, although bad consequences are not. Violations are closely related to risk taking. Violations are not caused by of lack of knowledge or experience but the problems relate to the safety culture encouraged by management and company structure. Violations may be directly or indirectly sanctioned, e.g. discouraging the use of safety equipment or a tacit acceptance of rule violation or assessing the outcome of an activity purely based how effective it is, etc.	Routine Violations. A typical routine violation is taking a short cut or sloppy radio traffic which is based on minimum effort and a indifferent environment where violations are not reprimanded. Exceptional Violations. Exceptional violations are situational so their spectrum is relatively wide (e.g. bypassing safety devises, unsafe speed). Typical factors influencing are an immediate gain of a less safe situation, over estimating ones own experience, enjoying taking risks viewing a risk of danger as theoretical, minimal or remote.

Table 6 Definition of error types (derived from Merenkulkulaitos, 1997)

	TYPE OF ERROR		
Task/Category	Slip (Sl)	Mistake (Mi)	Violation (Vi)
Planning of Operation (Pl)	PlSl	PlMi	PlVi
Assessment of situation and decision making (As)	AsSl	AsMi	AsVi
Performance (Pe)	PeSl	PeMi	PeVi

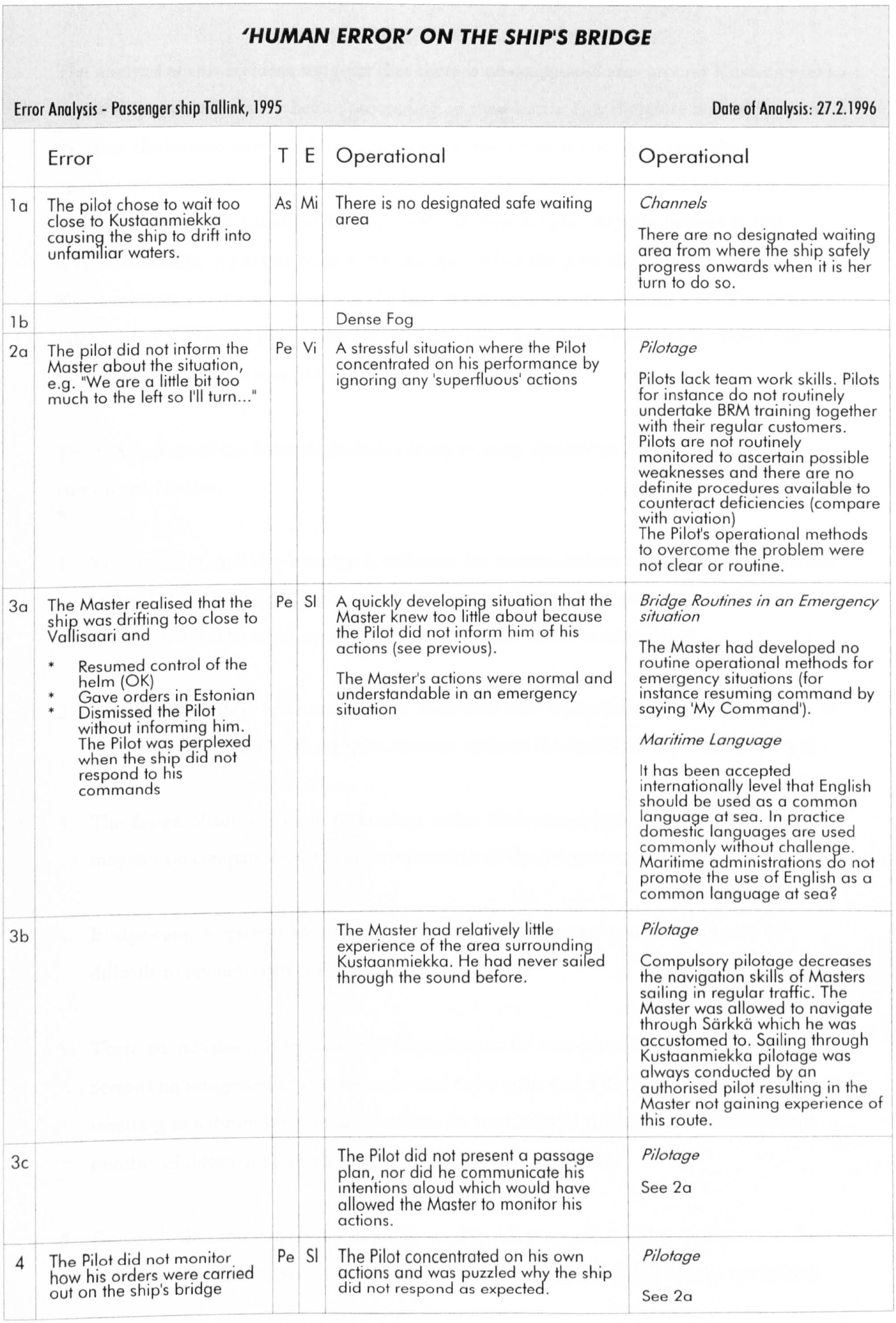
Table 7 Classification of type of errors (derived from Merenkulkulaitos, 1997)

Category	Description of Category	
Planning	Planning includes all pre-voyage planning occurring before the task has begun, for instance before departure. The planner may be for example a member of the crew, land based staff, person acting on behalf of a maritime administration or a pilot	Examples of Planning * Passage Planning * Course changes made during the voyage * Organisation of Watchkeeping * Coordination of activities * Installation of equipment * Maintenance of equipment * Planning needs for future training and education
Assessment of the situation	A person's or group's assessment of a situation resulting in a decision to solve the situation. Assessment is based on a person's experience and understanding of the developing situation. To make a decision the assessment is based on predicting the outcome of the situation in the near future (next few minutes/few seconds). At this time the situation is 'developing' and thus time for assessment and decision making is limited (compare with pre-planning) - but not all situations demand a rash decision	A person's assessment of a situation is affected by his appreciation of factors such as: * ship characteristics (type, draught, speed) * external conditions that influences the ship manoeuvring (channel width/depth, other traffic, weather and sea conditions) * Reliability of the information * How well each person manages the situation
Performance	Performance involves any orders relating directly to ship handling or orders given to another person who carries out the command	

Table 8 Description of categories (derived from Merenkulkulaitos, 1997)

The researchers developed a form to facilitate a systematic examination of the 8 accidents included in this study (a sample is shown in figure 6).

Figure 6 relates to the grounding of the passenger ferry the *Tallink* near Kustaanmiekka outside Helsinki. It illustrates the operational characteristics and the type of tasks that resulted in specific errors. The sample form confirms that an accident is unlikely to be caused by one single error made by one single person. Several different types of errors were made by the bridge team, individually and collectively.



'HUMAN ERROR' ON THE SHIP'S BRIDGE

Error Analysis - Passenger ship Tallink, 1995

Date of Analysis: 27.2.1996

	Error	T	E	Operational	Operational
1a	The pilot chose to wait too close to Kustaanmiekka causing the ship to drift into unfamiliar waters.	As	Mi	There is no designated safe waiting area	*Channels* There are no designated waiting area from where the ship safely progress onwards when it is her turn to do so.
1b				Dense Fog	
2a	The pilot did not inform the Master about the situation, e.g. "We are a little bit too much to the left so I'll turn..."	Pe	Vi	A stressful situation where the Pilot concentrated on his performance by ignoring any 'superfluous' actions	*Pilotage* Pilots lack team work skills. Pilots for instance do not routinely undertake BRM training together with their regular customers. Pilots are not routinely monitored to ascertain possible weaknesses and there are no definite procedures available to counteract deficiencies (compare with aviation) The Pilot's operational methods to overcome the problem were not clear or routine.
3a	The Master realised that the ship was drifting too close to Vallisaari and * Resumed control of the helm (OK) * Gave orders in Estonian * Dismissed the Pilot without informing him. The Pilot was perplexed when the ship did not respond to his commands	Pe	Sl	A quickly developing situation that the Master knew too little about because the Pilot did not inform him of his actions (see previous). The Master's actions were normal and understandable in an emergency situation	*Bridge Routines in an Emergency situation* The Master had developed no routine operational methods for emergency situations (for instance resuming command by saying 'My Command'). *Maritime Language* It has been accepted internationally level that English should be used as a common language at sea. In practice domestic languages are used commonly without challenge. Maritime administrations do not promote the use of English as a common language at sea?
3b				The Master had relatively little experience of the area surrounding Kustaanmiekka. He had never sailed through the sound before.	*Pilotage* Compulsory pilotage decreases the navigation skills of Masters sailing in regular traffic. The Master was allowed to navigate through Särkkä which he was accustomed to. Sailing through Kustaanmiekka pilotage was always conducted by an authorised pilot resulting in the Master not gaining experience of this route.
3c				The Pilot did not present a passage plan, nor did he communicate his intentions aloud which would have allowed the Master to monitor his actions.	*Pilotage* See 2a
4	The Pilot did not monitor how his orders were carried out on the ship's bridge	Pe	Sl	The Pilot concentrated on his own actions and was puzzled why the ship did not respond as expected.	*Pilotage* See 2a

T = Task E = Error

Figure 6 Sample form used in the Merenkulkulaitos study (Merenkulkulaitos, 1997)

The analysis of this accident suggests that there is no designated area around Kustaanmiekka where ships can wait safely before proceeding to their berth. It is therefore not sufficient to focus on the human element directly involved in the accident but the surrounding operational environment must also be considered. This analysis shows that both active errors and latent errors (discussed in Chapter 1 and outlined in figure 4) were present in this accident scenario. An active error is, for example, when the pilot chose to wait too close to Kustaanmiekka and a latent error is the lack of a designated safe waiting area. The lack of a safe waiting area could potentially increase the risk of future accidents due to increasing traffic and the introduction of larger ships.

The conclusions of the Merenkulkulaitos study relating directly to the ship's bridge are summarised below:

1. The layout of each ship's bridge is different. Recommendations and guidelines produced by the IMO and classification societies are out-of-date and only suggest minimum requirements. The integration of different navigation aids is insufficient.

2. A navigating officer often has to learn to operate new equipment 'on-the-job'. He has to learn to operate even very complex systems without the benefit of systematic training.

3. The design of automation is technology rather than user-driven. Individual components may not be compatible with the requirements of the integrated bridge system.

4. Bridge control systems have not been standardised. They are complex and may be difficult to operate correctly.

5. There are no common standards or requirements for user-interfaces on the ship's bridge. Screens on integrated bridge systems tend to be saturated with numeric information resulting in a diminished ability to assess the navigational situation. Furthermore, the number of different alarms is confusing - often even irritating.

6. Generally documentation and manuals tend to relate to individual components of the system and focus on the technology of the equipment. It is difficult for the navigating

officer to familiarise himself with the equipment and he may have to operate integrated bridge systems without access to relevant manuals and training documentation.

7. Bridge teamwork is driven primarily by personal motivations and experience rather than standard practices. The lack of standard practices is especially evident in emergency situations. The key to successful bridge teamwork is that the actions of each team member can be monitored effectively.

8. Inadequate use of check lists.

9. Bridge Resource Management training is available but has not influenced the shipowners' operational requirements. The benefit of the training is not fully understood because standard practices have not been developed across the entire industry.

10. The decision making process is impeded because tasks have not been clearly defined. This is particularly conspicuous during pilotage when it may become unclear who is really in command.

11. When an officer is promoted to assume command, he often has had inadequate instruction in ship handling and leadership training.

12. The internal communication between bridge team members on the ship's bridge suffers from a lack of standardisation. Communication with external sources also suffers from lack of standardisation. Existing standards are not complied with.

13. Automation on ships' bridges has increased mental work levels.

14. Fatigue is not considered a major problem in the Finnish merchant fleet at present. Automation enables situations to develop where crew members become bored resulting in a deterioration of the monitoring of the systems.

The Merenkulkulaitos study shows that 'Reason's Model' can be applied to examine accidents at sea, i.e., that errors can be classified according to type and related to a task onboard the ship. This analysis stresses the impact of changes in the environment of the ship's bridge.

These relate particularly to technological changes concluding that the weakest link is the lack of standardisation of user interfaces. Equipment installed on ship's bridges and operational practices vary considerably between different ships.

The study suggests that the present working environment on the ship's bridge may lead to serious consequences: tasks are difficult to learn, monitoring suffers, cooperation is ineffective and breaks in communication common. Most of the conclusions in the study focus on standardisation of equipment.

2.6 Evaluation of human factors

Human factors, as a concept, have evolved over the years to embrace different definitions and approaches depending on by whom the results are interpreted (e.g., practitioners, researchers). What one researcher or practitioner finds an invaluable aid to his work, others may consider vague or insubstantial in concept, difficult to use or variable in outcome. Wilson and Corlett (1990) provide a table of a general classification scheme or taxonomy of different human factors' methodologies which recognises the differences in approach, method (or method group), technique or measure. This table provides a frame of reference for all the methods used in the evaluation of research into human factors. The table has been included in Appendix A primarily as a convenient reference to these methodologies in the marine environment. It should be noted that the validity, reliability, sensitivity, etc. of any method is specific to the application.

2.7 Review of human factors' studies relevant to the marine environment

Following the examination of 'human error', a literature review was undertaken of approaches to research that may affect the examination of safety at sea and, more importantly, the human factors within the concept of safe navigation.

In reviewing the available literature a useful way of summarising the data is to collect it in a table as shown in Appendix B. Entries refer in one direction to the aim of the study and in the other direction to the methods used (adapted from Michon & Fairbank, 1973). Thus the rows represent the aims and the columns the methods of the various studies. The numbers in the cells refer to the list of references.

This is not intended to be an exhaustive list, but rather representative of the type of work considered relevant to the working environment of the ship's bridge. It therefore includes research carried out in other industries. The classification of the various studies and the choice of classifying them under the headings of fifteen aims and ten methods must be considered arbitrary since they are based on the author's discretion. The studies that seemed to overlap more than one area are listed in all applicable cells of the table. The table in Appendix B shows a wide diversity of both the ends and means of investigation. Finally, some applicable references may be missing because they have been unobtainable.

The objective of a method/aims analysis is to outline an overview of relevant studies. This allows examination of different methods used to study specific objectives and their relative ratio. It can be concluded that the literature does not provide a generally accepted procedure for determining what human factors affect the navigating officer inducing him to cause an accident.

Many variables affecting the navigational system have been measured, evaluated or predicted. In sampling the literature related to human factors, the task for those interested in the human element on the ship's bridge must obviously be to determine how (or even if) each of the available studies relate to human factors.

To this end the references shown in Appendix B have been divided roughly into three categories:

1. Research carried out predominantly in the shipping industry

2. Research into human factors in the aviation industry

3. General research into human factors

Only studies considered applicable to the shipping industry have been included in Appendix B.

2.8 Research carried out in the shipping industry

Current research in the marine environment relating to safe navigation focuses largely on development of 'technological fixes' and rules/regulations, possibly overlooking the long-term effects of human behaviour, e.g., social or psychological consequences of reducing the number of crew members.

2.8.1 Collision Avoidance

The value of the radar/ARPA as a tool for avoiding collisions is generally regarded highly by practicing navigating officers. Much of the research focuses on the radar/ARPA and collision avoidance. These studies have been mainly carried out through developing simulator experiments and/or surveys/interviews.

From a human factor's point of view this research is limited because collision avoidance is in theory rule based but is in practice based on interpreting a situation before the appropriate rule can be applied. Thus a collision between two ships is based on the interpretation of two people, not necessarily applying the same rule. Human factors therefore provide a fundamental underlying basis for understanding the role of the collision regulations in accidents at sea.

For example, in the events leading to the collision between the *Manuel Compos* and the *Auriga*[6] the two watchkeepers assessed the developing situation differently and therefore interpreted the situation differently. Both vessels were proceeding in southerly direction when the watchkeeper on the *Manuel Compos* observed the *Auriga* bearing about 10 degrees on starboard quarters and therefore assumed that she was overtaking the *Manuel Compos.*

The *Auriga* altered course soon thereafter and by the time of the alteration the vessels were converging at an angle of 24 degrees with a risk of collision if the courses were maintained. The watchkeeper on the *Manuel Compos* asserted that since the *Auriga* had been originally bearing more than two points abaft the beam and was proceeding faster than her, she was an overtaking vessel under rule 24 of the COLREGS. The watchkeeper on the *Auriga* argued

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[6] *The Auriga* [1977] 1 Lloyd's Rep. 384

that rule 24 only applied when the risk of collision existed. Such risk only arose when the *Auriga* had altered course by which time she was bearing less than two points abaft the beam of the *Manuel Compos* and the two vessels were now crossing. In this case rule 19 applied and it was the duty of the *Manuel Compos* to keep out of the way of the *Auriga*. It should be stressed that these arguments were made by the watchkeepers after the event and they may therefore not necessarily reflect the actual events.

Such differing assessments and interpretations invariably increases the possibility of 'human error'. The human element on the ship's bridge is in itself complex and a better understanding of human behaviour on the ship's bridge is required to ensure that the correct conclusions are drawn from research into collision avoidance.

2.8.2 Mathematical Modelling

Some researchers have focused on reducing collision avoidance to numbers which allows development of mathematical models. The chief aim of these studies have been to provide data to develop technological solutions to accident prevention at sea. Human behaviour, however, is difficult to reduce to simple figures and these studies add less to the understanding of human factors on the ship's bridge. Nevertheless, mathematical modelling can provide valuable information on human behaviour. For example, the ship's domain has been defined as the effective area around the ship that the watchkeeper would like to keep free with respect to other ships and stationary objects (Goodwin, 1975). This is a mathematical representation of the almost intuitive behaviour of the navigating officer.

2.8.3 Simulator Studies

The value of existing simulator studies for understanding collision avoidance as part of safe navigation is not self-explanatory. Firstly, there may be more than one 'correct' manoeuvre that can be carried out, e.g., (a) the give-way vessel may reduce or increase her speed or, (b) change course. Secondly, collision avoidance is an ongoing process engaging two persons. Research subjects, however, are likely to encounter ships manoeuvred according to a preprogrammed plan, rather than by other humans. The on-going assessment and interpretation of the developing situation has thus been reduced to only one side.

A disadvantage of conducting simulator studies in the marine environment is that the watchkeeper may act differently because he knows that he is not in command of an actual ship (e.g., the study may not induce operational pressures or fatigue). These conditions may not be easy to include and are costly additions to a simulator study. As the watchkeeper's actions are monitored he may also strive to carry out 'text book' manoeuvres. However, these disadvantages do not necessarily lessen the usefulness of simulator studies, especially when these factors are acknowledged in the final analysis.

The main weakness of simulator studies carried out so far, is that they cannot be compared because so many 'human' parameters have not been defined. There is a need to include background information, e.g., watchkeeping experience, type and trading patterns of ship that the navigating officer is working on at the time of the study.

2.8.4 Post-Accident Analysis

Post accident analyses have been carried out since the last century, mainly examining the causes of the accidents. It is a popular method because, if the reports can be broken down into a sufficient number of causes, the data can be analysed relatively easily. Such studies are generally quite detailed and have mostly concluded that 'human error' was a major cause of the accidents (see e.g., tables 2 (page 20) and 3 (page 21)).

The lack of standardised terminology and definitions contributes to the difficulty in replicating and comparing the studies. This has been noted by previous researchers, most recently by Andersen & Fredriksson (1995); Singh (1995); Smeaton, Moreton & Dinely, (1996).

2.9 Human factors research in the aviation industry

Shipping is a mode of transport and comparing it with, and learning from, the aviation industry is thus reasonable. The ship's bridge, however, is a unique working environment and the following distinctive factors must be considered when examining research carried out in the aviation industry:

1. During navigation the ship may be moving 24 hours a day. Her position must be fixed regularly to ensure that she follows a predetermined passage plan.

2. A voyage between two ports may include several changes of the navigational watch. The navigation of the ship is the collective responsibility of all navigating officers. The navigating officer may also spend many days beyond the sight of any land and weeks/months unable to go ashore.

3. One or more additional expert navigators, i.e., ships' pilots, may be introduced during a part of the voyage.

4. A ship has physical limitations such as draught and beam. Weather, wind and tides affect individual ships differently depending on type and geographical area, e.g., a fully laden oil tanker is affected differently to a car carrier by the same wind strengths or currents.

5. Different classes of ships, e.g., fishing or recreational vessels, compete for the same domain but may operate under different rules.

6. The legal framework of the operation of the ship depends on the port of registry.

Human factors' research has been well established in the aviation industry. The relevance of the conclusions to safety at sea may at times be less obvious. The studies shown in Appendix B are primarily included as a convenient reference for further research into human factors in the marine environment.

2.9.1 Aviation versus the shipping industry

Great care must be taken before using results gained from research carried out in other industries. Such results should mainly be used as a basis for carrying out further research within the specific working environment of the ship's bridge. For example, early recommendations for the redesign of ships' bridge equipment and bridge layout seem to originate in the aviation industry (Mara, 1969). This appears to have led to the development of the modern 'cockpit' bridge design. From a human factor's point of view there are, however, notable physical differences between an aeroplane cockpit and a ship's bridge.

The space in an aeroplane is limited due to the physical construction of the aeroplane. Therefore the ergonomics of the layout of instruments has to fit into the available space around the pilot. He must be able to reach all instruments from a fixed position. Additionally an aeroplane operates at much greater speeds, in three dimensions and the pilot is usually present continuously from take off to landing. An aeroplane pilot's working hours are also more strictly regulated than in the marine environment.

Conversely, a ship's bridge is generally spacious and the watchkeeper should be encouraged to move around on the bridge when looking out to avoid 'blind' spots caused by obstructions, e.g., the funnel. Although the top speed of a modern ship has increased, it is still relatively modest compared with an aeroplane.

The requirement of the navigating officers on this new type of bridge lay-out seems to have been reached without carrying out behavioural mapping studies. These have practical relevance for planning the location of technology and people's movement. Behavioural mapping is concerned specifically with people's behaviour in their environments. It involves an actual chart or plan of the area on which people's locations and activities are shown (Sommer & Sommer, 1986). The use of behavioural mapping is particularly important on a ship's bridge and should include both hours of daylight and darkness. For instance, due to the high number of equipments emitting light on the ship's bridge and the present layout of equipment, maintaining a proper look-out by sight during darkness (as required by Rule 5 of the COLREGS 72) may be difficult. As a result the watchkeeper may have to behave in an unexpected manner, e.g., lean over some of the equipment to look out beyond the light (personal observation by the author).

2.10 General human factors research

It is likely that navigating officers, like most people, are affected by common physiological or psychological factors such as stress, boredom or fatigue. Thus a navigating officer can be expected to react to the lack of sleep the same way as a worker in a land-based job. Sleeping at sea, however, can be difficult due to excessive motion or noise. Even when the period of sleep is long enough, it may not be of high enough quality to ensure that the required minimum of 'core' sleep has been reached (Horne, 1992). Additional disruptions may be caused by (frequent) port calls or false fire alarms.

Studies and accident reports show (see e.g., Dickens, 1994; Haapio, 1991 and Transportation Safety Board of Canada, 1995) that navigating officers are often exposed to poor and non-standardised design of user-interfaces. The effect of this has so far not been considered in specific detail in the marine environment. In isolation this would not be a problem but as the number of individual pieces of equipment on the ship's bridge increases, the navigating officer has to manage an increasing number of different interfaces.

Extensive human factors' research has been carried out within general or specific populations, usually including a control and a study group. Although the research has not been carried out within the specific environment on the ship's bridge some of the conclusions are likely to be applicable. For example, studies that illustrate general human behaviour, e.g., failure to follow safety instructions (Wright, 1981). Accident and voluntary incident reports appear to confirm such characteristics where the navigator has failed to follow instructions, e.g., the Master's Orders has not been followed.

2.11 A look beyond 'human error'

This Chapter shows that the relationship between human factors, 'human errors' and causes of accidents at sea is complex and often difficult to appreciate. 'Human error' is likely to be present in the working environment on the ship's bridge, even if assuming that regulations may be introduced in the future that would allow a ship to be legally operated unmanned. The 'human error' would in that case shift completely to originate outside the bridge (e.g., design of equipment).

To reduce future accidents the shipping industry must move away from focusing predominantly on active errors caused by one or several of the bridge team members. By employing recognised human factor's techniques to design the working environment of the ship's bridge latent failures in the system can be reduced preventing the potentiality for future active errors.

The Merenkulkulaitos study suggests that 'human error' on the ship's bridge is influenced by technology, rules/regulations and human factors. The relationship between the components is shown schematically in figure 7.

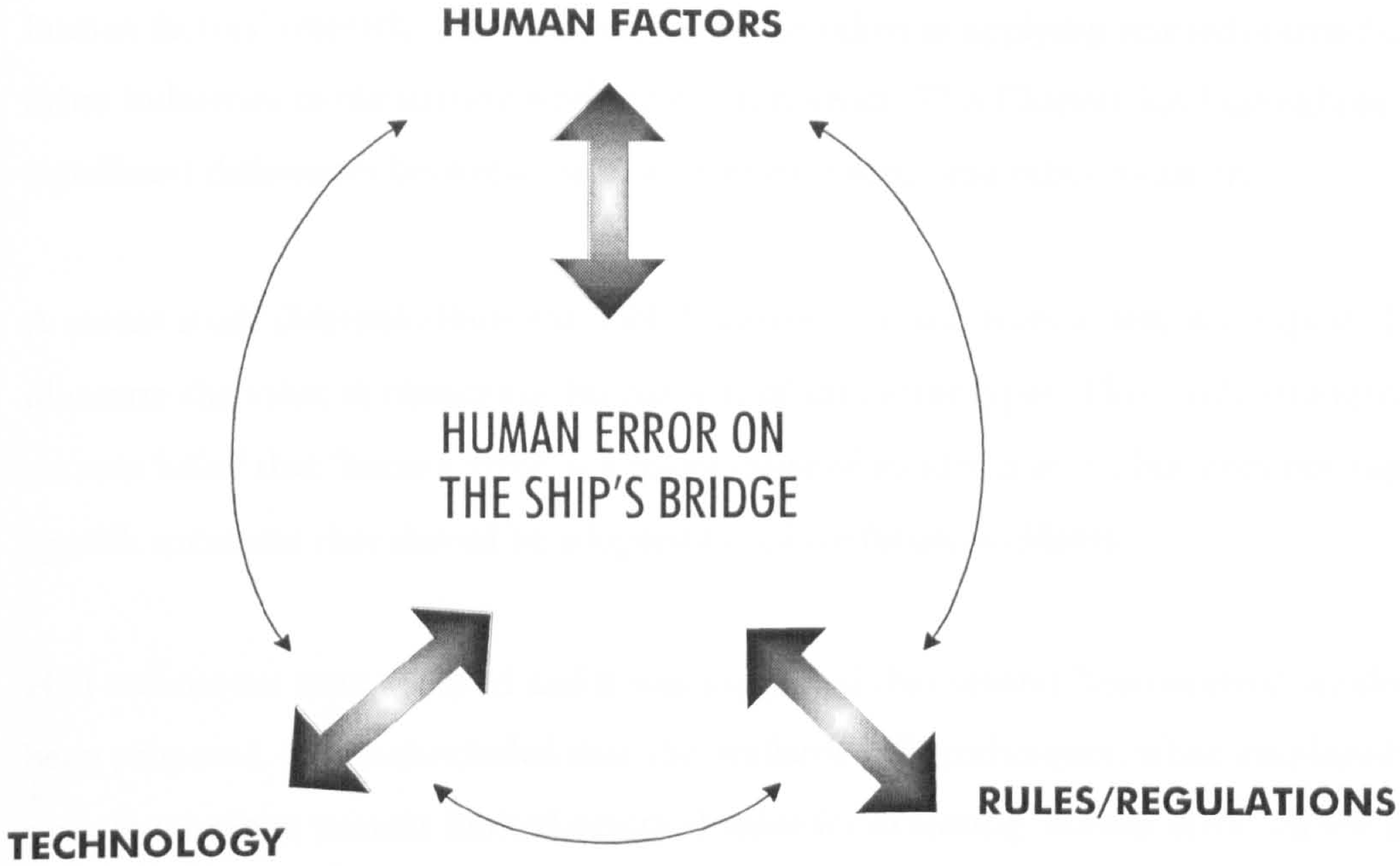

Figure 7 Factors affecting 'human error' on the ship's bridge

Figure 7 shows that human factors on the ship's bridge should not be viewed in isolation. In the past the marine environment has focused on 'human error' and what has been seen as the applicable technology or rules and regulations. To complete the picture of the bridge system human factors must be considered in the same detail.

2.12 Conclusion

This Chapter shows that the importance of 'human error' is increasingly acknowledged in the marine environment. However, the lack of worldwide annual statistics on collisions and groundings renders it difficult to compare studies, determine trends and assess the effectiveness of preventive measures. A summary of human factors studies relevant to the marine environment was discussed and presented in Appendix B. It was concluded here, that the existing literature does not provide an acceptable procedure for determining human factors on the ship's bridge.

The summary in Appendix B also shows that the aviation industry provides the most relevant human factors' research. However, care must be taken in applying research carried out in other industries to the marine working environments. This Chapter has highlighted the significant differences between the marine environment and other industries.

A recent study (Merenkulkulaitos, 1997), focusing on accidents at sea, was explored to illustrate the value of classifying 'human errors' into error types. This study strengthens the current belief that 'human error' is a major cause of accidents at sea but does not suggest specific measures that should be adopted to reduce future accidents.

HEI techniques were outlined and it was suggested that several 'human error' models have been proposed. It was concluded that the available HEI techniques, when employed in isolation, have at present limited practical value for exploring 'human error' on the ship's bridge. It was accepted that there was a need to obtain a better understanding of the working environment to improve the effect of current and future research techniques.

CHAPTER 3

FRAMEWORK OF THE WORKING ENVIRONMENT ON THE SHIP'S BRIDGE

3.1 Introduction

The human element operating in a complex system such as the ship's bridge interacts with the working environment. On the ship's bridge this can broadly be divided into two components, (1) the organisational framework and (2) the physical environment including associated situational/navigational activities. These components are illustrated in Figure 8 and outlined in this Chapter.

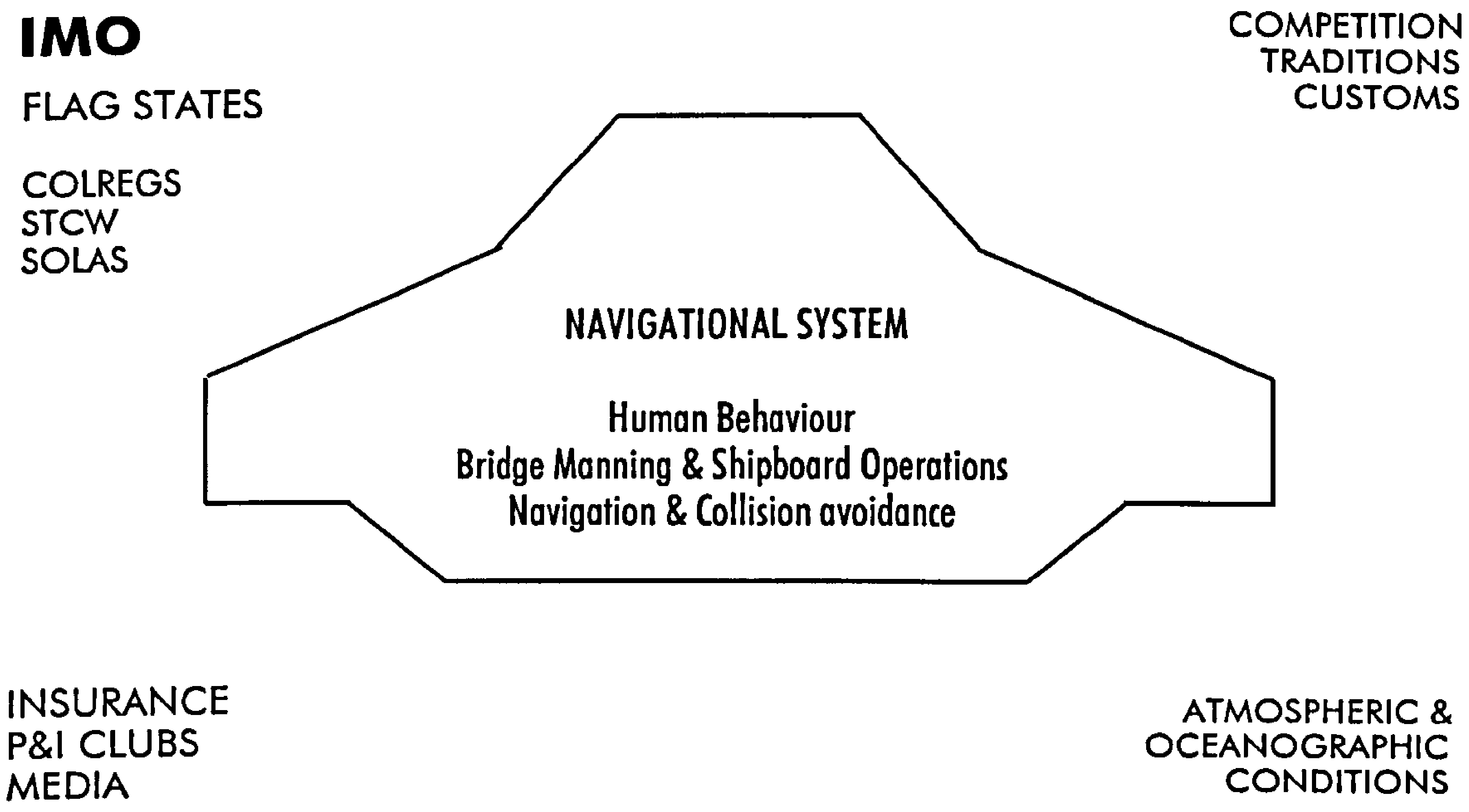

Figure 8 Major factors influencing the human element on the ship's bridge

3.2 Organisational Framework

3.2.1 The International Maritime Organization

The navigating officer works within an environment that is directly influenced by international conventions or resolutions adopted by the International Maritime Organization (IMO)[7]. Its primary role is to develop and adopt regulations to improve safety of international shipping and prevent pollution from ships.

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[7] Until 1982 called the Inter-Governmental Maritime Consultative Organization (IMCO).

IMO was established through a conference by the United Nations in 1948, as the first ever international body devoted exclusively to maritime affairs. Since then, it has adopted more than 40 conventions, protocols and other treaties and developed several hundred codes and recommendations (IMO, 1994a). Unless defined specifically the words rules and regulations will be used interchangeably throughout this thesis, to include IMO Conventions, Guidelines, Resolutions and Recommendations.

The IMO provides the regulatory framework affecting safe navigation, notably through the adoption of international conventions and resolutions e.g., the International Convention for the Safety of Life at Sea, 1974 (SOLAS 74), International Regulations for the Prevention of Collisions at Sea, 1972 (COLREGS 72), Standards for Training, Certification and Watchkeeping, 1978 (STCW 78, amended STCW '95), the International Management Code for the Safe Operation of Ships and for Pollution Prevention (International Safety Management (ISM) Code - the ISM Code), the Global Maritime Distress and Safety System (GMDSS) and Provisional Guidelines on the Conduct of Trials in Which the Officer of the Navigational watch acts as the Sole Look-Out in Periods of Darkness.

IMO as an organisation has no authority to enforce or implement any conventions or resolutions against any individual Flag State, ship or crew member. The compliance and verification mechanisms are therefore confined to those operated by the Administrations that have ratified the Conventions or by provisions in the Conventions requiring or permitting other Flag States to enforce the requirements (O'Neil, 1997). It should further be noted that the IMO does not generally commission research but results of independent studies may be submitted by the Flag States. These are then reviewed and discussed by the appropriate Committee or Working Group, e.g., developing provisions for allowing the officer of the watch (OOW) to act as the sole look-out during the hours of darkness.

The IMO is primarily engaged in developing conventions, resolutions and guidelines through different committees and working groups attended by representatives of the Member States and many independent maritime organisations. It has committees dealing with pollution prevention, technical cooperation, the facilitation of maritime traffic and legal matters and maritime safety (Kohn, 1997). In recent years the human element has attracted more attention and a list of Common Human Element Terms has been produced by a Working Group (IMO, 1996a).

In common with all treaties, IMO conventions are kept up to date by means of amendments. Previously the usual method was to hold a conference at which amendments could be formally adopted. These would then enter into force after being explicitly accepted by most of the 155 Member States (typically two-thirds). In practice this method was slow and some amendments never entered into force. The IMO has therefore more recently developed an alternative system known as tacit acceptance. Under this system the amendments enter into force on a selected date unless it is rejected by a specified number of Member States (typically one-third, or by Parties whose merchant fleets represent at least 50% of world merchant tonnage) (IMO, 1994b). The main advantage of tacit acceptance is that amendments can enter into force sooner allowing for urgent international matters to be dealt with faster.

A summary of the general provisions affecting the human element on the ship's bridge is provided below. Other relevant sections of IMO Regulations and Conventions are discussed later when applicable.

3.2.1.1 The International Convention for the Safety of Life at Sea, 1974

The International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) is perhaps the most important treaty dealing with the safety of international shipping (IMO, 1994c). The first SOLAS convention was the result of the 13 representatives attending an International Conference in 1913, following the report of the Court of Formal Investigation into the loss of the *Titanic*. The first convention was adopted in 1914 but never entered into force due to the outbreak of World War I (Cowley, 1989).

Historically, the first convention focused on technical matters such as lifesaving appliances and navigation in ice infested waters. The legacy of the first convention has resulted in the present regulations including such technical matters as Construction - Subdivision and stability, machinery and electrical installations (Chapter II-1) and Lifesaving appliances and arrangements (Chapter III).

Navigation is mainly covered in Chapter V consisting of 23 Regulations, e.g., type of equipment that must be fitted to certain types or classes of ships and the responsibilities of the maritime administrations. These must, for example, establish Meteorological Services (Regulation 4) and Aids to Navigation (Regulation 14).

Chapter V specifies in particular the type of navigational equipment that must be fitted onboard ships (Regulation 12), minimum number of crew members to provide safe manning (Regulation 13), use of Automatic Pilot (Regulation 19), Nautical Publications (Regulation 20) and Navigation bridge visibility (Regulation 22).

3.2.1.2 Accidents at Sea and Casualty Investigation

SOLAS 1974 requires Flag States to investigate accidents occurring to any of its ships when such an investigation may help in determining possible future changes in regulations (IMO, 1997). Many maritime administrations also investigate maritime accidents that occur within their territorial waters.

The IMO recognised the importance of maritime casualty investigation in promoting maritime safety and pollution prevention by adopting Resolution A.637(16) (IMO, 1989). The aim of the Resolution is to encourage greater consistency and cooperation relating to official investigations and reports of casualties.

3.2.2 Standards for Training, Certification and Watchkeeping, 1978

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW 78) is generally considered as second only in importance to SOLAS 1974 regarding safety at sea. It is the only international treaty dealing with the training, certification and watchkeeping of seafarers and forms the basis for national standards worldwide.

The STCW 78 was adopted by the International Conference on Training and Certification of Seafarers on 7 July 1978 and entered into force on 28 April 1984. The latest amendments were adopted in 1995 (STCW '95). Notably the original text has been provided in the Arabic, Chinese, English, French, Russian and Spanish languages. The purpose of the Convention is to:

> "Promote safety of life and property at sea and the protection of the marine environment by establishing in common agreement international standards of training, certification and watchkeeping of seafarers."

Briefly it can be noted that the Convention is comprehensive and covers all aspects of training, etc., of navigating and engine officers. Training facilities are provided through national nautical schools. The navigating officer generally receives his primary training at schools available in the country where he resides.

The provisions contained within STCW '95 include regulations for the training and assessment of seafarers. The regulations are minimum requirements for certification of officers depending on the size of the ship measured in gross tonnage. Further provisions provide for special training requirements for crews on certain types of ships, such as tankers or ro-ro vessels (V/1 and V/2).

The Convention additionally affords minimum requirements for emergency, occupational safety, medical care and survival functions. The regulations provide for the minimum requirements for certification of any person in charge of or carrying out radio duties on a ship required to participate in the Global Maritime Distress Safety System (GMDSS see below) (IV/2).

3.2.3 The International Regulations for Preventing Collisions at Sea, 1972

The aim of the International Regulations for Preventing Collisions at Sea, 1972 (COLREGS 72) is to provide the navigator with a set of rules that allows him to navigate his vessel safely in all traffic situations, i.e., when vessels are crossing, meeting end-on or overtaking. The legal aspects of the COLREGS 72 have been discussed extensively elsewhere (see e.g., Cahill, 1983 and Cockcroft, 1990) and are therefore not examined in detail here. Other aspects of the COLREGS 72 are explored below in the section covering the Navigational System (see page 71).

3.2.4 Provisional Guidelines on the Conduct of Trials in Which the Officer of the Navigational Watch acts as the Sole Look-Out in Periods of Darkness

Rule 5 of COLREGS 72 provides a basis for safe navigation through requiring that a proper look-out is maintained appropriate to prevailing conditions. This is further clarified in STCW '95 (Section A-VIII, Part 3-1, 3.13-3.15). The STCW '95 does not state directly that a look-out must be posted during the hours of darkness but implies it through stating that the OOW may act as the sole look-out in daylight provided specific conditions are met.

Toward the end of the 1980's several maritime administrations began to investigate the possibility of reducing the bridge watch to a single person during the hours of darkness. The implied changes to reduce crew levels generated a profusion of arguments for and against the concept in the shipping industry (see e.g., James, 1989; Lister, 1988; Lloyd, 1988; Thwaite, 1988). The IMO Maritime Safety Committee eventually approved provisional guidelines to conduct trials in which the officer of the navigational watch would act as the sole look-out during periods of darkness (IMO, 1991). These trials have become known as Watch One (W1) or One-Man-Bridge-Operations (OMBO).

Regulation I/13 of SOLAS 74 permits ships to participate in trials that may involve the use of automated or integrated systems to evaluate alternative methods of carrying out specific duties or satisfying specific arrangements. These must provide at least the same degree of safety and pollution prevention as provided by the STCW '95 (IMO, 1997).

3.2.4.1 The Watch One Concept

The Watch One concept focuses on four essential factors regulating the system configuration for bridge operations (Larsen, 1990):

1. Workload - the organisation of manual and automated operations must ensure that the total workload required for safe and efficient navigation, including traffic surveillance and other functions allocated to the bridge, must never exceed the capacity of one person under normal operating conditions.

2. The OOW must have a sufficient field of vision from the work stations on the bridge to maintain proper look-out including when he has other duties to attend, e.g., chart work, communication.

3. The OOW must be competent to perform the duties for which he is responsible. This includes the ability to take over an automated navigation function at any stage of the operation.

4. Procedures and necessary technical devices for safe operation under irregular and abnormal conditions must be established. This includes systems to safeguard that the technical system and the one person in charge are functioning within safety limits during daytime and periods of darkness.

Additionally, to safeguard the performance of primary bridge functions and ensure that the sudden disability of the officer of the watch does not endanger own or other ships, the following two principles must be maintained:

5. The OOW must be able to stop any secondary function during its operation by an instantaneous single action without impeding the safety of the ship.

6. Danger to navigation that may be caused by an unattended bridge, traffic or improper course-keeping must be monitored and warning of irregularities transferred to a back-up officer.

3.2.4.2 IMO Watch One Trials

The purpose of the Watch One trials was to collect information that would allow the IMO to debate the practice of allowing the officer of the navigational watch to act as sole look-out in periods of darkness. Since their start, the trials have been suspended (IMO, 1996b) and later resumed (Shuker, 1996).

Additionally the intention of the trials was to evaluate acceptable bridge layouts, appropriate levels of control equipment and instrumentation and safe and healthy operational procedures (IMO, 1991).

The guidelines suggest detailed conditions for bridge layout and instrumentation, bridge safety systems (e.g., 'Dead-Man's Alarm'), grounding and off-track systems, qualifications and additional responsibilities of the navigating officer and responsibilities of ship operators and masters. The guidelines also included a reporting form for the trials.

Five countries, Denmark, Germany, Norway, the United Kingdom and Vanuatu took part in the initial trials (IMO, 1994d). Although the trial guidelines are relatively detailed, no instructions were provided to ensure standardisation of methodology.

Several different methods were used, either singly or in combination, i.e., only personal observation or a combination of self documentation and post-trial interviews. A total number of 51 ships completed the initial trials as shown in table 9.

The trial results were incorporated into a report prepared by the Sub-Committee on Safety of Navigation (IMO, 1994e). The consolidated report concluded that for most parts human factors had not been assessed in any detail by the participating respondents.

The small number of participating ships and the lack of standard methodology renders it difficult to compare the results and determine the safety aspects of the concept.

	DENMARK	GERMANY	NORWAY	UNITED KINGDOM	VANUATU
Total Number of ships	19	25	1	5	1
Method	Independent observer (2 ships) Self documentation Limited post trial interview	Independent observer (8 ships) Self documentation Post trial interviews		Independent observer (all 5 ships)	Self documentation
Additional training for OOW	Not required	One day seminar	Require minimum 12 months independent navigation watch	No special training	No special training

Table 9 Summary of IMO Watch One Trials (derived from IMO, 1994e)

3.2.4.3 Additional Watch One studies

Since the Watch One concept was proposed it has been widely discussed and debated in nautical publications and the maritime press. Nylund (1993) conducted a small-scale survey focusing on seafarers in the Finnish Merchant Navy.

Most of the respondents considered that the availability of some type of additional assistance during the hours of darkness is necessary. Only 17% felt that the conventional lookout is essential, but 80% would like to have access to the assistance of an additional navigating officer or OOW. This suggests that the assistance required is not only a 'pair of eyes' but full navigational support.

Increased fatigue was identified as a major problem if the officer acts as the sole look-out during the hours of darkness. 70% of the respondents in the above study suggested that the best way to prevent fatigue would be to have a watch system that is either the traditional 3-watch system or a 1:1 relief. The results of the above are likely to reflect not only national traditions but also ship types and trading patterns.

Swedish navigating officers appear positive to the current development of Watch One operations (Olofsson, 1995). Not surprisingly those already operating on Watch One ships are more positive, perhaps because they can relate the concept to their own experience (shown in table 10).

Position	Traditional Watch Ships		Watch One Ships	
	YES	NO	YES	NO
Master	50	16	13	0
Chief Officer	42	18	13	1
Other navigational officer	59	46	15	5
Total	151 (65%)	80 (35%)	41 (87%)	6 (13%)

Table 10 The opinion of Swedish navigating officers as to whether Watch One operations are safe (derived from Olofsson, 1995)

3.2.4.4 Watch One Discussion and Conclusions

The IMO Watch One guidelines were expected, during the trials, to provide the same degree of safety as the traditional look-out. Verifying the safety of the concept has proven to be more difficult due to the varying definitions of 'safety of the concept'. For example, Habberley and Taylor (1990) approached it mathematically, defining a 'guarded' ship as 'Either the officer or the look-out (if present) looks out at least once during 2½ minutes' (see also IMO, 1994f). Schuffel et al. (1989) and Pourzanjani (1996) focus on increased efficiency provided by automated position fixing and subsequent track keeping. Larsen (1990) suggests that a way to assess the capability of the OOW to maintain proper lookout is the frequency and duration of look-out and the length of time he is distracted from the visual look-out.

Although the official trial reports submitted to the IMO concluded overall that the Watch One concept provided safe navigation, it has not been universally accepted by the Member States. It is suggested that the results from these and other studies are inconclusive as to the 'safety of the concept'.

3.2.5 The International Management Code for the Safe Operation of Ships and for Pollution Prevention (International Safety Management (ISM) Code)

The purpose of the ISM Code (IMO, 1993) is to provide an international standard for the safe management and operation of ships and pollution prevention. The objectives of the Code are to ensure safety at sea, prevention of human injury or loss of life and avoidance of damage in particular to the marine environment. This Code is primarily intended as an instrument for management to enable it to respond to the needs of those on board the ship to achieve and maintain high standards of safety and environmental protection. It outlines Company responsibilities and authorities as well as the Master's responsibilities and authority. This Code, when fully implemented is expected to raise the standards of ships overall.

The guidelines are intended to give ship operators directions on how to develop, implement and assess safety and pollution prevention according to good practice. It defines responsibilities and authorities within the company, including the designation of a person with direct access to the highest level of management to act as a link between the company and the ship's crew.

The Code covers the operation of the entire ship as part of a company. The aim is to integrate the technical and operational sides into a coherent system which is expected to be safer than operating an isolated safety system. Unless the integrity of the whole system is managed, an undetected error may result in an accident (Chauvel, 1997).

The ISM Code came into force on July 1, 1998 for all passenger vessels, including high speed vessels regardless of tonnage, oil tankers, chemical tankers, gas carriers, bulk carriers and high speed cargo vessels of 500 GRT and over. The Code is still in its infancy and thus far there are few instruments that can be used to determine its effectiveness on an international scale. As the Code matures indicators, such as the number of detained ships by Port States, may allow continual monitoring of its development and justify changes when necessary (DesVergers, 1999).

3.2.6 The Global Maritime Distress and Safety System (GMDSS)

The basic concept of the GMDSS is that search and rescue authorities ashore, and shipping close to a ship in distress, can rapidly be alerted to a distress incident in order to provide assistance in a coordinated Search and Rescue Operation with minimum delay. The system additionally provides for urgency and safety communications and the promulgation of maritime safety information (MSI) -navigational and meteorological warnings and forecasts and other urgent safety information to ships (IMO, 1992).

The introduction of GMDSS has slowly resulted in the loss of a dedicated radio operator. Consequently the navigating officer is now increasingly responsible for operating the GMDSS equipment and all other communications (e.g., by VHF ship-to-ship or ship-to-shore). The SOLAS Convention (as amended in 1988) require all ships subject to it, to fit all GMDSS equipment by 1 February 1999 (IMO, 1999; USCG, 1998).

3.2.7 IMO and the Human Element

The IMO is increasingly acknowledging the role of human failure in accidents at sea (IMO, 1998). The organization accepts that the human element cannot be solely managed through regulations and acknowledges that no single group or organisation can address this matter independently (IMO, 1995).

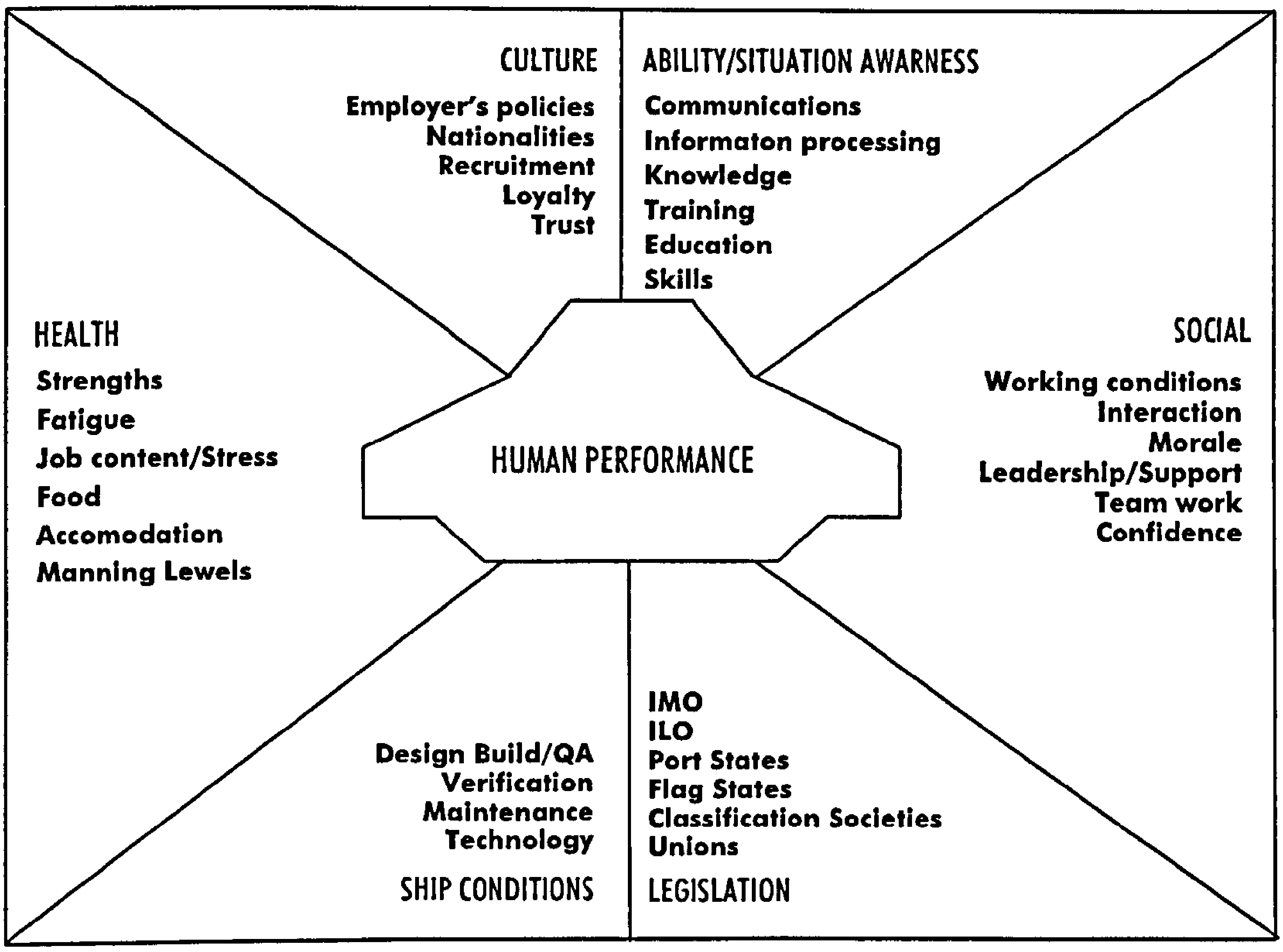

Figure 9 Factors affecting the human element in the marine environment (adapted from IMO, 1995)

IMO has consequently published a list of factors influencing human decision making for illustration and further development (Figure 9).

This list shows the various factors affecting the human element in the marine environment. The interaction between the components shown in figure 9 and the human element within the navigational system are explored further in this Chapter and Chapter 4. IMO was explored previously as the basis of the organisational framework on the ship's bridge. The legislative components examined in this research include primarily maritime administrations, port state control and classification societies, examined below. Collision avoidance and passage planning are also explored as part of the navigational system within this Chapter. Appropriate ship conditions are explored within section 3.5 the Ship's bridge and situational activities.

Ability/situational awareness and health issues are examined further in Chapter 4.

3.2.8 Maritime Administrations and Port State Control

3.2.8.1 Maritime Administrations and Flag States

A Flag State (Maritime Administration) indicates the government of the State whose flag the ship is entitled to fly. Traditionally a shipowner would register his ship in the country where his head office was based, recruit crew members from the same country and class and insure the ships with companies also of the same nationality. Initially a handful of countries were directly involved in the safety of international merchant shipping (e.g., Great Britain, France, Germany, etc.) and today these countries have more than a century of experience in shipping and generally assume a leading role in managing safety at sea.

Governments ratifying IMO Conventions must ensure the following:

1. That ships flying its flag meet the standards of the appropriate IMO Conventions and that it carries out certain duties in respect of safe manning. It must investigate accidents at sea and report to IMO accordingly. These obligations apply to all ships entitled to 'fly the flag of the Flag State'.

2. That foreign ships visiting its ports are safe to proceed to sea and not likely to cause severe pollution.

When a Flag State accepts an IMO convention, it must ensure that the convention becomes part of its national law. It also agrees to enforce it completely, including providing a properly trained Administration. It must employ an appropriately trained team of surveyors and inspectors to ensure that its ships comply with national and international requirements (IMO, 1994a).

Some duties of marine administrations are shown in Figure 10. Discretion must be used when interpreting this figure because of the inevitable overlap between the boxes. Not all Conventions can be applied equally.

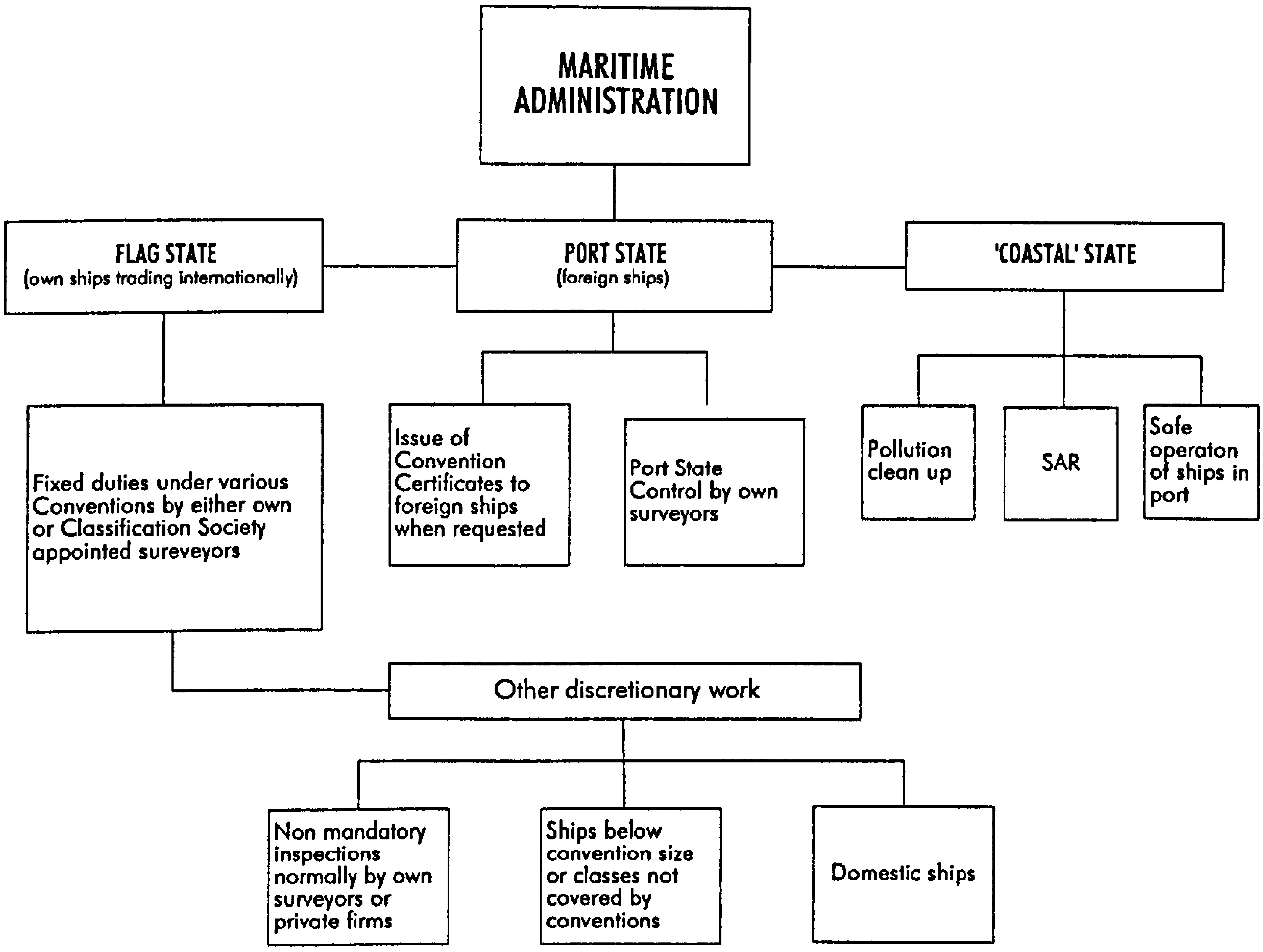

Figure 10 Some duties of Marine Administrations influencing safety of navigation

The law governing ships is derived partly from ordinary territorial jurisdiction and partly from registration. Generally when a ship, flying any flag, is within the territorial sea of any state it can expect to be governed by the laws of that state. This is subject to certain recognised limitations derived from public international law, e.g., the right to 'pass innocently' through territorial waters without interruption. Additionally a ship will be subject to the laws of the country of its registration which means that it is adopted into that state's legal system (Grime, 1991).

Some countries regulate their registered ships very closely including enforcing the applicable safety rules and laws governing the employment of seafarers. Above all, taxation may inflict a severe burden on the shipowner. Different states have different rules as to whether the ship is allowed to, or must be, registered in that particular state. Some countries adopt very strict rules, e.g., accept only ships built in the country's shipyards and owned by resident nationals, e.g., the United States. Others are extremely liberal and accept any vessel and thus enjoy the revenues that may be derived from that policy, e.g., Liberia (Grime, 1991).

3.2.8.2 Safe Manning

Safe manning is a function of the number of qualified or experienced seafarers necessary to prevent accidents at sea. To ensure that ships carry a minimum number of crew members IMO has passed Resolution A.481(XII) Principles of Safe Manning (IMO, 1981). The Resolution offers general guidelines for applying basic principles of safe manning to ensure the safe operation of ships. It acknowledges that the application may differ depending on factors such as size of ship and trading patterns, type of main and auxiliary propulsion units, and construction and technical equipment of the ship. Additionally it stresses the need for a sufficient number of qualified crew members available to meet peak workload situations. Maritime Administrations may retain or adopt arrangements that differ from the guidelines especially if adapted to technical developments or special types of ships and trading patterns.

3.2.8.3 Port State Control

Many treaties such as the amended STCW '95 and SOLAS 74 provide provisions allowing Flag States to inspect both domestic and foreign ships visiting their ports to ensure that they meet IMO requirements. The first regional Port State control agreement was the Paris Memorandum of Understanding of 1982. This has served as a model for other regions and there are now regional agreements covering Latin America, Asia and the Pacific and the Caribbean (IMO, 1996c).

The aim of Port State Control is to act as a second tier of enforcement by allowing Port States to inspect foreign ships in the interest of safety and pollution prevention. Consequently Flag States can impose their own laws within their territorial waters if they comply with the international conventions to which they are party (Bond, 1995).

The Memorandum of Understanding on Port State Control (MOU) is an agreement between the maritime authorities of fourteen European countries, aimed at establishing a harmonised and efficient system of port state control. The text of the MOU was adopted in January 1982 committing each authority to maintain an effective system of port state control. The aim is to ensure that foreign merchant ships visiting their ports comply with the standards laid down in the specified IMO Conventions, e.g., SOLAS 74, STCW '95, and so on (MOU, 1996).

The Convention allows inspectors in port States party to the Convention to verify that persons serving on national or foreign flag ships hold the appropriate certificates (Article X), that proper watchkeeping arrangements are maintained, and that watchkeepers are adequately rested (Regulation 1/4).

The advantage of the Port State Control is their powers to detain substandard ships arriving in their ports. This is intended to encourage shipowners throughout the world to comply with IMO minimum standards.

3.2.9 Flags of Convenience and Second Registers

3.2.9.1 Flags of Convenience

A Flag of Convenience (FOC) is used to describe the registration of ships under the flag of certain States when they are in fact beneficially owned and controlled by nationals of other countries. FOC ships are often manned by foreign crews and they rarely, if ever, enter the jurisdiction or ports of their country of registry. After World War II, because of high operating costs, unsubsidised United States shipowners transferred their ships to FOC. This provided for tax immunity and allowed them to gain economic advantages over European competitors. The Greeks similarly transferred ships to avoid heavy taxation but also to avoid inconvenient government regulations (Hill, 1989).

According to the International Transport Workers Federation (ITF) criteria ships are defined as FOC when (ITF,1998a):

- the country allows aliens to own and control vessels
- access to and easy transfer from the registry
- the country of registration does not need the shipping tonnage for its own purposes but is eager to earn tonnage fees
- manning by non-nationals is freely permitted

- the country lacks the power (or willingness) to impose national or international regulations on its shipowners

FOC registrations allow ship operators to select crews from any nationality provided they are trained according to the conventions adopted by that nation. This has led to an increase of multinational crews. It should be noted that ships have traditionally carried mixed crews. Thus a multinational crew is defined for this research as a crew where the deck and/or engine department is made up of members from more than one nationality, e.g., if the deck department consisting of three to four people are of more than one nationality.

IMO conventions require maritime administrations to provide the legal framework to enforce conventions that the countries have ratified. The standards of the maritime administrations of FOC countries vary widely. Some countries are unable to provide proper survey staff of their own. They may delegate the task of enforcement and surveys to any classification society, private surveyor or individual who is willing to carry out the tasks on their behalf (Cowley, 1989).

The status of nationally owned ships is dependent on a satisfactory union agreement with local ITF affiliates. Non-national ships are automatically classed as FOC (ITF, 1998b). Although a FOC ship may operate at a lower standard this should not be assumed automatically. The standard of each ship operation must be evaluated on its own merits.

3.2.10 Second Registers

Many Flag States discovered during the shipping crisis in the 1980's that shipowners increasingly chose to re-register their ships abroad, i.e., with FOC. Freight rates were low and taxes and social costs of domestic crews were high. At the same time there was a decline in international trade and an increased supply of tonnage throughout the world. This led to the development of so called second registers that would provide the benefits of flying the national flag but with lower costs (Torpmann-Hagen, 1997).

Norway, for example, established a second register, the Norwegian International Shipping Register (NIS) in 1986. This differs from the national register as follows:

- It allows registration of foreign owned ships
- It excludes ships trading in Norwegian coastal waters
- The limit of the number of foreign crew members on board, to one third, does not apply to NIS ships
- Social benefits for foreign crews are different from those of Norwegian crews

The standards of Second Registries vary widely but generally they emulate the national registers, particularly regarding safety issues. The aim of the second registry is primarily to provide more equal competition with FOC ships and encourage ship owners to provide work for their own nationality seafarers.

3.2.11 Classification societies and marine insurance

3.2.11.1 Classification societies

The need to assess the risk of insuring ships brought together London Underwriters in 1760 to form Lloyd's Register of Shipping whose main function was to classify ships according to their condition (Grime, 1991). Today the classification of a ship is at the core of maritime safety embodying the technical rules, regulations, standards, guidelines and associated surveys and inspections covering the design, construction and through-life compliance of a ship's construction. Classification societies contribute further through technical support, compliance verification and research and development (IACS, 1998).

Many classification societies are also authorised to act for national maritime administrations. This is because no maritime administration has sufficient resources to deal with all statutory surveys required under the various conventions (Cowley, 1989).

Research carried out by the classification societies is primarily directed toward technical matters. Det Norske Veritas (DNV) has carried out research into 'human error' (Karlsen & Kristiansen, 1981) and developed the concept of Watch One (W1) in response to the IMO guidelines (DNV, 1991).

3.2.11.2 Marine Insurance

The aim of marine insurance is to encourage merchants and shipowners to trade to the full extent of their capacity. They should have no fear of loss by 'perils of the seas' which they are unable to avoid by the exercise of judgement and foresight (Dover, 1975).

Theoretically marine insurance is a contract of indemnity, i.e., commonly the indemnity is agreed upon in advance. These values may be greater or lesser than the values actually at risk. The insurance typically covers loss or damage caused by 'perils of the seas' which include collisions, groundings and pollution. The purpose of an insurance policy is to secure and indemnify against accidents which may happen, not against events which must happen. It should be noted that marine insurance typically covers negligence of masters, officers, crew or pilots (Templeman, 1986).

It was recognised at an early stage that the system of marine insurance afforded means of protecting individual shipowners by transferring the pecuniary responsibility of any loss to the underwriters who insured them. This encouraged less care in the construction of ships, less efficiency in their equipment, less security for their adequate management at sea, inasmuch as the risk of such loss could be covered by a fixed premium of insurance. This cost could then be charged on the freight and the re-charged on the goods conveyed (House of Commons, 1836). Thus the shipowner had little incentive to ensure the safety of his ships.

3.2.11.3 Protection and Indemnity Clubs

Protection and Indemnity Clubs (P&I Clubs) began as mutual insurance associations in the late 18th century when groups of shipowners formed mutual nonprofit making clubs to share their hull claims.

Today the Clubs protect shipowners and charterers against third party claims made against them. When unsuccessful in protecting them, they indemnify the shipowners against losses they may incur by way of those liabilities (Newcastle P&I Club, 1998). P&I Clubs have a strong interest in loss prevention and have developed publications to assist in reducing the risk of accidents, e.g., "The Master's Role in Collecting Evidence," and "Loss Prevention Calendars" published by the North of England P&I Club.

In recent years the Clubs have also carried out research and published studies relating to safety at sea. For example, the UK P&I Club (1996) published the "Human Factor - A Report on Manning" which examines manning and management policies, service and experience, training and endorsements and language and nationality. Their publication "Analysis of Major Claims" (1992, updated 1999) examines loss prevention and various claims, including collision claims.

3.2.12 Other organisations involved in the marine environment

Many other maritime organisations have important roles in assisting the navigating officer through regular meetings and publication of nautical journals that assist in providing the officers with timely information. Such organisations include the Nautical Institute, the International Federation of Ship's Masters' Association and the Honourable Company of Master Mariners. These are international organisations and are based in London, UK.

Local (e.g., Numast in Britain) and international (e.g., the International Transport Worker's Federation (ITF) and the International Labour Organization (ILO) trade unions focus on developing and enforcing international standards for improving working conditions onboard ships (ITF, 1998b; ILO, 1998). Charitable organisations, e.g., various 'Seamen's Churches' (e.g., Missions to Seamen) operate in ports throughout the world providing practical assistance during port visits (Missions to Seamen, 1998).

3.3 Safety at sea and the organisational framework

The outline of the organisational framework shows that many institutions are involved in maritime safety and their interrelated functions are often complex. The shipping industry also relies on a widespread use of insurance for ships and cargoes. Ship operators are, overall, legally allowed to limit their liabilities to others.

International shipping is characterised by free competition meaning that ships carrying cargoes between different countries are readily substituted for others and they are readily transferable geographically and between flags. This means, in practice, that the beneficial ownership, nationality, operational management and crew of a ship can be, and frequently are, different (Goss, 1993).

Consequently, accidents occurring outside a nation's territorial waters may only be investigated by the Flag States. For example, the collision between the Bahamanian registered passenger vessel the *Norwegian Dream* and the Panamanian registered container vessel the *Ever Decent* occurred in the English Channel approximately 5 nautical miles beyond British territorial waters. Notwithstanding, that this particular accident resulted only in physical damage to the ships and minor injuries to passengers, there is a valid demand for a detailed investigation, including examining the role of human factors. Had the *Norwegian Dream* collided broadside with a fully laden tanker carrying volatile hydrocarbons the outcome could have been catastrophic, see e.g., the collision between the *Western Winner* and the *British Trent* (MAIB, 1993). However, although the *Norwegian Dream* was on course to Dover, the accident will be investigated only by the Bahamanian and Panamanian authorities. They are, however, expected to submit full reports to the IMO (Porter & Smith, 1999).

Traditionally, multilateral enforcement of multilateral agreements, i.e., flag state control supplemented by international agreements through IMO and ILO has prevailed because ships have an historic right to 'innocent passage' through a nation's territorial waters. In principle any ship, flying any flag, of any country, may enter any port and carry any cargo anywhere. Despite the long history of 'innocent passage', increasingly, the international shipping community is adopting unilateral enforcement of multilateral rules (e.g., Port State Control) thus allowing more control over safety matters (Goss, 1994).

3.4 The navigating officer and the organisational framework

The navigating officer has little direct control over his working environment as illustrated in Figure 11. For example, the physical environment of the ship's bridge, including navigation aids, is generally designed, manufactured and classified before he actually steps onboard. He may be trained only to the minimum requirements provided by the STCW '95 and SOLAS 74. He may also be required to work with crew members of other nationalities with whom he may not have a mutual language.

The Master of a ship traditionally had full authority to make whatever decision he felt appropriate to ensure the safety of the ship. In fact he was known as 'Master under God'.

Today's navigating officers strongly believe that the Master has less and less authority but ever more responsibilities and duties. Instant communication with the various players, e.g., ship owner, has changed the working environment.

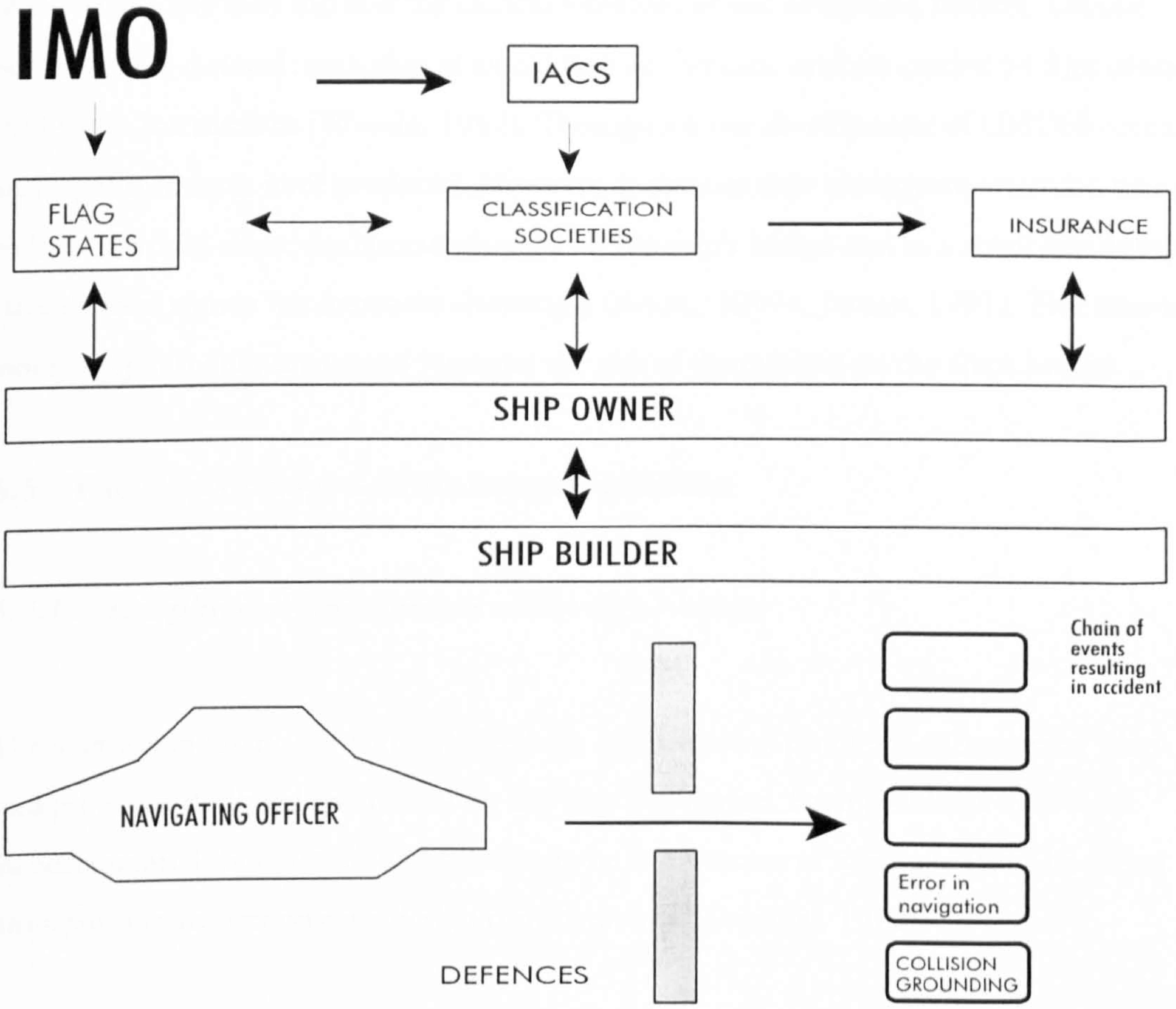

Figure 11 **The influence of the organisational framework on the human element on the ship's bridge which may provide a pathway for breaking defences and resulting in a collision or grounding**

Today the Master is expected to consult with the owners/managers before taking any action, thereby removing his traditional authority for decision making. Thus many critical decisions may be made ashore by shipowners, managers, cargo planners, charterers, agents and government departments. In theory, according to the ISM Code, the Master has the right to countermand any decision, but it is a brave man who will interfere with the slick world of

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commerce today (Sahu, 1999). There is widespread belief that if the Master refuses to sail he is likely to be advised that he will be replaced by a different Master who is willing to sail (Schmeisser, 1997).

Some regulations may themselves increase the risk for an accident, e.g., the implementation of the ISM Code may increase the clerical workload of the navigating officers. On one occasion, it is claimed, each ship of an old fleet of chemical tankers carried 54 files containing ISM Code Instructions (Woinin, 1997). Throughout the development of GMDSS technical and legal standards were produced. However, it appears that inadequate attention was given to how it would affect the human element on the ship's bridge and as a result the number of false distress alarms has increased alarmingly (Anon., 1997a; Jensen, 1997). This strains the emergency response teams and increases the risk of distractions on the ships bridge.

3.5 The ship's bridge and situational activities

3.5.1 The physical environment of the ship's bridge

The aviation industry has acknowledged the seriousness of problems encountered when a cockpit is not designed specifically for the user population. Such problems may seem inconsequential, but aircraft and crews may be lost because of what appear to be minor or unimportant anthropometric design considerations (Kennedy, 1972).

Similar problems exist in the marine environment, e.g., care must be taken to ensure that there is an unrestricted view from the bridge. The basic functional requirements for bridge configuration, bridge arrangement, bridge equipment and bridge environment have been specified by the European Standard EN ISO 8468:1994. Its aim is to ensure that the designs of ships' bridges adequately provide for the requirements for safe navigation.

The physical environment can broadly be divided into (1) localities inside and (2) outside the ship's bridge. The interior includes the physical layout of the bridge, design of hardware and related information processing. The exterior environment includes the atmospheric and oceanographic conditions and natural hazards that the ship may encounter during its passage.

3.5.1.1 The internal environment

3.5.1.1.1 Bridge Layout and Space

Each ship is generally designed as a prototype resulting in different bridge layouts even on sister ships (Goss, 1993). There are two general types of layouts of ships' bridges as shown in figure 12.

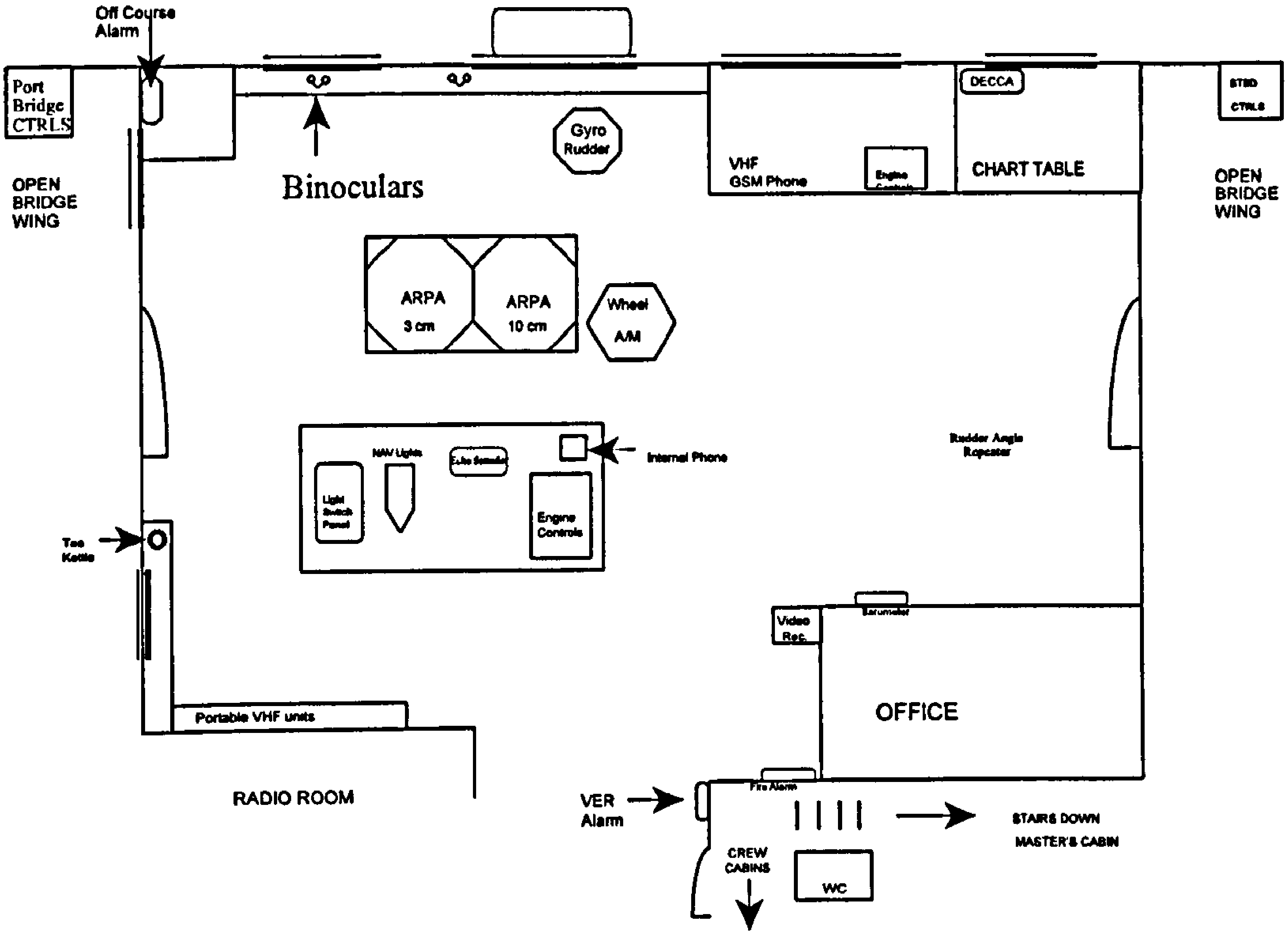
The most obvious difference between the two types of bridge layouts is the use of space and general location of the navigation aids. Modern bridges have become increasingly 'cockpit' style where the displays and controls surround the positions of two, sometimes more, persons, e.g., navigating officer, master and pilot.

3.5.1.1.2 Integrated Bridge Systems

Traditional design of a ship's bridge is such that the navigating officer may have to spend considerable time collecting sufficient information to make the correct decision. During normal navigational operations, at any given time, one person is generally responsible for the navigational decisions. The role of any additional person is to assist in collecting information needed by the navigating officer to help him make the correct decision (e.g., the look-out). On a traditional bridge the officer may also be unable to make his decision from the place where he collects the information (e.g., his position at the chart table may not allow him to observe other traffic).

The basic principle of minimum manning and automation is to reduce high labour costs of seafarers by installing electronic navigation aids to reduce workload. The common denominator among the systems being developed is automatic guidance, i.e., the automation of the navigation process is integrated with automatic ship control (Dove, 1992/93). Integrated bridge systems were developed with the aim to reduce operational costs through redeveloping the ship's bridge as an operational centre for performing both navigational and supervisory tasks. The design of integrated bridge systems is based on function allocation, i.e., determination of which functions can be performed by man and which by automated equipment (Schuffel et al., 1989).

Sketch of 'Traditional' Bridge



Sketch of Watch One Classified Bridge

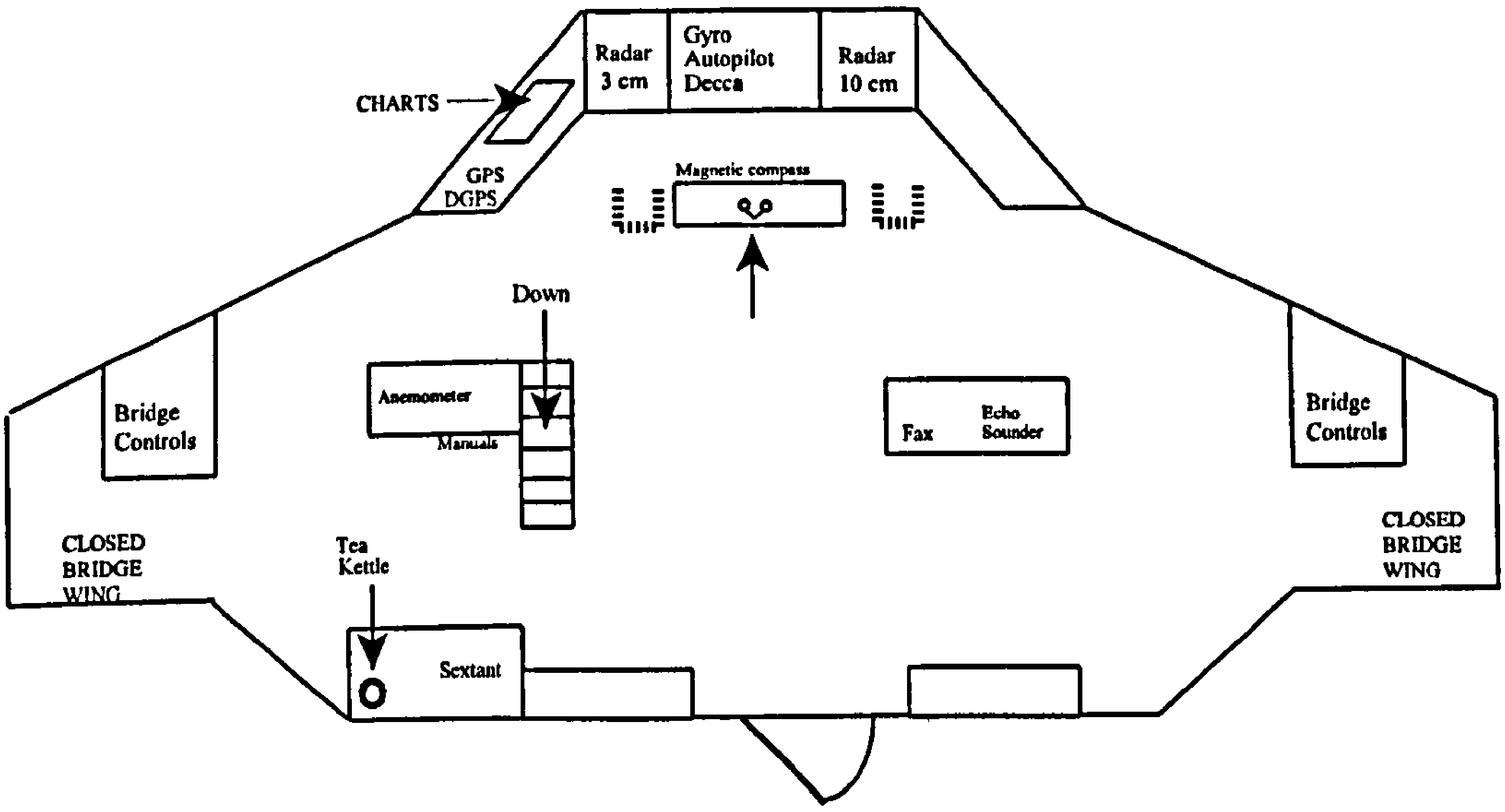


Figure 12 Simplified sketches of a 'traditional' bridge and an integrated bridge of a similar size (not to scale)

3.5.1.2 The External Environment

Oceanographic and atmospheric conditions are never static at sea, ships are influenced by tides, currents, waves, fog and so on. Additionally ships may regularly or occasionally encounter other physical hazards such as conditions resulting from freezing temperature, i.e., sea ice, glacial ice or superstructure icing (Anon., 1981; Varsta, 1985; DeAngelis 1974). Underwater hazards may pose unexpected problems in poorly surveyed waters (Richards, 1994) or because some underwater structures are not stationary (e.g., sand banks) (Caston & Stride, 1979).

Unlike land-based organisations the ship moves through the natural environment during its voyage from port to port. The navigating officer must therefore constantly be aware of the external environment. Services such as the International Ice Patrol (IIP) and Weather Forecasting and Routeing were developed to provide assistance in planning a safe passage. The IIP, formed because of the sinking of the *Titanic,* monitors the position of icebergs in the North Atlantic (Anon., 1981; Beattie 1978). National weather forecasting services provide short range forecasts for shipping (Evans, 1968) and weather routeing services can assist in predicting the most favourable voyage for the ship (Couper, 1989)

3.5.2 Navigation and the navigating officer

A detailed historical account of navigation and the associated instruments has been covered elsewhere (see e.g., May, 1973; Kemp, 1988).

The definition of a navigating officer, for the purpose of this research, is any person who is directly involved in navigation as part of the navigation team on the ship's bridge, i.e., the Master's or Pilot's role is primarily regarded from a navigating officer's point of view, rather than from their respective other roles.

Pilotage is defined as the act of navigating a ship near land under the advice of a pilot who is a qualified navigator and an expert on local harbour and channel conditions (Kemp, 1988). The pilot is an expert who uses his local knowledge of the nature of channels and shoals, land- and sea-marks, tides, currents and other local factors that influence safe navigation.

3.5.3 Bridge manning and shipboard organisation

Merchant shipping is characterised by longer than average working periods (often weeks or months), unconventional working hours and days and regular and extensive night operations. During navigation, periods of intense activity may be interspersed by periods of relative inactivity.

Traditionally manning of a ship's bridge was organised according to a nominally fixed schedule of four watches based on local time. This allowed for a work schedule of four hours on and eight hours off. In recent years manning of the bridge has changed and watch systems of 5 on 5 off or 6 on 6 off are now employed widely.

The crew complement has traditionally been divided into three departments, i.e. deck, engine and catering/steward. This study focuses on the activities of the deck department and includes the Master, generally 2 or more navigating officers and a complement of ratings and/or Able Seamen. The Master has at all times overall responsibility for the safe navigation and operation of the entire ship.

The responsibility of the deck department can broadly be divided into navigation, communication and loading and unloading of cargo. Typically the navigating officers share the round-the clock watches. The Master should not engage in regular watchkeeping but be available to assist during periods of increased risk of danger, e.g. deteriorating weather conditions or visibility.

3.6 Collision Avoidance

3.6.1 Radar/ARPA

It is likely that the radar has had a greater impact on safety of navigation than any other navigation aid used on commercial ships since the early 1950's. The radar was developed in the early 1940's and it allows objects to be detected by sending out pulses of radio waves. Originally the radar was used on warships during WW II for shadowing the enemy and providing ranges for gunnery (Kemp, 1988). Conventional radars and later developments e.g., ARPAs (Automatic Radar Plotting Aids) can be used as two separate aids to navigation, namely as: (1) an aid to determine risk of collision, or (2) for position fixing.

It is essential to understand that neither a conventional radar nor an ARPA can determine how to avoid a collision on their own. They provide the navigator with the necessary information to enable him to make the correct decisions (Bole, Dinely & Nicholls , 1992). The major difference between a conventional radar and an ARPA is that the latter can carry out tasks and calculations automatically which otherwise would have to be carried out manually. In this research the words radar and ARPA are used interchangeably unless otherwise specified.

3.6.2 Collisions and the Rules of the Road at Sea

During the events leading to a collision the pilot acts primarily as an expert navigator and therefore his presence on the bridge, in itself, should not have a significant bearing on the outcome of the events. The risk of collision may occur at any stage of the passage and cannot generally be anticipated. The risk is, nevertheless, expected to be higher in areas of high density of traffic (e.g., the English Channel, the Malacca Straits). Any action or procedure to avoid a collision must be based on the compliance with the COLREGS 72 (Bole et al., 1992).

3.6.2.1 The Early Days of the Rules of the Road at Sea

It must be noted that at the time of the introduction of the first international collision regulations, work was also being carried out to introduce uniform side lights and some type of formal examination of deck officers.

The early Rules of the Road at Sea were developed as a response to an increasing number of accidents between steamships. Some set of common rules was apparently needed to ensure that ships would be able to avoid each other in all traffic situations (House of Commons, 1843 a/b).

The first set of truly international rules, the Regulations for Preventing Collisions at Sea were adopted by 31 countries and came into force in 1863. The extract of the Sailing and Steering Rules of 1863 as shown in figure 13 suggests that the present COLREGS 72 originate directly from these initial rules. Some general observations of their historical impact should be considered due to their probable influence on the present COLREGS 72.

Two Ships under Steam meeting	Art. 13 If Two Ships under Steam are meeting End on or nearly End on so as to involve the Risk of Collision, the Helms of both shall be put to Port, so that each may pass on the Port Side of each other.
Two Ships under Steam Crossing	Art. 14 If Two Ships under Steam are crossing so as to involve Risk of Collision, the Ship which has the other on her own Starboard Side shall keep out of the Way of the other.
Sailing Ship and Ship under Steam	Art. 15 If Two Ships, one of which is a Sailing Ship, and the other a Steam Ship, are proceeding in such Directions as to involve Risk of Collision, the Steam Ship shall keep out of the Way of the Sailing Ship.
Ships under Steam to Slacken Speed	Art. 16 Every Steam Ship, when approaching another Ship so as to involve a Risk of Collision, shall slacken her Speed, or, if necessary, stop and reverse; and every Steam Ship shall, when in Fog, go at a moderate Speed.
Vessels overtaking other Vessels	Art. 17 Every Vessel overtaking any other Vessel shall keep out of the Way of the said last-mentioned Vessel.
Construction of Articles 12, 14, 15 and 17	Art. 18 Where by the above Rules One of Two Ships is to keep out of the Way, the other shall keep her Course, subject to the Qualifications contained in the following Article.
Provision to save special Cases	Art. 19 In obeying and construing these Rules, due regard must be had to all Dangers of Navigation; and due regard must also be had to any special Circumstances which may exist in any particular Case rendering a Departure from the above Rules necessary in order to avoid immediate Danger.
No Ship, under any Circumstances, to neglect proper Precautions	Art. 20 Nothing in these Rules shall exonerate any Ship, or the Owner, or Master, or Crew thereof, from the Consequences of any Neglect to carry Lights or Signals, or of any Neglect to keep a proper Look-out, or the Neglect of any Precaution which may be required by the ordinary Practice of Seamen, or by the special Circumstances of the Case.

Figure 13 Extract from the 1863 Regulations for Preventing Collisions at Sea

For instance, Gray (1867) concluded that most of the collisions were caused by poor look-out and neglecting to show lights and that no rule of the road could meet such cases.

Gray stated further:

> "The Legislative have made plain, simple, effective rules. The seaman must now do his part in carrying out these rules into practice in the manner and spirit intended by the framers and the advocate and jurist must do their part by investigating and understanding them."

Interpretation of the rules was recognised as a problem from the very beginning. Apparently few students sitting examinations seemed to fully understand the new Steering and Sailing Rules. It was further noted that "so as to involve Risk of Collision" can be interpreted very differently, "in fact according to the state of their nerves" (House of Commons, 1868-69)

The rules have changed extensively since then, primarily in response to difficulties in interpretation and changes in technology. For example, the original rules stated "every ship drawing near another ship should port her helm" (known as the Port-Helm Rule). This was later changed to "each steamship shall alter her course to starboard" providing an important alteration in wording, but not in substance (Gray 1878). The current COLREGS 72 Rule 14 (a) states ... "each shall alter her course to starboard so that each shall pass on the port side of the other".

The early rules evidently did not consider the effect of human behaviour on the interpretation of the rules. Colomb voiced his concerns in 1867:

> "The law at sea should merely deal with enabling ships to avoid all dangerous proximity; but when the dangerous proximity has arisen, either from accident or necessity, law should cease and seamanship must do the best it can".

Steam ships introduced the concept of speed into the Rules, especially with respect of course and speed of the stand on vessel (then holding vessel). The 1884 Rules stated "where by the above Rules one of two ships is to keep out of the way, the other shall keep her course". This resulted in misunderstandings as some mariners automatically slowed down confusing the give way vessel. The wording was therefore amended to "the other shall keep her course and speed".

Mr William Walton expressed his views that the word speed was fraught with great danger as it would mean that the stand-on vessel would almost typically keep her speed, not only until she has run into position involving risk of collision, but into such extreme danger that would almost certainly result in disaster (Board of Trade, 1891).

3.6.2.2 The Collision Regulations today

The International Regulations for Preventing Collisions at Sea, 1972 has been ratified by 67% of the IMO Member States. Notably the Philippines, which supplies about 20% of worldwide seafarers (Anon., 1998a), has not ratified the Convention (IMO, 1996d).

Examining the original Rules of the Road at Sea shows that they generally focused on legal aspects, as much as, on providing the mariner with a practical tool to avoid collisions. After a collision has occurred an action may be brought to recover damages. The course of action which arises as a result of a collision is based on negligence and this inherently includes a personal element. Such negligence is based on the failure of skill and care which should ordinarily be expected of a competent and prudent seaman. The Admiralty Court in the UK recognises that negligence charged in a collision case may not necessarily be negligence in navigation. It could be negligence in management of the ship, e.g., failure to adequately care for equipment or breakdown of steering gear due to neglect or carelessness. Any successful defence to such an allegation would likely be that the defect was latent, i.e., it could not have been discovered even by the exercise of due diligence (Hill, 1989).

In most cases, Masters of ships involved in collisions will be charged with negligence or contributory negligence. The only argument that forms a basis for a good legal defence in Britain is when the act of negligence was committed solely in the 'agony of the moment'. For this to succeed, it must be shown that the Master had no time to think of imminent danger, no time to form a deliberate and properly calculated alternative form of action to avoid the critical situation with which he was suddenly confronted, see e.g., the collision between the *Princess Alice* and the *Bywell Castle*[8] (see also Padfield, 1966) summarised here:

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[8] *The Bywell Castle* (1879) 4 P.D. 219; [1874-80] All E.R. 819; 41 L.T. 747; 28 W.R. 293; 4 Lloyd's Rep. 207, C.A.

> The *Bywell Castle*, a merchant ship was navigating down the River Thames and about to pass the *Princess Alice*, a passenger-carrying paddle-steamer proceeding along the south bank up the river. When close to each other the *Princess Alice* suddenly starboarded[9] the wheel and unaccountably turned sharply to port and under the bows of the other vessel. The Master of the *Bywell Castle* equally hastily, but incorrectly, put her wheel hard-a-starboard and struck the *Princess Alice* on her starboard bow. The *Princess Alice* sank with the loss of nearly 500 lives.

The Court of Appeal held the *Princess Alice* solely at blame. The Master of the *Bywell Castle* was considered entirely excusable despite taking the wrong action.

3.7 Passage Planning and Position Fixing

When navigating a ship from one port to another, a passage plan reduces the risk of straying off course and going aground. The aim is to prepare a plan for the navigation of the ship so that the intended passage can be undertaken safely from berth to berth. Without planning, the time to process essential information may not be available at critical times, when the navigating officer is occupied confirming landmarks, altering course, avoiding traffic or carrying out other bridge duties such as communications (Holder, 1994).

The course should be laid out on the relevant charts. The ship does not proceed at constant speed and is affected by currents and waves that may carry her off course. The position must thus be fixed regularly and marked on the chart. Traditionally the position would be fixed with the aid of, e.g., limiting danger lines, leading lights in port areas, parallel indexing, buoys and light houses.

3.7.1 GPS and ECDIS

Modern technology has introduced electronic versions of traditional tools in the form of the Global Positioning Systems (GPS) and Electronic Chart Display and Information Systems (ECDIS) which can be used independently, or as an part of an integrated bridge system.

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[9] Until 1931, in the UK, starboarding the wheel turned the ship's head to port and vice versa

The GPS consists of three operational segments (Evans, 1999):

- Ground station tracking/processing network, controlled and operated by the U.S. Department of Defence (USDOD).

- 27 operational satellites which allows the user receiver normally to see at least four.

- User segment consisting of GPS navigation receivers typically mounted on the vessel bridge. The receiver is designed to track, continuously and simultaneously all the satellites which are visible to it.

The GPS system is available free to all users but it should be noted that the USDOD deliberately degrades the GPS stand alone positioning performance to an accuracy of ± 100m for 95% of the time (known as selective availability (SA)).

The GPS computes the position in latitude/longitude with respect to a specific coordinate reference system based on the WGS-84 datum and spheroid. In many cases this will not match the datum/spheroid on the charts used on the bridge. Thus, a position plotted from the GPS system directly on to a chart without correction may result in position errors of several hundred metres.

Solar sunspot activity, which occurs on average over an eleven-year cycle, can during peak periods create high levels of electromagnetic noise in the ionosphere. GPS signals have to pass through the earth's atmosphere and the additional background noise may affect the GPS performance particularly during the next two years culminating in a peak around 2001. It is unknown how badly the GPS may be affected. Users may experience short periods of instability and/or reduced number of satellites which may result in a drop of service over a few tens of minutes to at worst, several hours. The effects are likely to vary with time of day and geographical locations and seasonally. Developed in the former SovietUnion, GLONASS is equivalent to the GPS system, and it operates in a very similar manner.

The paper chart has been a fundamental navigation tool for centuries. It is basically a pictorial model of the real world based on data obtained through hydrographic and other surveys. All ships must carry paper charts incurring a fixed cost, when purchasing the initial portfolio, and an annual upkeep cost. Additionally paper charts must regularly be corrected manually (Almond & Aldridge, 1996).

Falling prices, increased performance of computer and display technology and expected improvements in navigation safety led to the development of electronic charts (Smeaton, Dinely & Tucker, 1995).These, together with information from other integrated components, e.g., GPS, gyro, provide the basis for the Electronic Chart Display and Information Systems (ECDIS). This permits continuous display of the ship's position and can be used for all routine chart work, e.g., passage planning.

3.8 The human element in the navigational system

The concept of navigation has remained largely the same since the introduction of steamships. The navigating officer's main responsibility is still to follow a safe passage plan and avoid collisions.

The IMO provides the regulatory framework of the working environment. This framework has changed both through revisions of existing Conventions (e.g., STCW '95) and the introduction of completely new regulations (e.g., GMDSS). Although required to comply with the new regulations, information on changes is not always readily accessible to the navigating officer since he may spend several months at sea.

The physical working environment has changed extensively during the last few decades. The introduction of container and other specialised ships has reduced port turnaround time. They, and many other ship types, e.g., chemical tankers sail according to 'fixed routes' along relatively fixed sea lanes and according to relatively established time tables. This may result in more pressure from the company for the Master to 'cut corners' and ignore safety issues. Shipping is also a competitive industry that operates within a traditional environment of freedom of the high seas. The increasing number of electronic navigation aids has resulted in a higher mental work load. Officers may not always have access to the necessary training for the new equipment.

The above outline confirms that the organisational framework of the working environment on the ship's bridge is complex. Failings of the individual navigating officer therefore stretches far beyond the ship's bridge. An error made by an individual officer resulting in an accident, should thus not be regarded in isolation, but in relation to other factors influencing the navigational system.

3.9 Conclusion

This Chapter has recognised that there is an interaction between distinct components within the working environment. Consequently, the organisational framework and the navigational system, as parts of an integrated working environment of the ship's bridge, were explored.

The organisational framework is based primarily on conventions and resolutions adopted by the IMO but it has no enforcing powers. Consequently, the Member States shoulder the main responsibility for implementing and managing legislation. The navigational system focuses on components of safe navigation and the physical environment.

Collision avoidance is considered a central part of safe navigation. The Rules of the Road at Sea were therefore examined and the influence of the original rules was discussed. It was shown that the early rules focused on the legal aspects, perhaps lessening their practical value as a tool for avoiding collisions, i.e., the interpretation of the rules was left to a court of law after the event. The historical review suggested that this legacy may have affected the current COLREGS 72 potentially resulting in navigating officers interpreting the rules differently during the time leading to a collision.

The Watch One concept has attracted much attention in the past two decades. The concept and subsequent IMO trials and studies were discussed. Additionally a selection of other Watch One studies were reviewed. The IMO Member States have not, as yet, universally accepted the safety of the concept. It was therefore suggested that, at present, the available studies provide inconclusive evidence of the safety of the Watch One concept.

This Chapter also showed that the navigating officer has little direct influence on the working environment of the ship's bridge. It is suggested that research into human factors must acknowledge and consider the effect of the various components, individually and in combination, within this environment. It is envisaged that this Chapter can be used as a practical guide to the working environment on the ship's bridge.

CHAPTER 4

HUMAN FACTORS ON THE SHIP'S BRIDGE

4.1 Introduction

This Chapter focuses on the ship's bridge and relevant human factors are explored in sections: (4.4) Design of hardware and related information processing, (4.5) Communications, (4.6) Documentation and manuals and, (4.7) Learning processes and training. Health and safety is considered briefly in section 4.9 as it envelops the activities of the navigating officer thus affecting his behaviour on the ship's bridge.

This Chapter also reviews a descriptive memory aid for exploring human factors and confirms its usefulness for examining human factors on the ship's bridge. Task analysis is examined as a useful method for designing and evaluating system design and specific man-machine performance problems in the marine environment.

4.2 A descriptive aid for human factors

The significance of human factors gained increasing recognition in the aviation industry in the mid-70s. The US Airline Pilot's Association for instance, campaigned for many years for the development and installation of a Head-Up Display (HUD) to improve safety. Having succeeded, commercial airlines, who ultimately absorbed the costs, demanded a reduction in weather operating limits to obtain a financial return for their investment in the new equipment. There appears to be no studies showing whether the safety level at lower weather limits with an HUD is much better than operating with less critical weather limits without one (Hawkins, 1990).

The marine environment experienced similar changes with the introduction of radar and other electronic navigation aids. The radar was held as little short of a miracle as it enabled the navigating officer to 'see' in poor visibility. It may have provided the mariner with 'eyes' in poor visibility but obtaining an accurate aspect of the other ship required time-consuming manual plotting. The newly installed equipment may have resulted in an inclination to maintain speed, thus reducing the time available to work out the course and speed of the other vessel and consequently execute the correct manouevre. Such characteristic behaviour may thus have counteracted some of the benefits of the radar.

4.2.1 Human factors and the SHELL concept

The traditional sequence of system design in the aviation industry is shown in figure 14. The components, E for the environment surrounding the pilot, H for hardware, S for software and L for Liveware suggested a system which was 'hardware dominated' and largely neglected the human component (Edwards 1972) .

To clarify the scope of human factors in aviation safety the block diagram shown in figure 15 was proposed. This represents the components with which human factors on the flight deck could be addressed. It also provided for a convenient acronym to be used - the SHELL model representing the Software, Hardware, Environment and Liveware (Hawkins, 1990).

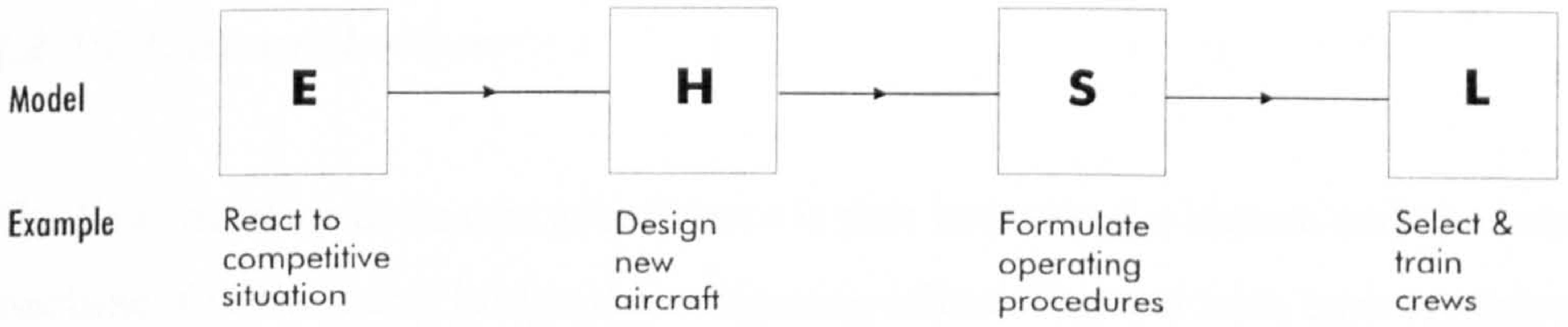

Figure 14 Traditional sequence of system design (Edwards, 1972)

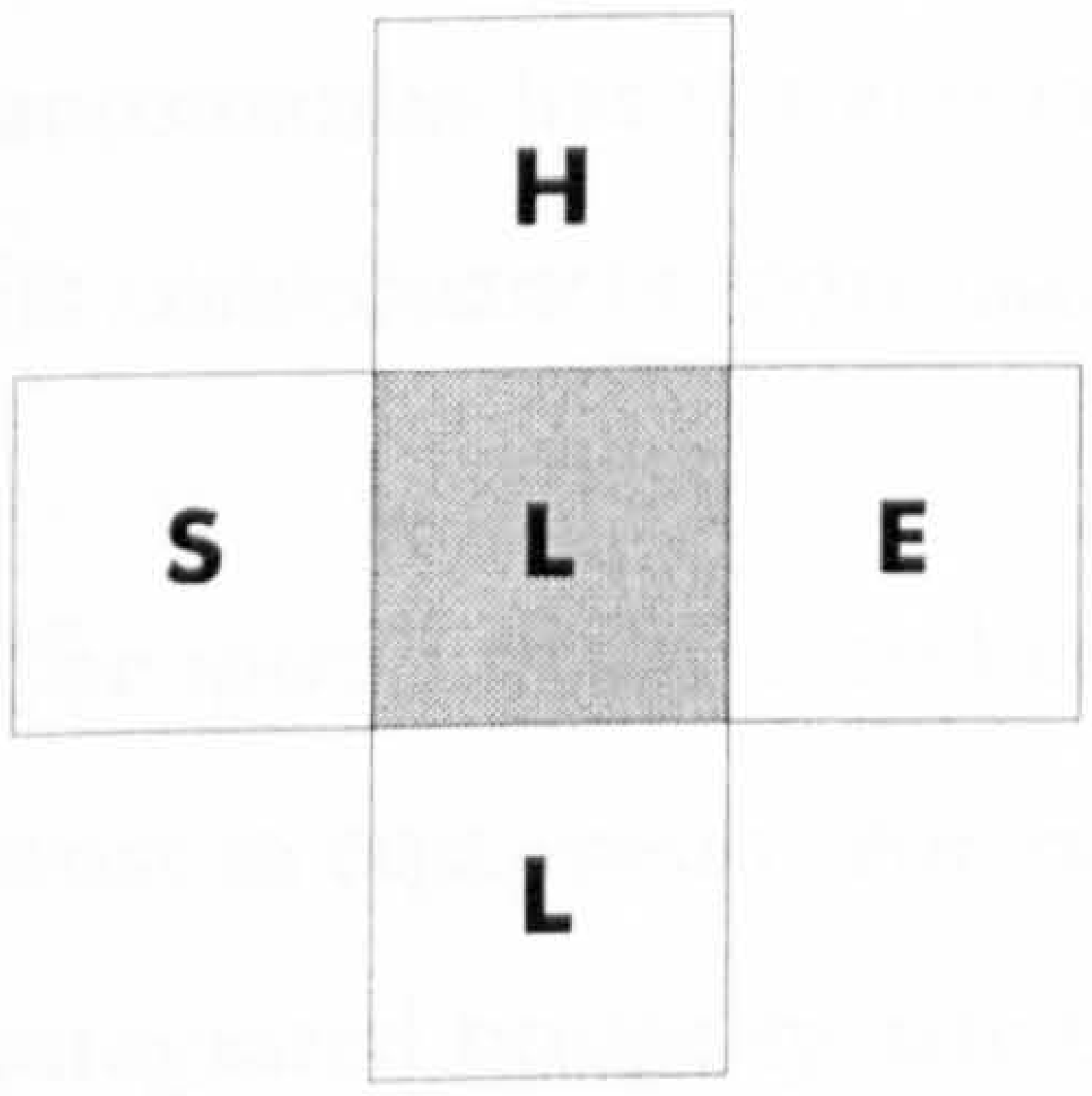

Figure 15 SHELL diagram representing human factors' components on the ship's bridge (Hawkins, 1990)

On the ship's bridge Liveware, i.e., the navigating officer, is in the centre of the system and is the key to system safety. There is a need to understand the capabilities and limitations of the officer so that he can operate safely in a highly complex system. The human component in the centre of the system must additionally interface effectively with the other components, including other Liveware, e.g., additional bridge team members or VTS operators. The SHELL interfaces are described briefly as follows.

4.2.1.1 Liveware/Software

The interface between the human operator and the Software, i.e., the navigating officer and operating manuals or display concepts have attracted attention in the aviation and other industries. There have been calls from the end users in both the airline industry and the marine industry for better operating manuals (e.g., see Dolby, 1989; Seaman, 1992; Willerton, 1989).

4.2.1.2 Liveware/Hardware

The first interface to be concerned about is that between the human and the hardware, or the machine. On the ship's bridge the navigating officer interacts with both traditional and electronic navigation aids.

Specialised automated systems have become the norm, introducing another area where the interface between man and machine must be optimised. Hawkins (1990) suggests that automation has not eliminated 'human error' but has changed its nature and has often made its consequences more catastrophic.

The introduction of technology at sea has resulted in officers some times placing unlimited trust in equipment. For example, the *Royal Majesty* (NTSB, 1997) which was fitted with an integrated bridge system (IBS) ran aground after the watch officers failed to realise that the ship, steered by autopilot, was 17 miles off course. The National Transportation Safety Board (NTSB) concluded that one probable cause of the grounding was the watch officers' over reliance on the automated features of the IBS. Additionally rapidly developing equipment may not work as well under difficult shipboard conditions as under test conditions (Wachtel, 1993).

4.2.1.3 Liveware/Environment

The interface between the navigating officer and his immediate physical environment has changed both in the aviation industry and the marine industry. For example, in modern aircraft wearing a thick leather jacket against cold or goggles against the wind is no longer necessary.

Ships are increasingly designed with closed bridge wings to protect sensitive electronic equipment. Closed bridge wings may protect the navigating officer from the elements of weather but they can also make it more difficult to observe the exact position of the ship when manoeuvring in constricted areas. The officer may therefore have to lean out of the window while operating the bridge controls (personal observation by the author). As well, the marine environment is becoming increasingly inhospitable due to higher traffic density, shorter port turnaround times, smaller crews and faster and larger ships.

The interface between Liveware and the Environment was discussed in Chapter 3.

4.2.1.4 Liveware/Liveware

The last interface in the SHELL model is that between people both at sea and land-based organisations, e.g., between the navigating officers and other bridge team members or shore management, depending on the focus of the system analysis being performed.

4.2.1.5 The SHELL model and the ship's bridge

The SHELL concept provides a descriptive aid for understanding how the various components affecting safety interact on the ship's bridge. When applying this to the marine environment, the interaction between the navigating officer and Hardware/Environment is considered part of the physical environment of the ship's bridge. Interaction between Software/Liveware is considered part of the navigational environment on the ship's bridge illustrated in figure 16.

Figure 16 The SHELL diagram and the ship's bridge

4.3 Exploring human factors in the marine environment

The table included in Appendix A shows that a range of techniques can be used by practitioners and researchers to identify and evaluate human factors in a given system. Kirwan & Ainsworth (1992) suggest that task analysis provides a basic method which helps to focus on specific issues. Such concerns can arise in the marine environment when:

- Overall safety is especially important (e.g., when evaluating the Watch One concept)
- Technology is vulnerable to 'human error' (e.g., GMDSS equipment)
- System changes may create uncertainty about the system integrity (e.g., introducing new components into integrated bridge systems)
- A particularly high quality product is required which depends on human performance (e.g., introduction of state-of-the-art electronic navigation aids).

Task analysis is a useful method when designing a system, evaluating a system design or if a particular man-machine system performance problem has been 'targeted' to be analysed and resolved. It is the study of what operators, e.g., navigating officers (or bridge teams) must do in terms of actions and/or cognitive processes to achieve a system goal, e.g., safe navigation. These methods can further be used to document the information and control of facilities used to carry out the task. The application of task analysis provides a detailed picture of human involvement in a given system.

4.3.1 Hierarchical Task Analysis (HTA)

Hierarchical task analysis (HTA) is a broad approach to task analysis which establishes the conditions when various sub tasks should be carried out to meet the system's goal. HTA produces a hierarchy of operations and plans. Operations are basically different activities that operators carry out within the system and plans are statements of the conditions which are necessary to undertake these operations.

HTA provides an effective means of stating how work should be organised to meet a system's goal. It can be used flexibly by the analyst as a framework for: (1) employing other task analysis methods, or (2) human factors' expertise to gain information or suggest system modifications. HTA can be used to deal with specific issues, such as interface design, work organisation, the development of operator manuals and job aids, training and 'human error' analysis.

An example of a hierarchical diagram for collision avoidance is shown in Figure 17. It should be noted that collision avoidance is a sub task of navigation and manoeuvring which may have other sub tasks such as communication, picking up a pilot, changing course, etc.

The main advantages of applying HTA in the marine environment are:

- It is an economical method of collecting and organising information in parts of the hierarchy where it is justified or required;
- It assists in focusing on crucial aspects of the task within the context of the overall task;
- It provides a context in which other specific approaches to task analysis (e.g., data collection for modelling design possibilities) may be applied to a greater effect;
- It forms the basis for many other assessments, e.g., communications analysis; and,
- It provides a convenient check to verify that no task elements have been omitted at any stage. This is because each task element is only broken down into a few sub-elements,.

To achieve optimum value from task analysis Ainsworth (1999a) suggests that the following points should be addressed:

1. A detailed definition of the purpose at the outset of the study.
2. At least one member of the task analysis team must have a background in psychology or human factors. Vice versa, at least one member must have a good understanding of the task being analysed.
3. Undertake, when possible, some form of trials using subjects with operational experience of the system or generically similar system (e.g., simulator trial).

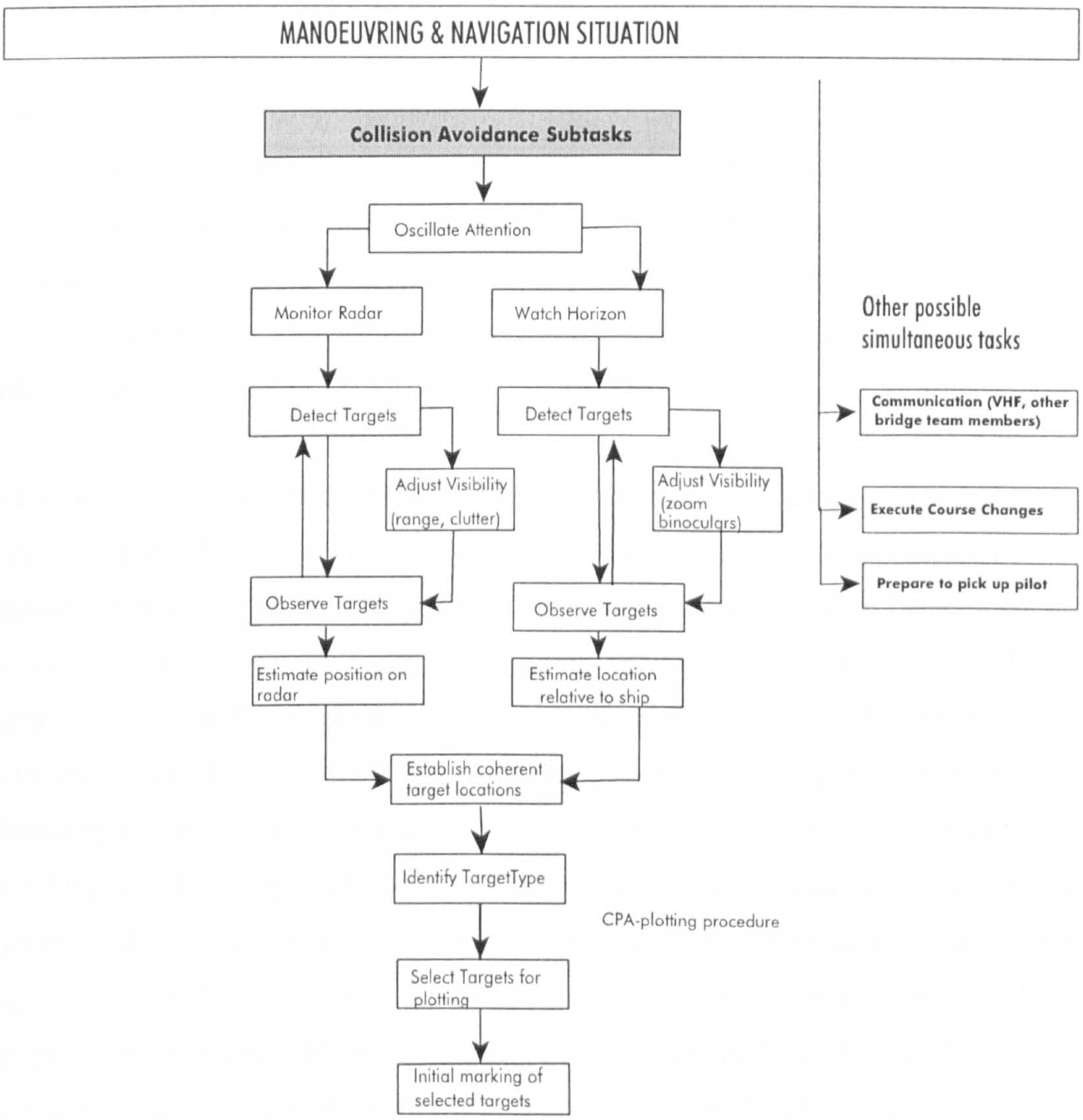

Figure 17 HTA for collision avoidance (derived from May, 1999)

4.4 Design of hardware and related information processing

The interface between Liveware and Hardware in the SHELL model focuses on the interaction between the operator and the machine. Hopkin (1993) suggests that human factors' problems may occur when an operator cannot be trained successfully to perform a planned task, cannot understand the instructions, cannot follow procedures, cannot do the tasks at the required pace or to required standard or cannot cope with the job as designed. Such problems may originate from general management or safety policies, the objective and plan of operations or the specification or designs of equipment.

4.4.1 Development of bridge aids

The development of electronic equipment, whether consumer goods or specialist navigation aids, tend to be driven by cost and technology. Increasingly, however, users have been involved in the development of the user-interface (Cushman & Rosenberg, 1991).By introducing electronic navigation aids the shipowner expects to lower long-term cost, e.g., by reducing the number of crew members. Additionally manufacturers may wish to secure or increase their share of the market or enter new markets.

As an example of the diversity of equipment that may cause problems it can be noted that the evolution of radar displays has produced a collection of mixed user-interfaces. Thus a non exhaustive review of modern radar systems reveals operation philosophies based upon a touch-sensitive screen, tracker ball system control, combined keyboard and tracker ball system, part keyboard, and part menu system operated with a joystick. Clearly, at present, manufacturers can do almost what they want, providing the system passes the relevant technical specifications and type approvals. From the operator's point of view, this can be a major dilemma. Type approval standards may be high, but not necessarily up to date and may vary in different countries. Often manufacturers take the opportunity, whenever they produce a new product, to change the system, including not only cosmetic changes, but perhaps layout of controls, terminology and sometimes the symbols (Hughes, 1992). Such changes may result in navigating officers confusing one control with another or failing to identify a control when it is needed. Fitts & Jones (1947b) concluded it would be possible to reduce the number of accidents attributed to these types of errors by designing equipment in accordance with human requirements.

4.4.2 Design of Controls, Symbols and Displays

Research into human engineering focusing on the design of equipment for human use has concentrated on such factors as design for ease of operation, presentation of information, equipment control, etc. This has resulted in an acceptance that people going against established habits are likely to make errors (Holding, 1969). For instance, a man trained to drive a vehicle with controls laid out in one way is likely to make mistakes if he transfers to another vehicle where the layout is different (Kletz, 1990).

Schiffrin and Schneider (1977) suggest that man can acquire two types of habits, those expressed through 'instinctive' actions and typical to mankind, and those formed by experience operating specific equipment. Marine accident investigators rarely acknowledge directly these types of factors. Consequently it is difficult to determine how common or significant errors caused by such habits are and to determine the appropriate preventive measures to reduce such accidents in the future.

'Instinctive' actions are generally more easily recognised. For instance, the Transportation Safety Board of Canada (1991) suggested that the physical layout of the bridge on the Canadian registered ferry the *Howe Sound Queen* contributed, at least in part, to the striking of a dock. The *Howe Sound Queen* is a double-ended ferry with only one wheelhouse amidships. The two conning positions are on alternate sides of the control console. To obtain an unrestricted view of the vessels bow, some masters preferred to position themselves in front of the manoeuvring console. As a result the master would have to turn his head and body back and forth while manoeuvring. The ferry was under the conduct of a trainee Master (with approximately 26 years of sea service on various types of vessels). During the final approach he realised that the vessel was not slowing sufficiently. His instinctive reaction was to pull the control toward himself to obtain astern thrust but this action engaged the forward propeller and provided forward thrust instead.

Lord Donaldson (1991) suggested, in the report following the inquiry into the engine failure and subsequent grounding of the oil tanker *Braer*[5], that any recommendations for further

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[5] See also MAIB, (1993), Report of the Chief Inspector of Marine Accidents into the engine failure and subsequent grounding of the Motor Tanker *Braer* at Garths Ness, Shetland on 5 January 1993

measures to prevent accidents at sea must take into account human nature rather than seeking to change it.

As part of a larger study carried out in Finland marine pilots were asked whether they required more specific knowledge about new navigation aids on modern ships' bridges (Haapio, 1991). 82% of the pilots answered yes and 18% answered no. When they were invited to comment further on the type of problems they encounter, the consensus was that there is a lack of common symbols and terminology, particularly for radar/ARPAs.

In a more recent study (Dickens, 1994) navigators at British and Greek nautical colleges also requested more cooperation between manufacturers and standardisation of controls and terminology. The study was not specifically designed to examine standardisation of symbols and terminology and does not provide explanations whether the respondents' concerns were related to any specific aspects of safety or mainly related to the frustration the officers experience when they encounter unfamiliar equipment (see also Hughes, 1992; Wachtel, 1993; Transportation Safety Board of Canada 1990).

4.4.3 Information Processing

The navigating officer analyses and interprets information that he collects from various bridge aids ultimately to make decisions that affect directly the safety of the ship. The average navigating officer is not employed because he is familiar with specific electronic bridge aids but because he is trained to a minimum level of competence (e.g., STCW '95).

In many land based industries the difficulty of operating different systems has been recognised. For example, people using software systems generally specialise in only a few manufacturers' products, e.g., Lotus®, Excel®, WordPerfect®, etc. The operators are likely to find it difficult to use alternative products to best effect at short notice without extensive cross training. Thus operators may have to adapt to the system rather than the system to the operator.

4.4.3.1 Automation & feedback

Research carried out in the airline industry shows that increased automation has not appreciably reduced the workload of airline pilots, instead it has increased the operational effectiveness of the system. Air planes can fly faster leaving less time for navigation, communications with ground control and system management (Perrow, 1984).

Shipping is facing a similar situation where technology is constantly developed with the aim to decrease workload (and ultimately reduce manning). Rather than reducing the number of accidents, there is a considerable risk that the rate of loss will remain unchanged.
For example, the grounding of the *Royal Majesty* (NTSB, 1997) highlighted the fact that automation cannot substitute inadequate primary training and poor user interfaces. Automated features require additional specific training. The *Royal Majesty* grounded on the Rose and Crown Shoal near Nantucket Island (US) about 17 miles from where the watchkeepers thought she was. A significant contributing cause was that the watchkeepers plotted the hourly fixes on the chart using position data from the GPS. Unbeknown to them the GPS had automatically defaulted to Dead Reckoning (DR) mode when the antenna cable to the receiver had disconnected. In this mode the GPS did not correct for the effect of wind, currents, or waves.

Feedback is a well-known concept in the science of control and information theory. It sends back information to the user about the actions carried out. Feedback can be tactile, sound, visual, etc. (Norman, 1990). For example, the whistle of a boiling tea kettle may have prevented some watchkeepers from assuming that the ship has moved into sudden fog (caused by steamed-up windows).

Modern navigation aids have an increasing number of features and provide less feedback, e.g., most ships are today steered regularly by autopilot which may not provide sufficient feedback to ensure that it has been engaged correctly.

For example, the Canadian stern trawler the *Zagreb* grounded on Grey River Rocks approaching from the north into Ramea, Newfoundland. The vessel was fitted with an autopilot. The change over between manual and autopilot was provided by an external switch located at the console. When in 'Auto' mode the course setting and/or course alteration could be carried out by depressing the demand-activated course-setting knob on the control panel and setting it to the desired heading. This feature eliminates the possibility of accidental course alterations. In this mode the gyro pilot computer converts the heading error or rudder order into control signals which are then transmitted to the power unit by means of a single floating port/starboard relay and a cut-out relay. When the new course has been reached, the relay is broken and the electrical signal neutralised. Thus the accuracy and performance of the autopilot are dependent upon the precision of the input to its (compass) repeater from the master gyro (Transportation Safety Board of.Canada, 1993b).

Alternatively, the 'Follow-up' mode could be used for course alteration. Once the ship has settled on the new heading, the 'heading pointer' on the autopilot must be reset to the new course and the steering switched back to 'Auto'. Failure to reset the course would result in the ship in effect continuing on the previous course.

It was reported that during the latter part of the voyage the mate altered course on the autopilot without closely monitoring the manoeuvre to ensure it had the desired effect. The lack of appropriate feedback in this situation resulted in a failure mode on skill-based level, i.e., inattention by omitting to perform the necessary attentional monitoring at a critical moment (see further Reason, 1990b).

4.4.3.2 *User confidence and technology*

Increasing automation, together with reduced feedback, may lead to increased confidence in the infallibility of technology. Simultaneously poor performance or, performance not as expected, and false alarms have induced less confidence in technology.

When Commander Lovell[6] performed his first night flight from an aircraft carrier off the California coast, he expected to be guided back to the ship by an automatic radio direction finder (ADF) receiving on 518 kHz (Lovell & Kluger, 1994).When he turned back and reached the spot where the ship and other planes were supposed to be, he was unable to locate them. He was absolutely certain that the ADF could not be wrong. However, he did not know that a tracking station on the Japanese coast was also broadcasting a homing signal

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[6] Later Commander of Apollo 13

at 518 kHz. In hindsight, had he known that the power of the shipboard ADF was low for security reasons, and that other homing devices might operate on the same frequency at higher power levels, he might have appreciated sooner that he was flying away from the ship (Lovell, 1996).

Alternatively, if technology fails regularly to perform as expected, e.g., due to false alarms, the operator may in the end not trust the equipment. Some time before the passenger ferry the *Estonia* sank off the Finnish coast in September 1994 the master and crew on the passenger ferry the *Mariella* had been monitoring her progress on the radar. When the *Estonia* suddenly disappeared from the *Mariella's* radar screen, the initial reaction of the master was that the radar had failed (Alberius, 1995). This was due to the unreliability of the newly installed radar and the poor quality of the radar picture caused by severe sea clutter on this stormy night (Törnroos, 1997). Additionally, it can be presumed that it would have been unthinkable for the master that the ship he was monitoring on the radar screen could simply disappear.

Navigating officers, as all humans, are occasionally prone to forgetfulness, confusion, making mistakes and not following instructions as intended. This may be due to either lack of understanding or lack of commitment. Shorter port turn-around-times (Osler, 1996) mostly forced by tighter schedules may result in operating ships at increasing speeds perhaps affording less time to make critical decisions. These factors may also increase fatigue or boredom. This is likely to have an even greater effect as both passenger and cargo ships capable of increasingly higher speeds are brought into service.

4.4.4 Design of user-interfaces

The purpose of the display of an electronic bridge aid is to transmit a message to the watchkeeper to enable him to make a correct decision, e.g., using information provided by the GPS to follow a safe course. Traditionally communication between technology and the operator on the ship's bridge is presented either by text or a symbolic message.

Information is now presented at an ever increasing speed to the navigating officer but understanding of the information is still acquired relatively slowly. Additionally software and hardware developers do not always appreciate that human operators may use the equipment differently from that intended. For example a computer software that translated 'Out of sight, out of mind' into Russian did it reasonably well. When it was then translated back into English it became the 'invisible maniac' (Tingstad, 1996). The intention of the programmer of the translation software was presumably for the program to be used for one-way translations only. Unfortunately human operators are innovative and likely to explore the use of any technology beyond the immediate intentions of the programmer.

4.4.4.1 Text and Symbols

The text of information is the plain content of the message which is communicated to the user. A sub text is the subconscious message which is communicated via a medium (i.e., hard copy or online), through navigation (i.e., paths to move around the information) and presentation (i.e., layout and fonts used to communicate the text) (Coe, 1996).

Baber and Wankling (1992) suggest that an effective information display must provide correct information, in the correct format and at the correct time. Symbols are frequently assumed to allow better 'glance legibility' than text. Text and pictures access different processing mechanisms in the human cognitive system. There appears to be an assumption that symbols represent some form of 'universal language' that can be understood by people from different language groups and cultures. The researchers found that a number of studies suggested that a combination of text and symbols produces significantly enhanced recognition compared with symbols or text alone. This implies that redundant information may be beneficial in aiding comprehension. The inclusion of redundant information on displays can therefore reduce uncertainty.

4.5 Communication

The interface between Liwevare/Liveware in the SHELL model focuses on communication between people. There is perhaps an assumption that safe communication at sea is embodied primarily in a common mother tongue between crew members. Linguistic knowledge alone, however, is not enough to ensure effective communication between people of the same or of other cultures.

In times of extreme stress it is said that people revert to their mother tongue and may therefore not understand or be able to express their intentions clearly. This notion is aptly illustrated in the film "The Fifth Element[7]" where the character *Korben Dallas* (acted by Bruce Willis), remarks "I only speak two languages, English and Panic."

The term communication refers to the exchange of messages and the creation of a meaning, whether between two or more persons, an operator and a machine or documentation. Communication on the ship's bridge therefore refers to exchanges of messages between the navigating officer and any of the following:

- Other persons, e.g., crew members
- Relevant rules, e.g., COLREGS 72.

A significant aspect of communication on a ship's bridge focuses on communication between persons on the ship and persons that may be indirectly involved in shipping, e.g., designers of user-interfaces, etc.

4.5.1 Message and meaning

A prevailing theory of communication is that only a message is transmitted and the person who receives the message, attaches his or her own meaning to it. Communication is therefore considered effective when the person attaches a meaning to the message similar to the intended. Messages are created by using a medium translated into a channel of communication using symbols which are things used to represent something else. Virtually anything can be a symbol, words-non-verbal displays, flags, etc. Referents for symbols can include objects, ideas or behaviours (Gudykunst, 1991).

The word 'vessel' for example, illustrates how as a symbol it means a ship to a mariner or a bottle/beaker to a scientist. The relationship between a symbol and its referent is arbitrary and varies from culture to culture, as well as within cultures. There are, nevertheless, direct connections between our thoughts and a symbol and a thought and our symbol's referent (Gudykunst, 1991).

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[7] Directed by Luc Besson, produced by Gaumont/France 1997

The word 'ship' can have many different definitions. Corbet (1986) provides at least 21 different sources of definitions. These range from the Concise Oxford Dictionary through various legal definitions, e.g., The International Convention for the Prevention of Pollution from Ships, 1973/79, Article 2 and The International Convention on Civil Liability for Oil Pollution Damage, 1969/76 (CLC). The former includes fixed or floating platforms, whereas the latter only includes any seagoing vessel actually carrying oil in bulk as cargo.

4.5.2 Language and aviation safety

Cushing (1997) examined problems arising from using spoken language as the medium of air-ground communication. He suggests that the complexity and flexibility of the natural language may cause confusions and misunderstandings arising from linguistic phenomena. He demonstrates that language-related misunderstandings have been a significant contributing factor in aviation accidents and incidents.

He suggests that problems related to communication in aviation safety can arise from:

- Characteristics of the language itself, e.g., ambiguity arising from a word or phrase which may have more than one meaning;
- Ways the language can refer to the world, e.g., problems arising from determining who is being addressed in a particular communication;
- Inferences that are drawn in the course of communication, e.g., inferences drawn by a listener being confronted with unfamiliar terminology;
- Repetitions which can fail or succeed in preventing or repairing a communication error, e.g., problems arising from repetition across more than one language;
- Use of numbers serving as an interface with technical equipment, e.g., digit confusions and reversals;
- Misuse and use of radio, e.g., when a radio is installed but the crew declines or forgets to use it;

- Circumstances unrelated to communication, e.g., distractions, fatigue, impatience, obstinacy;

- General problems arising when attempting to convey a meaningful message, e.g., when a message is not sent or when it is sent but not heard.

The work carried out by Cushing is not directly applicable to the marine environment because of the differences in the two industries. The main difference between the two industries is the working environment itself. This directs the terminology used in a given situation, e.g., in the aviation industry an aircraft would be cleared to a given height, e.g., 'cleared to eleven thousand' which is understood to mean 11,000 feet. It is suggested that communication problems in marine accidents should be examined adopting a similar methodology.

4.5.3 Communication on the ship's bridge

Communication problems at sea are rarely deliberate, i.e., incorrect orders are not given with the intent to cause an accident. Errors resulting in accidents or incidents generally follow from a misinterpretation of the message.

The increasing use of technology available to assist in navigation combined with smaller crews and an increase in new or revised regulations, e.g., ISM, has changed the process of communication on the ships' bridges today. Messages can be transmitted directly between two persons or between an operator and a user-interface. Messages may involve three or more pathways, e.g., a message transmitted from a radar display must have a meaning attached to it; this meaning is then used to associate it with, for example, a correct rule of the COLREGS 72. Finally the officer may take direct action or make a verbal order, e.g., to a helmsman, to resolve the situation.

4.5.4 Communication between persons on the ship's bridge

Messages on the ship's bridge are generally transmitted verbally between two or more persons who may, or may not, speak fluently the same language. The working language of a ship was traditionally the mother tongue of the crew members of specific ranks. For example, a British ship may have employed British officers (both deck and engineer) and the remaining crew members of another nationality, e.g., Chinese or Indian.

The increase in mixed nationality departments in the preceding decades has resulted in more ships carrying crew members with different mother tongues. The resulting belief that this may cause problems have led many ships to adopt a common working language, generally English (UK P&I Club, 1996). One study found that inadequate knowledge of the operating language was a contributing factor in approximately 10% of the incidents or accidents examined (Transportation Safety Board of Canada, 1995).

All watchkeepers should be trained to a common standard, i.e., according to STCW'95. These standards may differ depending on the requirements of the national maritime administrations (referred to in Chapter 3). The common level of training should ensure that the watchkeeper assigns the intended meaning to the message he receives even when is unable to speak fluently in the language used.

4.5.5 Bridge Resource Management

4.5.5.1 Cockpit Resource Management in the aviation industry

The National Transportation Safety Board (NTSB, 1994) found in a study that procedural, tactical decision and monitoring/challenging errors were the most common types identified. As a result of this study the NTSB recommended that the Federal Aviation Administration (FAA) should apply the results to the design and use of check lists to improve error-tolerance. FAA should also demand that U.S. air carriers provide a comprehensive crew resource management programme.

Many airlines, e.g., the Scandinavian Airlines (SAS) have implemented successful cockpit resource management courses (CRM) for their flight crews. The SAS programme has been subsequently adapted to the marine environment as a Bridge Resource Management (BRM) course (Scandinavian Airlines, 1994). The main objective of the course is to initiate a change of attitudes. Additionally it provides increased knowledge about managing human and technical resources on the ship's bridge.

4.5.6 The bridge team

The shipping industry has historically been quite hierarchical, i.e., divisions between the ranks and different departments were marked. Such cultural traditions may cause additional communication problems even when all crew members are of the same nationality. Larger crew complements may have had some 'redundancy' built, in but present day smaller crew complements provide less scope for casual conversations or helpful interpretations by other persons that may clarify the intended meaning of a message.

The Master/crew-Pilot relationship has largely remained unchanged, tending to contain a residual level of resentment between them when working together on the ship's bridge. Problems arising from hierarchical relationships, varying levels of competence and different linguistic skills may also be causal factors in groundings and collisions. For example, the grounding of the *Queen Elizabeth II (QE2)* is partly attributed to the lack of coordination of watchkeeping activities between several officers and the pilot on the bridge (MAIB, 1992; Sager, 1995).

The Transportation Safety Board of Canada (1995) concluded that misunderstanding between the pilot and master, inattention by the pilot or the OOW, or lack of communication between the pilot and the OOW were often attributed as a primary cause of the accident. The complexity of the master/pilot relationship was emphasised by frequently conflicting opinions given by masters, OOWs and pilots in this study.

4.5.7 Communication ship-to-ship and ship-to-shore

4.5.7.1 Universal ship borne Automatic Identification System transponders (AIS)

A transponder is a radio or radar receiver-transmitter activated for transmissions by reception of a predetermined signal.The aviation industry has benefited from transponders for many years. Acknowledging this, the demand for some type of automatic identification system for ships has grown (see e.g., Donaldson, 1994). The Maritime Research Centre (1995) at the Southampton Institute carried out a study for the Marine Safety Agency (UK) which suggested that ship-to-ship transponders would enhance maritime safety (see also Atwell, Pourzanjani & Pearce, 1996).

This report is based on a survey into the expected user requirements for transponders, ship-to-ship and ship-to-shore. It concludes that the majority of respondents believe that transponders would make a valuable contribution to maritime safety and would like to see them become mandatory.

The IMO has now completed a draft performance standard for transponders. The standards will encompass (i) definition of the operational requirements of the system, (ii) technology and telecommunications protocol necessary for the system and (iii) type approval test requirements. The 44th Session of the Navigation Subcommittee is considering recommending that AIS devices should become mandatory on ships subject to SOLAS 74 from as early as July 2002 (Crothers, 1998).

Trials have been conducted with the support from the IMO to gain experience with transponders in busy waters such as the English Channel (Prescott, 1995). The United States Coast Guard has also supplied, as part of their Ports and Waterways Safety System (PAWSS), approximately 50 fixed and portable transponders to mariners sailing along the lower Mississippi River. The PAWSS includes an automatic identification system (AIS), a radar subsystem, VHF marine communication to and from the shore-based operational centre (based in New Orleans), multiple operator work stations, an integrated database, and a synchronous record and replay system. This trial is expected to establish the effectiveness and safety of transponders in crowded waterways (Kinsella 1999, Ledet 1999). Such trials can indicate underlying problems, e.g., DGPS can provide a more accurate position than the underlying ECDIS charts (see also e.g., Richards, 1994).

4.5.7.2 Ship-to-ship transponders

A significant assumption for the application of transponders appears to be that when a navigating officer knows the name of the other vessel he can call her up on the VHF so that they can confer and mutually decide their respective actions. By identifying the other ship the number of VHF calls: 'vessel on my port side' or 'vessel on my starboard side' could be reduced.

Based on this assumption alone, fitting ships with transponders, is unlikely to prevent a collision. This is evident from the collision between the *M.T. New World* and the *M.V. Ya*

Mawlaya (Marine Department, 1994) which occurred in moderate visibility. This is a 'classic' two-ship encounter, where the watchkeepers detected each other by ARPA in good time before the collision. As the ships closed to about 4 miles apart, the watchkeeper on the *Ya Mawlaya* called up the *New World.* The call is recalled as "Vessel on my starboard side change your course to port". The 2nd officer on the *M.T. New World* replied "No I will not change my course to port. You must be the one to change to your starboard because I am stand-on vessel and you are a give-way vessel". Some time later the *New World's* officer called the *Ya Mawlaya* on channel 16 and said "Vessel on my port side, what are you doing? You have to change your course to starboard".

Although the watchkeepers did not know the name, each officer was clearly aware of the other vessel. A transponder would therefore not have prevented the conflict and hence the collision, here.

4.5.7.3 Ship-to-shore Transponders

Vessel Traffic Services (VTS) have been defined as any service carried out by a competent authority designed to improve safety and efficiency of traffic and the protection of the environment. It may range from the provision of simple information messages to extensive management of traffic within a port or waterway. A VTS typically provides three types of services (1) General Information, e.g., dredging activities, damages to external navigation aids (e.g., buoys that have moved position), (2) Advice, e.g., specific ship movements within the area and (3) Instruction, e.g., clearance to enter the area (Routin & Deutsch, 1987).

At present, many port authorities require a ship carrying a hazardous cargo to report her position at regular intervals. Such communications can be distractive, especially in areas where traffic density is high, e.g., Dover Straits. The benefit of transponders would be that, 'tagging' ships carrying hazardous cargoes would be possible, and a possible cause for distraction on the bridge thereby eliminated.

Before transponders become mandatory, human factors should be considered to ensure that any equipment installed is user-friendly and provides the optimum amount of information. This may vary according to ship/cargo type and trading patterns. Further, the implications of only fitting some ships, e.g., only commercial ships and excluding others, e.g., naval, fishing or recreational vessels must be considered.

4.5.8 Communication between rules and persons

The basic intention of the COLREGS 72 is to give the watchkeeper a set of rules that advises him how to avoid collisions in close quarter situations. Should a collision occur the ensuing analysis of the events is typically from a legal perspective, i.e., (i) the sole fault of one ship, (ii) the fault of both ships, or (iii) as an inevitable accident, i.e., neither ship was at fault and each should bear its own damages (Hill, 1989).

In terms of communication the COLREGS 72 transmits a message to the watchkeeper whose decision is based on the meaning he assigns to it. His assignation of a meaning may depend on his interpretation of the aspect or definition of the other ship(s).

Although the intention of the rule makers is clear, i.e., to make sure that all ships are able to avoid collisions, the message transmitted by a specific rule can have different meanings attached to it. What exactly is safe speed? It is generally accepted that the manoeuvrability of a vessel decreases with the reduction in speed. Therefore although reducing the speed provides more time to make a decision, the vessel will respond slower.

The wording "moderate speed" in the 1960 collision regulations was changed to "safe speed" with the introduction of the 1972 collision regulations. From the point of view of assigning a meaning the words "moderate speed" may have been easier to relate with speed reduction. Safe speed according to the rules is the speed that allows the vessel to avoid a collision in a close quarter situation. Each navigating officer is likely to attach his own meaning to the word safe speed depending on his training, experience, cultural background and type of ship.

4.6 Documentation and manuals

The interface between Liveware and Software in the SHELL model concerns the operator's interaction with operating software and their related documentation.

The navigating officer typically learns the operational instructions for electronic bridge aids by reading the manuals. The intention of the text and drawings of the manual is to provide the officer with sufficient and correct information to enable him to operate the equipment in the manner that the manufacturer intended.

There are no common standards for the production of manuals. Navigating officers must frequently use more than one type of reference aid. Their ability to solve problems or answer technical questions depend partly on the coordinated usage of a variety of types of manuals. Although the intentions may be good, the outcome of the use of manuals is often not quite as intended.

A study by Scerbo and Fisk (1990) concluded that a user's success was largely determined by the adoption of an appropriate search 'heuristic'. The use of a 'heuristic' may give the user some key locations in the manual to begin looking for the information. As a result the user can operate the equipment more efficiently. The results also suggest that the frequency of usage for different kinds of documentation may differ greatly from what is commonly expected. It suggests that important documentation such as glossaries and overviews may be almost neglected despite the naivety of the users. A well structured indexing system may affect significantly the amount the user spends looking at the table of contents.

Carroll, Smith-Kerker, Ford & Mazur-Rimez, (1987-1988), developed a Minimal Manual to address difficulties equipment operators have using state-of-the-art self-instruction manuals for learning to use electronic devices. Their study showed that the proposed Minimal Manual afforded more efficient learning progress than a comparable commercially developed self-instruction manual. It was also superior in the specific areas as predicted by the design team.

Ainsworth (1999b) suggests that written procedures can have a critical impact upon task performance. Changes to written procedures can be used to overcome deficiencies in hardware or software without the need for costly changes in their design. Task analysis can be used to optimise written procedures to examine the following four aspects of the procedures:

1. The format and presentation of the procedures
2. The level of operator support within the procedures
3. Navigation through procedures
4. Task-specific issues

4.6.1 Following Instructions

Wright (1981) suggested that following instructions is one of the most difficult comprehension tasks required in daily life. Understanding and complying with instructions that accompany consumer goods is not always easy and indeed often people choose to ignore instructions completely. He concludes that instructions must be factually accurate, simple to understand and easy to find. Such a specification requires skilful application of a variety of design procedures.

4.6.1.1 Documentation for other cultures

The shipping industry is by its very nature a multicultural industry. Documentation on the ship's bridge is likely to be translated into one or more foreign languages. It may also be used by someone whose first language is not the language of the manufacturer. Thus in addition to multicultural considerations the needs and limitations of the translation process and interaction with the translation vendor must be considered (Coe, 1996).

4.7 Learning processes and training

Navigation is a learned skill and thus training and education has a significant effect on safety of navigation.

4.7.1 Learning processes

In theory people with similar qualifications will carry out identical tasks in a similar manner. In practice, this is rarely true because learning processes depend on cultural background and individual information processing capability.

To illustrate the effect of different cultural backgrounds figure 18 shows how a simple arithmetic operation can be set out in different ways. Each method provides the correct result and each person generally finds his own method the most comfortable. The possible dangers of processing information differently depending on cultural background is particularly important to note in the marine environment where mixed crews are increasingly common.

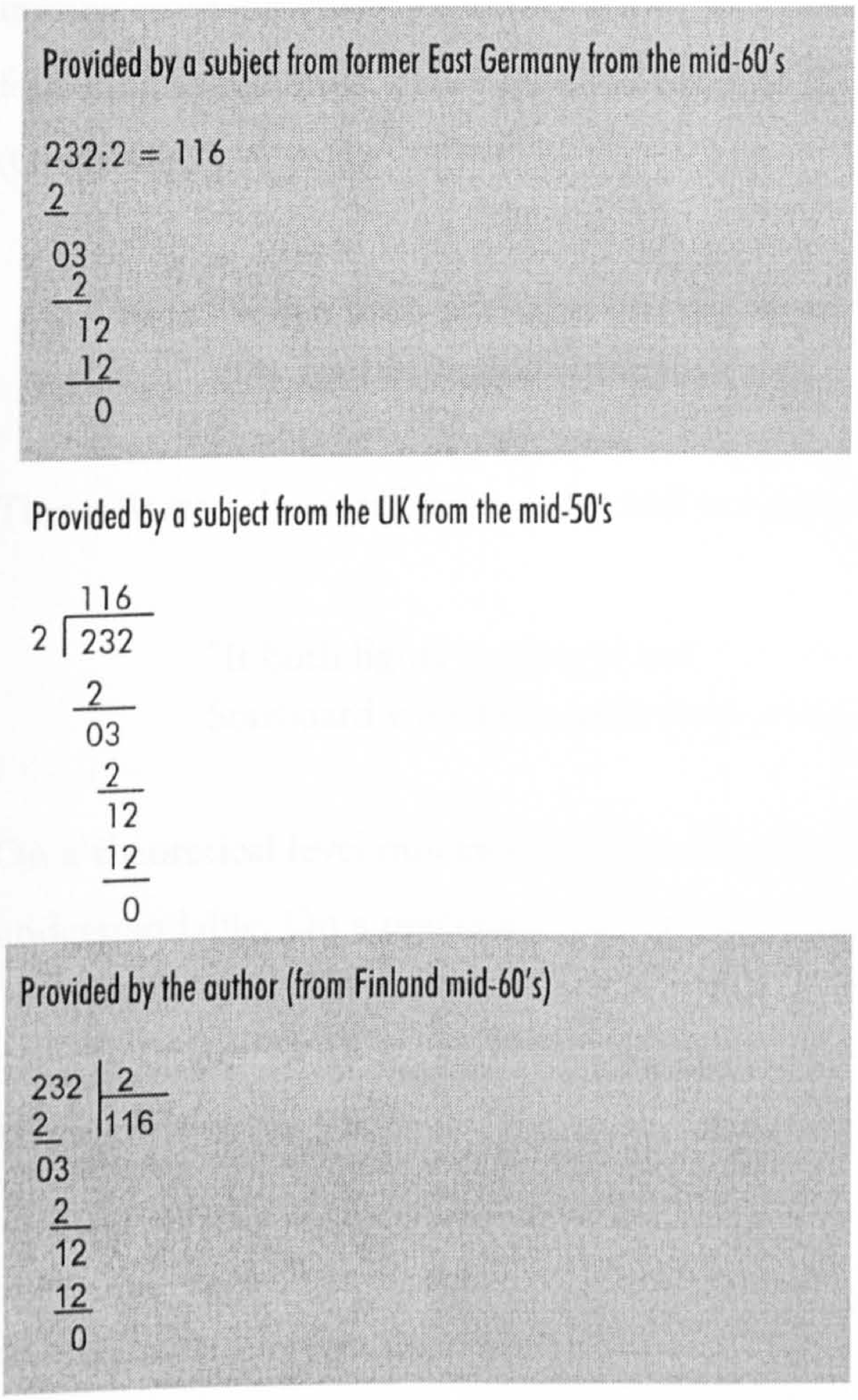


Figure 18 Different ways of solving an arithmetic operation

The learning capability of an individual is unique and depends to some extent on how that person thinks. There are ways of improving learning capability, e.g., mnemonics and 'errors as opportunity'. A danger associated with learning is the ability for humans to devise explanations.

4.7.1.1 Mnemonics

Mnemonics are mental techniques that may help an individual to learn and remember specific items of information (Gregory, 1987a), e.g., port and starboard may be confusing and therefore a 'cue' such as 'left and port have the same number of letters' may assist in linking the confused items of knowledge. Mnemonics have frequently been used in the marine environment, e.g., during the development of the early Rules of the Road the following mnemonics were suggested to assist the navigating officer in avoiding a collision (Gray, 1867):

> "When both sidelights you see ahead
> Port your helm and show your red"

This reflected the initial helm order and was superseded by:

> "If both lights you see ahead
> Starboard your helm and show your red"

On a theoretical level mnemonics helps to make difficult information more meaningful and understandable. On a practical level they have both uses and limitations.

4.7.1.2 Explaining errors

Lewis (1986) shows that learners can devise explanations which makes the effects of even disastrous errors seem reasonable. As a result subjects would sometimes continue to work without any attempt to correct the error because they had explained it away. Explanations may be an important mediating structure in learning to use a system. Explanations are important because:

- The process appears to play a role in the failure to detect errors: learners can explain satisfactorily to themselves events that may reflect a serious problem.

- Some sequences of events are easier or require less knowledge to explain than others.

4.7.1.3 Errors as Opportunity

Navigation is a cooperative task where learning on the job is inevitable. Errors will occur in the distributed task setting due to the need for on-the-job training. Seifert and Hutchins (1992) examined learning within a cooperative system. The study involved observation of distributed activity in the team navigation of a large naval ship. They concluded that there were frequent individual errors but also that successful detection and correction of errors occurred.

4.7.2 Training

Most people involved in a skilled task will at some point be involved in training others. On a ship the Master passes on his knowledge to others as part of the on-the-job training, so that over a period of time he passes his experience to junior officers.

4.7.2.1 Maritime education and qualification

Examination of seafarers was introduced when most ships still operated under sail, although steamships were slowly increasing in numbers. The shipping industry showed considerable resistance to the examination of navigating officers in Britain when the concept was first proposed during early last century (Anon., 1838 a/b).

Traditionally deck officers would follow a 'time-served' training structure under which the trainee was selected primarily on academic criteria. The periods of training and service at sea were fixed and the emphasis in the examination was on the knowledge and the ability to apply it. Recently there has been a move toward 'time-independent' training which encompasses mandatory minimum periods of service at sea and the assessment of the trainee's competence. This can be established through observation of actual performance on the ship's bridge and/or by using a simulator.

The most valuable part of a future officer's training is considered to be onboard a working ship (Brunicardi, 1990). The active seafaring community is concerned that substituting simulator training for actual sea-time may reduce the competence of future navigating officers.

4.7.2.2 Dual purpose officers

Some countries, e.g., France, Germany, Japan, The Netherlands, UK and USA have introduced some type of dual-purpose training of officers. This is still a lesser used route to obtaining a certificate. Cross (1992) suggests that the term "dual purpose" stands for some form of integration of deck and engine department operations. The idea is believed to have originated in France in the late 1960's. The main areas of application are in the industrialised and developed maritime countries where crew wages are higher.

4.7.2.3 Continuing training

There are generally few statutory requirements for additional and/or continuing training once the officer has achieved the certification of the highest qualification. The provision for additional and continuing training has frequently lagged behind the introduction of new technology, e.g., when the radar was introduced in the 1950's onboard ships there was inadequate provision for training how to use it (Baillie, 1990). Many other industries require mandatory continuing training, e.g., British Airways pilots undertake mandatory assessed training in a simulator every six months (McGregor, 1994).

4.7.2.4 Effectiveness of training

Baddeley and Longman (1978) suggest that retention of training depends on the amount of practice per day and the length of the interval between successive training periods. Their study shows that attempting to include too much training into a single session or single day is counterproductive. There is a limit to how much learning can be accomplished in one day.

4.7.3 Ship simulators

Most high-risk industries, especially the aviation industry, use simulators to good effect. Flight simulators date to the late 1920's (Stark, 1989). In the shipping industry simulators have been mainly used for radar and ship handling courses. The Radar Simulator course became mandatory in the 1960's for those requiring a certificate of competency as First Mate. There has been a shift in the marine environment toward carrying out much of traditional onboard training using onshore simulators (Angas, 1992). Modern type of ships simulators are particularly suited for specific training such as integrated bridge systems and the Watch One concept (Habberley & Pourzanjani, 1992).

Ship simulators have additionally been used for research purposes (as shown in Appendix B) and to provide assistance for expert witnesses in courts of law (Corlett, 1993).

4.7.3.1 Simulator training

The main aim of simulator training is to impart practical 'situational' knowledge to the student in a safe environment. A summary of a study on the effectiveness of simulator training concludes that simulator-based training is more cost-effective than onboard sea training for achieving many training objectives (Centre for Marine Simulation, 1994/95).

However, simulator training must also be effective in terms of imparting the required skills. All elements of the simulator training system must be considered acknowledging that the instructor has the most substantial impact on the effectiveness of the training (Hammell et al., 1980). This is acknowledged by Carpenter (1991) emphasising that the instructor must have excellent practical skills and be good at imparting his skills to the students.

O'Hara (1990) examined the loss of skills across a nine-month retention period following a simulator-based training programme. This was developed to enhance the watchkeeping skills of merchant marine cadets. The results showed that (1) training improved watchkeeping skills, (2) skills declined during the nine-month retention interval, and (3) refresher training effectively mitigated skill loss for some skill areas.

Overskeid (1990) examined the effect of simulator training based on the basic competence of navigating officers. The study showed that the group with a low basic level of competence gained most. The group with moderate basic competence improved some, but the group with a high basic level of competence did not improve significantly.

In a similar study but in a quite separate discipline, DeAnda & Gaba (1991) examined the effect of experience in anaesthesiology. They concluded that although responses to planned incidents improved on average with experience, fewer errors were made by experienced individuals. The study recommends strategies to make errors more observable and strengthen the preparation and training of anaesthesiologists to cope whatever situations arise.

Stark (1989) noted that human perceptual and learning processes are not understood well enough to predict accurately the level of information (or fidelity) required to ensure that the training has the desired effect. Researchers at British Airways made the assumption that data based on a survey following the simulation exercises would be objective. They discovered, however, that few students were interested in filling a questionnaire after the training session. The researchers therefore requested training captains to highlight after each month's simulator work the most common errors and reasons for them (Seaman, 1992).

4.7.3.2 Classification of ships' simulators

Marine simulators can be broadly divided into complete ship handling simulators and PC-based simulators. Modern ship handling simulators are typically capable of all, or part of the tasks undertaken on the ship's bridge (shown in table 11) (Woodyard, 1997a).

- Radar/ARPA simulation
- Ship handling
- High speed craft
- Propulsion plant
- Cargo Handling training
- Ballast Control training
- GMDSS and SAR training
- Communications equipment training
- VTS Management training
- Oil Spill Management training

Table 11 Shiphandling simulator tasks (Woodyard, 1997a)

PC-based simulators are becoming increasingly popular, usually offering individual components, e.g., collision avoidance and watchkeeping (Woodyard, 1997b). Testing and evaluation of these types of simulators suggest that they can be acceptable for complying with the provision of simulator-based training as required by the STCW'95.

The shipping industry has been concerned for some time that a variety of marine simulators are available but, as yet, there is not an internationally agreed technical specification or classification of simulators (Drown, 1993). Recently a classification system similar to that used in the aviation industry was proposed to the IMO (Woodyard, 1997a). This classification system includes four categories as follows:

Category 1.	Full mission (total environment, including advanced functions)
Category 2.	Multi Task (total environment, excluding advanced functions)
Category 3.	Limited Task (environment for limited training)
Category 4.	Single Task (a specific subsystem)

4.7.3.3 The human element and simulator training

A marine simulator can never completely substitute seagoing experience, mainly due to the high number of variables affecting the working environment of the ship's bridge (referred to in Chapter 3). Nevertheless, simulators can be useful for training purposes and classifying them into the above broad categories is a significant step toward ensuring that simulator training in the marine environment will be effective.

Examination of the studies referred to previously in this Chapter suggest that a simple framework for the evaluation of factors affecting the human element in simulator training can be proposed (shown in figure 19).

The effectiveness of simulator training is related to the competence of the teacher and the course material. Furthermore, the student's level of competence/ experience and type of task influences the selection of the most effective simulator category. The student's level of competence/experience can be divided into three levels (1) Low, (2) Medium, and (3) High. Tasks can be divided into three types (a) basic/general training, (b) training aimed at learning a specific task, e.g., docking a new type of ship, and (c) a refresher course, e.g., collision avoidance.

Finally, a program for assessing the student's proficiency must be developed to ensure that the training has been effective.

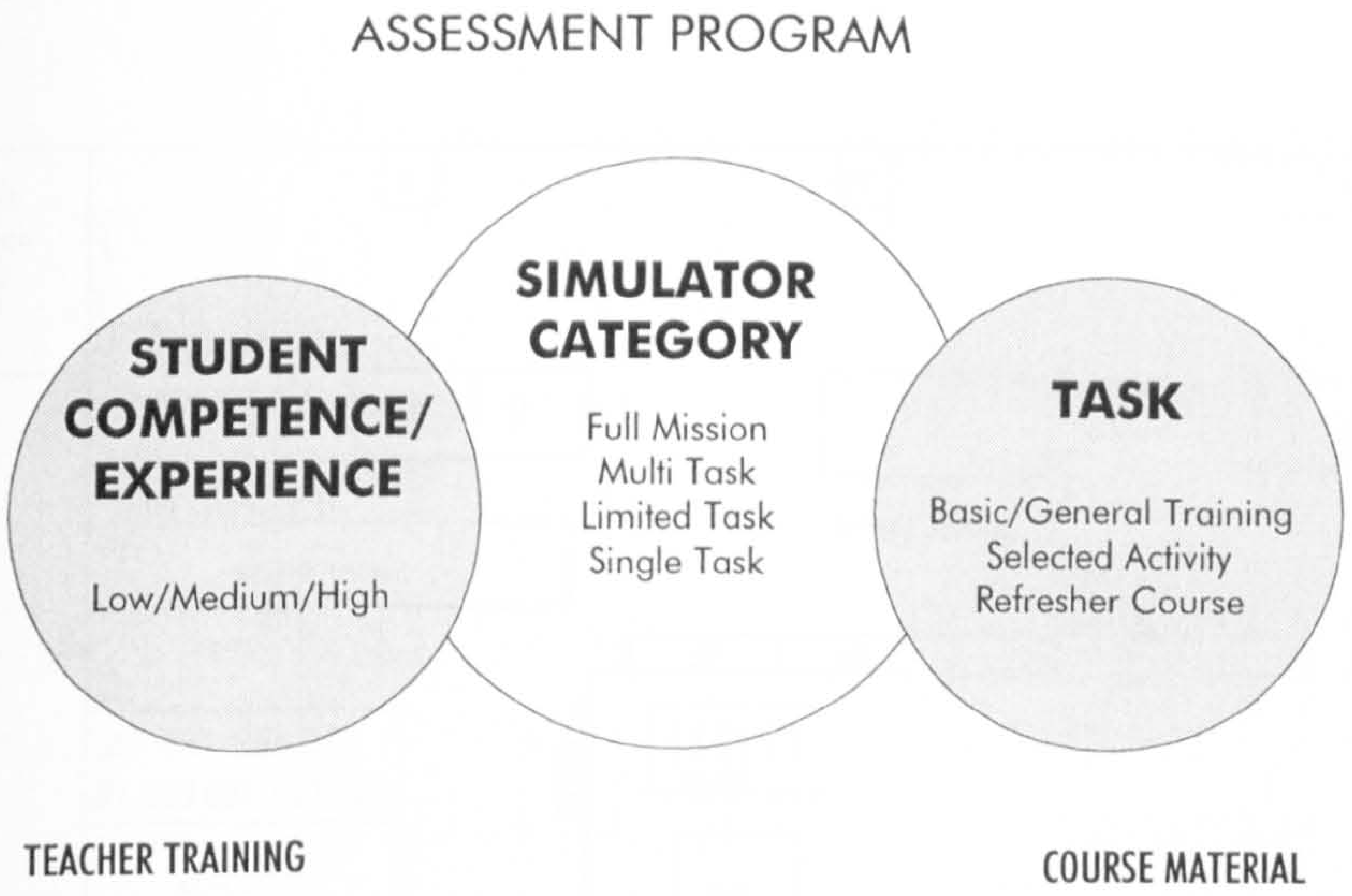
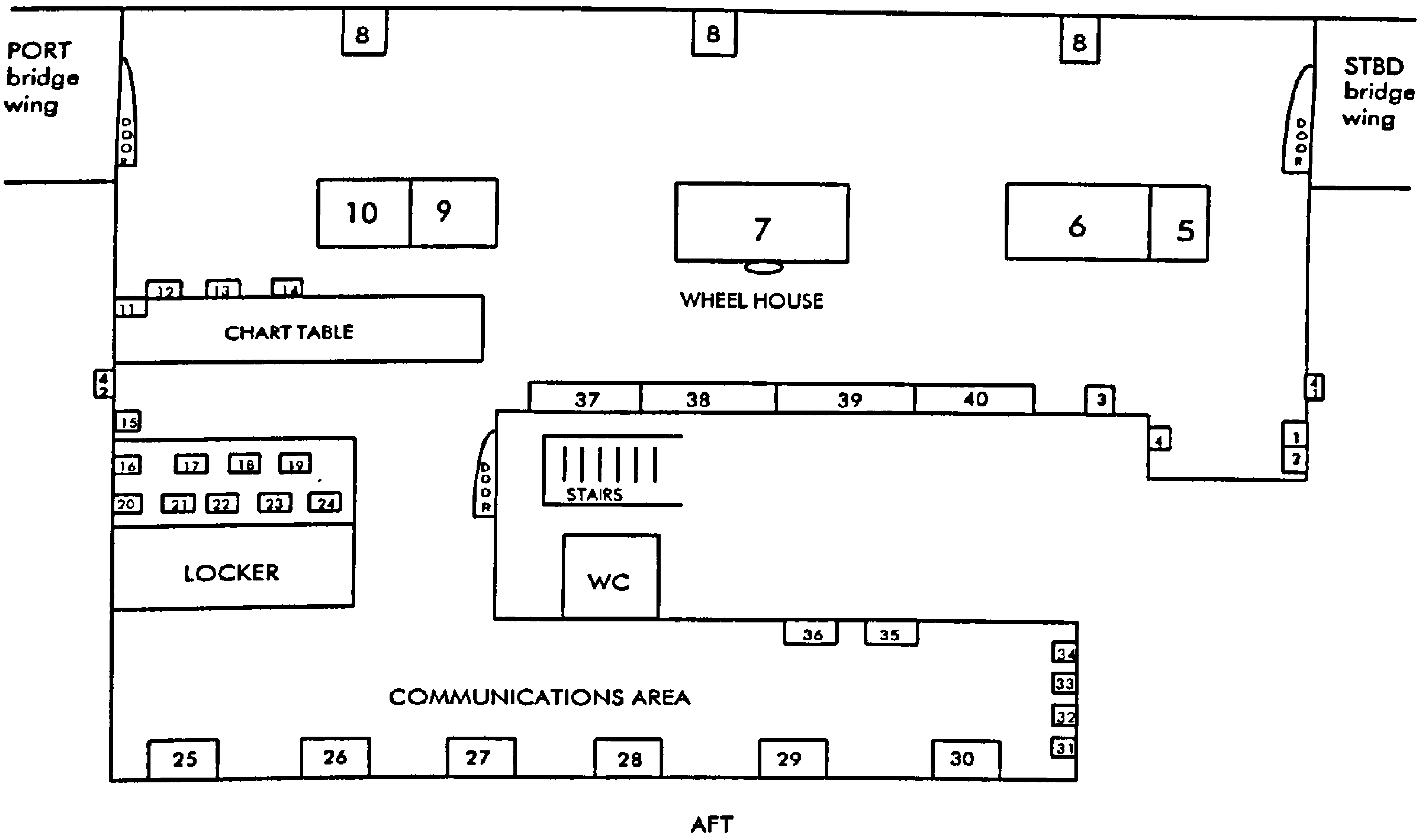


Figure 19 Factors affecting the human element in simulator training

4.8 Failure mode analysis and alarms

Alarms and warnings may have a significant role in assisting the watchkeeper in navigating the ship safely in all types of conditions. As a result of an increasing number of electronic bridge aids some 30-40 individual alarms may be found on the ship's bridge (illustrated in Figure 20). Some are related directly to navigation, such as steering gear alarm or rudder angle indicators, others relate to the cargo (low/high temperature or pressure indicators) or the engine room. Depending on the type of ship there may also be other indicators, e.g., for water leakage detection or watertight door positions.

According to IMO regulations, e.g., SOLAS 1974, and other associated rules and regulations, all ships must be fitted with specific alarms, including fire and general distress alarms which have important functions relating to the safety of the ship and its crew. Personal observation and spontaneous remarks made during the author's visits to ships suggest that the increasing number of alarms on the ship's bridge is distressing.



Key to Diagram

1. Halon Fire Extinguisher
   Alarm Monitor (Var.)

2. Inert Gas (N_2) Panel (Var.)

3. Magnetic Compass for Off-Course Alarm

4. Off Course Alarm

5. Bow Thruster Control Panel
   Var. - Over Load Start Failure
   -Control Start Failure
   - Hd'r Tank Low Leverl
   - Hyd. Oil Low Pressure, etc.

6. Main Engine Control Panel (Var.)
   - Dead Man's Alarm
   - Pump Room Fire Alarm
   - Bilge Alarm (Var.)

7. Steering Unit & Master Gyro
   Var. - Power Failure
   - Rudder Limit
   -Monitor Failure, etc.

8. Windscreen wiper & heater unit

9. Radar 1 (Var.)
10. Radar 2 + ARPA (Var.)

11. Direction Finder

12. GPS 1
13. GPS 2

14. Doppler Log
15. Inmarsat 'C' Phone

19. MF/HF Radio
20. NAVTEX
21. Sat 'C' Phone Ext. Speaker
22. Sat 'C' Printer
23. Sat 'C' Processor
25. Weather Fax Rec'r
26. Fax
27. Rydex (Wan)
28. Sat 'A' Txl Rx + Phones
29. Modem
30. Printer for Wan
31., 32., 33. Handheld 2-way Distress Radios
34. Auto alarm HF
35. Printer
36. Computer
37. 2 VFH's (Auto Distress Function)
   - 2182 kHz Alarm
   - ½-hr watch alarm
   - Morse Code Reader
38. Echo Sounder
   General Alarm
   Fire Detector Panel
39. Enginer Room Alarm
   Emergency Fuel Stops
   Fire + General Service P/P alarm + start/stop
   Cargo Tank Temperature Abnormal Alarm
   Steering Motors Alarms + start/stop
40. Lights - Navigation & Domestic
   Alarm Distribution Panel
   Earth Alarm
41. Cargo Level High Alarm
42. Cargo Overflow Alarm

Figure 20 Schematic diagram of alarms found on a modern chemical tanker (based on a sketch by D.G. Grewal, 1996).

The grounding of the *Royal Majesty* illustrates the importance of the functionality of alarms (NTSB, 1997). When the GPS switched over to DR mode, it issued a series of aural beeps for a total duration of 1 second. It then displayed continuously SOL (solution) and DR on a liquid crystal display (measuring 3" x 3.5"). This display was positioned away from the ship's main controls thus making it less likely that it would be noticed and acknowledged.

A brief review of literature relating to human factors shows that research into alarms has been sporadic in most industries and particularly scarce in the marine environment (shown in Appendix C). Research has been mainly carried out in aviation (civil and military), the medical field and manufacturing/ processing plants.

Aldridge, Brooks, Moreton and Smeaton (1997) suggested that to reduce human factors' related incidents integrated bridge systems should acknowledge the operator's needs. The researchers offer a format for evaluating failure modes and alarms on ships' bridges. The authors suggest that alarm information and handling must consider the uniqueness of the working environment of the ship's bridge. The grounding of the *Royal Majesty* indicates that an appropriate alarm function alone might have prevented the accident. However, had the officers shown pertinent attention to good navigation practices, it is likely that they would have realised in time that the ship was off course.

Alarm analysis and management should be considered as an integrated part of the resources on the ship's bridge. Both the literature reviewed during this work and personal observations confirm the important premise that alarms must support, rather than distract, the navigating officer.

4.9 Health and Safety

The working conditions of seafarers, including exposure to injury and health problems, unsafe procedures, fatigue, stress and inadequate health care are regulated by the International Labour Organisation (ILO) (ILO, 1998; Nilssen, 1995).

The health and safety of the navigating officer may affect his behaviour directly, e.g., falling asleep due to fatigue, or indirectly, e.g., his attention may be reduced due to increased boredom. An outline of health related factors affecting safe navigation are shown in table 12.

Current research into the health and safety of seafarers is scarce and irregular. There is also a widespread lack of basic data on deaths, injuries and illnesses in the shipping industry (Goss, 1995).

- Exposure to noise, up to 100 db
- Vibration
- Thermal stress, exposure to exceptionally high (tropical) or low (arctic) temperatures
- Constantly changing atmospheric conditions during voyages
- Changes of time zones
- Air pollution (e.g., dust, exhaust fumes in ferries, toxic vapours or gases in tankers
- Dangerous cargo
- Work related accidents, injuries, diseases
- Less physical work, increased mental stress
- Psycho-social problems, high turnover of personnel
- Barriers imposed by hierarchy
- Less contact with other people onboard due to smaller crew complements
- Fewer opportunities to go ashore in ports due to shorter turn-around-times
- Security problems in foreign ports, piracy, wars, strikes, etc.

Table 12 Health related factors affecting safe navigation are shown in table (adapted from Tomaszunas, 1995)

4.9.1 Working Hours

Olofsson (1995) examined the changes in working conditions for Swedish seafarers. The study examined employing a questionnaire whether seafarers had to work when fatigued thus showing a subjective view of fatigue (table 13). Most seafarers have had to work when feeling very fatigued. However, the very nature of shipping is such that it attracts abnormal working hours.

Position	Very often (%)	Often (%)	Sometimes (%)	Rarely (%)	Never (%)
Master	9	20	56	12	3
Chief Officer	12	35	39	12	1
Other navigating officers	4	16	58	19	3

Table 13 Have you ever had to work when affected by fatigue (extracted from Olofsson, 1995)

The working hours for Swedish Chief officers are higher than for other positions onboard as shown in table 14 (Olofsson, 1995). There is reason to believe that this is true on most ships. Working hours in the marine environment are essentially unregulated although ILO has recently proposed regulations for maximum working hours (ILO 1998)

Position	Working Hours/Week
Master	68.0
Chief Officer	74.3
Other Navigating Officer	67.2

Table 14 Average working hours for Swedish navigating officers (derived from Olofsson,1995)

4.9.2 Fatigue

Concern for increasing fatigue and its adverse effects have long been expressed in the shipping industry (see e.g., Bland, 1990; Drahos, 1992 a/b; Gozdzik, 1992; Marriott, 1993; Stein & Hajarnavis, 1995; Torpmann-Hagen, 1995). The main concern is longer working hours brought on by decreasing numbers of crew members and shorter port-turn-around times. There are at present ships trading within the European coastal waters where the total crew complement may be as few as 5 or 6 persons.

Fatigue is defined as the deterioration of an individual's performance with passage of time. It is associated with tiredness, slowing down and making simple errors. The most common reason for fatigue is the lack or poor quality of sleep. The effects of fatigue are increased by adverse conditions such as cold, excessive heat, noise and vibration, isolation, lack of oxygen, being wet or seasick or being under the influence of alcohol and drugs (Gregory, 1987b).

According to Kroemer and Grandjean (1997) there are six different types of fatigue:

1. Eye fatigue: arising from overly straining the visual system
2. General body fatigue: physical overloading of the entire body
3. Mental fatigue: induced by mental or intellectual work
4. Nervous fatigue: caused by overstressing one part of the psychomotor system, as in skilled, often repetitive work
5. Chronic fatigue: an accumulation of long-term effects
6. Circadian fatigue: part of the day-night rhythm and initiating a period of sleep

4.9.2.1 Measuring Fatigue

The extent of fatigue cannot, as yet, be measured with any precision. Tests for fatigue according to Kroemer and Grandjean (1997) include:

- Quality and quantity of work performed;
- Recording of subjective perceptions of fatigue;
- Electroencephalography (EEG);
- Measuring frequency of flicker-fusion of eyes;
- Psychomotor tests, and;
- Mental tests.

These types of tests generally provide indicators rather than measures of fatigue.

4.9.2.2 Time-of-Day

Regular changes in alertness and human efficiency occur throughout the day. Studies examining the effect of time-of-day on vigilance are divergent. Davies el al., (1984) concluded that the time of day affected performance on successive- and simultaneous-discrimination tasks.

Performance on the simultaneous-discrimination tasks improved with time of day, whereas performance of the successive-discrimination tasks deteriorated. Successive-discrimination requires that a target is distinguished from a non-target reference represented in recent memory, e.g., detection of an increase in the brightness of a repetitively flashing light. In simultaneous-discrimination tasks, target and non-target features are provided within the same stimulus event, e.g., a disk of a paler hue in a display of several disks.

4.9.2.3 The effect of sleep

Studies into the subject of Total Sleep Deprivation (TSD) indicate that the major effects focus on the brain and behaviour. The rest of the body incurs very few real problems. At the same time there is no conclusive evidence showing that sleep is really restorative for the brain. The reason that the brain needs to sleep is that unlike the rest of the body it does not really close down when a person is awake. Even when lying down relaxed but awake in a sound-dampened and dark room, the EEG shows that the brain remains vigilant (Horne, 1992).

Research shows that adults can successfully adapt to 1.5-2.0 hours less sleep than considered normal (i.e., about 8 hours) on a daily basis, i.e., to approximately 6 hours of sleep. This does not mean being more sleepy during daytime or finding it more difficult to get up in the morning. Such adaptation cannot be achieved overnight but must be accomplished over a few weeks. Findings suggest that sleep beyond the first six hours is "optional". This type of sleep is very flexible. It can be either used, or not, with little side effects. Sleep length can be shortened and lengthened within limits without adverse effect, given time for adaptation (Horne, 1992).

A realistic simulation for Artillery Fire Direction showed that the performance of the subjects deteriorated markedly after one night of TSD. Eventually all teams were forced to withdraw by 48 hours. This was mainly because the subjects had totally lost their appreciation for the tactical situation. The types of tasks particularly vulnerable were those that required revisions of preplanned data based on new information and keeping updated the "situation map" as the scenario changed (Neville, Bisson, French, Boll & Storm, 1994).

Naitoh et al. (1994) investigated the effectiveness of short naps in maintaining cognitive function. The results of the study suggest that a 20-minute nap taken every 6 hours, before the accumulation of sleep deprivation, maintains the baseline level of cognitive functions necessary to maintain accuracy of performance on the 4-choice task. The naps also helped to reduce, but not fully prevent a slower response speed. They also failed to maintain the number of responses at a high baseline level.

4.9.2.4 Lessons from the aviation industry

The aviation industry introduced in the early 1980's aircraft fitted with sophisticated flight management systems and electronic displays (so-called glass cockpits) designed to be operated by two pilots. Grieve and Roscoe (1992) examined the relationship between workload and fatigue in this new type of working environment. The study was based on tiredness scores collected using fatigue rating forms. Predictably the highest scores were generally given at the end of night flights. Most of these were preceded by poor sleep.

The aviation industry has been more progressive than the marine environment, e.g., current projects include the "Fatigue Countermeasures Program" carried out by NASA (Fatigue Countermeasures Homepage, 1998).

There are considerable differences between the working environments in the marine and aviation industries. A similar program should therefore be initiated for the marine environment with the aim to:

- determine how much fatigue, sleep loss and circadian disruption affects the navigating officer
- determine the impact of these factors on the performance of the navigating officer
- develop and evaluate countermeasures to mitigate adverse effects of these factors and maximise the performance and alertness of the navigating officer

4.9.2.5 Visual illusions and fatigue

The navigating officer has traditionally relied on his eyesight to verify images within his optical environment. He may at times experience visual illusions because the brain can misinterpret images sent by the eyes. Such illusions could arise in daylight when the navigating officer must use distance cues or fixed points (perhaps distorted by atmospheric conditions) to identify ships and navigation aids. During the hours of darkness, in coastal waters, a ship or buoy can be lost in the glare of background lights, e.g., street or car lights.

The officer must scan the horizon for other ships and obstacles and focus on any that are observed. In an open ocean it requires effort to focus on distant objects since the eyes tend to focus on a much closer point. This natural tendency to focus somewhere in the range of one to two metres is referred to as empty field myopia (Thom, 1994).

The navigating officer on a modern ship's bridge increasingly relies on displays providing him with information, e.g., radar/ARPA, GPS, ECDIS. During the hours of darkness these may emit high levels of light resulting in the deterioration of his night vision.

Visual fatigue can magnify hazards arising from visual illusions and other problems associated with eyesight. Megaw (1987) discusses critically the measurement and definitions of visual fatigue concluding that there is a need for improved recording methods and the knowledge of oculomotor systems.

It is important for the marine environment to understand and acknowledge that there are problems associated with eyesight that may affect safe navigation.

4.9.2.6 Boredom

Dyer-Smith (1993) suggests that boredom and depression are related. His study suggested that the tolerance for performing a boring task differs greatly. A major problem is to define boring tasks of navigation, e.g., a nightly crossing of the Atlantic could be similar in terms of boredom to a day sailing through moderately busy but familiar route.

4.10 Conclusion

This Chapter has explored the human factors affecting the navigating officer within the working environment on the ship's bridge. A descriptive memory aid for human factors (SHELL) is outlined briefly and it is suggested that it can be utilised in the marine environment.

This research focuses on the human element on the ship's bridge and consequently only human factors relevant to the working environment were outlined, i.e., the design of hardware and related information processing, learning processes, maritime education and training and communication.

Communication is a complex issue and safe communication at sea is often assumed to be a common natural language between crew members. This assumption was found to be too simplistic and consequently the term communication was explained in more detail. The relevant aspects of communication were reviewed. It is expected that this will provide a useful framework for all aspects of communication at sea.

Health related factors may influence the behaviour of the navigating officer and increase the risk of a collision or grounding. Fatigue and boredom were considered to have the greatest impact and were examined in more detail.

CHAPTER 5

DATA COLLECTION AND CLASSIFICATION

5.1 Introduction

While the working environment has changed with the introduction of technology on the ship's bridge, the human characteristics have remained largely the same. Research into human factors on the ship's bridge must therefore look at integrating the best of yesteryear with the best of the future, i.e., examine how to exploit human strengths while improving and developing technology to support his weaknesses.

This Chapter focuses on the collection and classification of data relating to the navigating officer's working environment as outlined in Chapter 3. Techniques for researching human factors on the ship's bridge are examined briefly. The data employed in this research is explored and a marine human factor's classification system proposed.

5.2 Techniques for researching human factors on the ship's bridge

The main techniques for carrying out meaningful research into preventing collisions and groundings at sea are through (1) Personal observation of watchkeepers on the ship's bridge, (2) Post-accident analysis/statistical analysis of computerised accident records, (3) Analysis of voluntary incident reports, (4) Carrying out a survey/interview, (5) Designing and carrying out simulator experiments, (6) Personal logs, (7) Observation using a remote radar

5.2.1 Personal observation of watchkeepers on the ship's bridge

Personal observation is a useful, but rarely used technique in the marine environment. It cannot be carried out without permission from both the shipowner and the Master and his crew. From a practical point of view ships' bridges are generally spacious enough to afford unobtrusive observation. Although shipowners increasingly recognise the importance of research into human factors, it can still be difficult to obtain permission to conduct research through personal observation. Nevertheless, the author's experience shows that Masters are, when permitted by the shipowner, generally supportive of inviting independent researchers onboard the bridge.

The main disadvantage of personal observation is high cost due to the time-consuming nature of this technique. Ships may be delayed, or change ports unexpectedly thus making it difficult to predict the time required to stay onboard the ship. To ensure maximum benefit the researcher must stay onboard during several port departures and arrivals. However, ships may spend long times in open seas thus adding research time. The main advantage of personal observation is that the researcher may observe common types of incidents, relating to the same or different ships, e.g., difficulties in finding unilluminated switches in darkness.

5.2.2 Post-accident analysis/statistical analysis of computerised accident records

Post accident analysis has been a favoured technique in the marine environment (see e.g., Bryant, De Bievre & Dyer-Smith, 1987; Wagenaar et al.,1987). The main advantage is that many maritime administrations offer some access to official accident reports. The usefulness of post accident analysis depends on the details acquired from the accident report. In collision cases the reports may provide specific details of only one ship (e.g., the flag ship). At present there appears to be few experienced human performance investigators involved in examining accidents at sea. Consequently information relating to human factors may be overlooked and omitted from the final report. The reports are generally summarised and independent researchers have customarily no access to the initial 'raw' data.

5.2.3 Analysis of voluntary incident reports

Many industries encourage voluntary incident reporting. For example, the aviation industry has several reporting schemes managed by airline operators or government agencies (e.g., Feedback administered by the Civil Aviation Authority in the UK). The aim of such schemes is to collect ongoing information on incidents that, although they did not result in an accident, had the potentiality to do so. The higher the level of anonymity offered to the reporters the more successful the scheme is.

The main benefit of voluntary incident reports is that they provide information before an accident has occurred. This allows measures to be considered which may prevent future accidents. The main disadvantage is that they are mostly reported in free format and therefore may not provide as much information as needed. In addition to the lack of trust in confidentiality, the nature of shipping also makes it difficult to contact the reporter to obtain further information after the incident has been reported. Published reports can provide useful feedback benefiting the reporter and other parties interested in maritime safety.

5.2.4 Carrying out a survey/interview

A survey can be conducted by developing a questionnaire and distributing it to a select number of respondents. Alternatively the researcher may conduct personal interviews. The main benefit of a questionnaire is its relative inexpensiveness and ease of distribution, e.g., via trade or professional journals, to many respondents. The main disadvantage is that the information collected is likely to be limited, because questionnaires are often designed with closed questions (yes/no) for ease of analysis using a computer program. Open-ended questions are structured, unlike 'free format' reports and although they have limitations, they resemble personal interviews and thus are likely to yield more detailed information.

A personal interview usually yields a lower number of responses and may require that the interviewer has some level of understanding of the study area. The main disadvantage is high cost which tends to result in a smaller number of responses. A major benefit is that an interview can lead to further informal discussions indicating other areas of concern.

5.2.5 Designing and carrying out simulator experiments

Simulators and simulator training were referred to in Chapter 4. Simulators were initially developed in the marine environment for training purposes, e.g., to train collision avoidance. A well-designed simulator experiment can provide useful data on human factors. The main advantage of a simulator experiment is that lifelike situations can be reproduced safely. The main disadvantage is high cost which tends to result in fewer subjects engaged in each experiment.

5.2.6 Personal logs

Personal logs have been used to collect data in other industries (see e.g., Neville et al., 1994; Rosekind et al.,1994). These can be useful for collecting data, especially in the fields of health and safety. By keeping a detailed personal log it is possible to collect, for example, fatigue related data, e.g., hours of working, sleeping and recreation. These can then be correlated to the status of the ship, e.g., whether in port, at anchor, under way, etc. The main benefit of a personal log is the relative ease of collecting large amounts of data. However, personal logs are tedious to keep which can lead to a difficulty to ensure the integrity of the data provided.

5.2.7 Observation using remote radar

Observation using a remote radar, e.g., VTS, may supply good real-time data. Analysis of data collected by VTS provides information relating to a specific traffic area, e.g., the English Channel. The data collected may include the number of 'rogue'[8] ships and other navigation incidents, number of VHF messages received/transmitted, number of collisions and so on (Clipsham, 1990). The main benefit of remote observation is that data can be collected passively over a long period. Thus, it lends itself to analysis of annual changes and other trends within a specific traffic area. A major disadvantage is the lack of specific ship details, e.g., ship/cargo type.

5.3 Data collection

The choice of research technique depends on the availability of financial support and the aim of the research. Data for this research was collected from the following sources: (1) Personal observation, (2) Official accident reports (3) The Marine Accident Reporting Scheme (4) Database - Databank for Sikring af Maritime Operasjoner (5) Survey using a questionnaire.

5.3.1 Personal observation

During this research the author was invited onboard several ships sailing in European coastal waters. The passages were undertaken on medium size ships and covered most visibility conditions, including fog, night, rain and sleet. They included ships carrying hazardous cargo and high windage ships, berth and lock approaches and inward and outward passages. They have included UK and foreign registered ships.

Only limited informal discussions and interviews were conducted to ensure that no disruption was caused during the navigation of the ship. Observing the behaviour of the navigating officers in their natural surroundings revealed situations that are unique to their working environment (e.g., false fire alarms or total blackout). Such situations are difficult to identify solely through literature reviews, discussions with officers or analysis of accident/voluntary incident reports.

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[8] A 'rogue' ship is defined as any ship not complying with the requirements of the TSS rules (Clipsham,1990)

Talking informally to navigating officers, allowing them to propose areas of interest and confirm general beliefs, supplemented information gained elsewhere, and thus provided useful background information. Sometimes comments were made spontaneously and sometimes prompted by referring to a specific accident/incident, e.g., poor design of a particular piece of bridge equipment. Such informal comments reflect the notion that many critical observations relate to technology and are common to navigating officers irrespective of their backgrounds, training or experience.

Although research has been carried out on ships' bridges by independent observers (see e.g., table 9, page 51) at present there are no specific guidelines for employing this method in the marine environment. The main objective of conducting individual observations in this research was to confirm incidents documented in accident/incident reports and discussed in nautical journals.

5.3.2 Official accident reports

The accident reports that were analysed in this research are all official accident reports published by various different Maritime Administrations. They include both minor and major navigation related accidents. Only complete reports on collisions and groundings were included.

The reports included in this research were provided by the Maritime Administrations of Australia, Canada, USA, UK, Hong Kong, Sweden and Finland. A total of 98 reports of collisions and groundings that occurred between 1982 and 1996 were obtained (shown in table 15). The data represents 58 groundings and 40 collisions involving two or more ships.

It is difficult to ascertain how well this sample represents the worldwide population of groundings and collisions generally, e.g., regarding geographic, oceanographic and atmospheric conditions, trading patterns, crew nationalities and ship types. This is because there is lack of worldwide statistics on the annual rate of collisions and groundings (referred to in Chapter 2).

Source	No of Reports
The National Transportation Board of Australia	47
The National Transportation Board of Canada	24
The National Transportation Safety Board, US	8
Haverikommisionen, Sweden	8
Marine Accident Investigation Branch of the UK	6
Marine Department of Hong Kong Government	3
Oikeusministeriö, Finland	2
TOTAL	98

Table 15 Breakdown of Sources of Accident Reports

Additionally the author gained access to unofficial accounts of accident investigations courtesy of the North of England P&I Club. These accounts provided original data, e.g., copies of statements from several or all the crew members or original simulator analysis of events leading to a collision. A detailed examination of these accounts suggested that for the purpose of situational analysis such background data can provide additional valuable information generally not present in the final report.

Problems associated with using data from final accident reports include:

- They are not uniform and therefore similarity of causes may be difficult to ascertain
- It is likely that some human factors related information is not included in the report
- Some reports are less detailed than others
- In collision cases more information is generally available for one ship than the other

5.3.3 Marine Accident Reporting Scheme

In 1992 an initiative was taken by The Nautical Institute (NI) to establish the Marine Accident Reporting Scheme (MARS). This provides a means for voluntary collection of 'near misses' at sea through a confidential reporting system. The main objective was to provide complete confidentiality to encourage seafarers to send in reports. The scheme is administered by Captain R. Beedel, the only person with access to the full reports. The reports include navigation related and other incidents, e.g., dangerous anchorages, problems with life boats, etc. (Beedel, 1992).

The standard of a report varies depending on the detail that the individual reporter provides. The reports are further edited to remove any references to persons or ships and they are assigned a reference number to allow NI members to comment on reports through the correspondence column of Seaways. This could result in the removal of meaningful information, although is unlikely to have occurred to any great extent.

Main disadvantages of the MARS scheme are:

- They are based on the reporter's view only
- They are generally composed after the event (sometimes after the reporter has left the ship)

For the purpose of this research 105 navigation related reports published between October 1992 and April 1997 were included.

5.3.4 Database - Databank for Sikring of Maritime Operasjoner (DAMA)

The Nordic[9] countries elected to employ the same software to provide systematic collection of data on marine accidents. This database, Databank for Sikring af Maritime Operasjoner (DAMA) was developed in Norway and has been used for systematic reporting and compiling of data on accidents at sea since 1988 (Sjöfartsinspektionen, 1995). Each country investigates accidents involving ships flying their own flag and accidents that have occurred within their territorial waters.

The Swedish Maritime Administration (Sveriges Sjöfartsadministration) generously provided selected records from their database on marine accidents. These records include collisions and groundings that occurred from 1988 until 1993. A total of 739 records are included in this study. They include 443 groundings and 296 ships involved in collisions.

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[9] Denmark, Norway, Sweden, Finland and Iceland

5.3.5 Survey using a questionnaire

Time and cost constraints, especially in view of the nature of the shipping industry makes it difficult to approach personally an adequate number of respondents. This encouraged the adoption of a questionnaire as an instrument to collect supporting data.

The questionnaire was designed to present most questions as open to ensure freedom and spontaneity of the responses thus replicating an interview situation (Q1-Q8; Q12-Q14; Q16-Q17, Appendix D). It was accepted that such an approach would be more demanding for the respondents and subsequent data processing.

The number of previous surveys relating directly to navigating officers has been limited. Surveys often target all crew members on ships of the same registry (see e.g., Olofsson, 1995). When the targeted group has been restricted to include only navigating officers they may have attended one or a few specific nautical schools (see e.g., Dickens, 1994).

Navigation, however, is truly international and officers from different backgrounds, on different types of ships, etc. 'compete' for the same, sometimes limited, domain at sea. Therefore, this research approached respondents in a different way, i.e., targeting only ships' Masters but encouraging respondents from different backgrounds.

The survey was aimed at actively serving officers holding a Master's ticket, whether currently in command or serving as chief/first officers. The main advantage is that most officers holding a Master's ticket should have a certain common level of competence (i.e., STCW '95) notwithstanding how long, or whether they have been in the command of a ship.

Thus some common level of competence can be assumed, including a minimum amount of sea experience. Additionally, because of their seniority, officers holding a Master's ticket are more likely to be aware/know of significant faults/errors that may have occurred on their ship. The role of the officer, notwithstanding his rank, in this survey will be considered primarily as that of a navigating officer.

5.3.6 Design of the questionnaire

The questionnaire follows established guidelines (see e.g., Oppenheim, 1992) and comprises a foreword, six sections and a closing statement. The foreword includes notes to the respondents, return date and, because of the sensitivity of some replies, a guarantee that all responses will be treated in strictest confidence (Appendix D).

When the questionnaire was prepared there was anecdotal evidence that a number of ships operated according to the Watch One trial guidelines although IMO discontinued the trials in spring 1995. It was considered useful to investigate how widespread such a custom may be. IMO has since changed its position and resumed the trials until December 1997 (Shuker, 1996). It is not considered that the value of the data will change appreciably.

It is recognised that the final sample may contain bias due to non-response.

5.3.6.1 Distribution of the questionnaire

Although a questionnaire can be distributed relatively easily through distribution channels such as trade journals or nautical schools, a worldwide distribution aimed at populations such as actively serving mariners is hampered by the fact that the respondents are difficult to reach. The survey was initially distributed with the IFSMA Newsletter published in March 1996. For cost purposes the survey was sent to the various national IFSMA coordinators worldwide. These coordinators were then expected to forward copies to their local members.

It was recognised at an early stage that this method might not bring in a sufficient number of responses. An alternative distribution channel was therefore agreed through the Nautical Institute. It has a large worldwide membership register and was able to forward the questionnaires directly to selected members. For distributing the survey through the Nautical Institute the section on Accident Reporting/Nautical Publications was removed to reflect the fact that MARS reports are published in Seaways which is provided to all members who are consequently likely to be aware of the scheme.

The response rate remained low from both distribution channels. From comments by the respondents it became evident that although, in both cases 6 months had been allocated from the date of distribution, it was not sufficient time for them to return the questionnaire. Therefore, any future survey must allow more than 6 months to return the questionnaire. This increases the research time considerably.

Due to the low response rate alternative avenues were explored through the Internet and contacting nautical schools directly. The Internet provides access to people involved in the marine environment through the MARINE-list. This is administered by the Canadian Coast Guard and provides a forum for discussions on many topics in the marine environment. The initial response from list members was good and several offers for assistance were received.

However, eventually only a few questionnaires were returned. Nautical schools were contacted at random in several countries. A few schools responded and only a few responses were returned.

A total of 32 responses was obtained through all the distribution channels as shown in table 16.

Source	No of returned Questionnaires
IFSMA	9
NI	9
Internet	2
Nautical Schools	12
TOTAL	32

Table 16 Sources of the responses to the questionnaire

The aim to control the responses failed in that the initial distribution channels did not provide enough responses. Therefore the responses include only 18 Masters (IFSMA and NI). The other distribution channels provided a mixture of qualifications. The nautical schools provided mainly 2nd and 3rd officers and the Internet first officers. In addition to the short return time, the low response rate is assumed to be due to (1) the worldwide focus of the survey and (2) a general lack of trust in the confidentiality offered by the survey.

The number of responses provides a useful geographical spread of nationalities thus satisfying one of the aims of the survey. The response rate to the open questions was acceptable, although not all the questions were answered. This may be because (1) the officer did not have any details to report, (2) the officer did not understand the question, or (3) the officer did not appreciate its relevance. Some respondents have reported more than one mistake/incident. This could be useful for collecting information on specific types of problems, e.g., interpreting or operating bridge equipment. At present limited public data of this type is available in the marine environment. It is anticipated that the data may provide a useful basis for further research into specific areas of human factors on the ship's bridge.

5.4 Data Classification

5.4.1 A theory of safety at sea

Goss (1989) suggests that there are four approaches to managing the theory and practice of safety at sea, namely:

1. Rely on the expertise of a very talented person;

2. Bring together a number of experienced and knowledgeable people and rely on the resulting consensus;

3. Rely on the operation of market forces with appropriate modifications;

4. Make underlying principles explicit, deduce functional relationships and carry out sufficient research to quantify various components in terms that allow them to be properly incorporated into a safety strategy.

It is naturally hard to define a 'talented' person or a body of 'experienced and knowledgeable' persons and thus the two first methods are unlikely to be successful. Traditionally the shipping industry relies to a great extent on the operation of market forces.

The final method requires a more scientific approach and involves identifying the effects of safety measures, quantifying them in physical terms and evaluating them in economic terms. It is, as yet, difficult to identify the effects of safety or evaluating them in economic terms. It is, nevertheless, suggested that attempting to quantify components that may affect safe navigation is reasonable. Safety at sea is often considered in broad terms, i.e., accidents to all ships are examined. The results are likely to provide general answers, i.e., what happened. Knowing what happened is mostly sufficient to propose universal changes in regulations or technology with view to reduce the number of accidents at sea.

5.4.2 Causal analysis of accidents and classification of 'human error'

After the event, an accident at sea is generally investigated in an attempt to try and understand why it happened. This usually takes the form of trying to describe a particular course of events and identify the causes of this particular accident.

Rasmussen (1990) suggests that the identification of accident causes depends on the aim of the analysis, i.e., whether the aim is to:

- Explain the course of the events
- Allocate responsibility and blame
- Identify possible system improvements

The miscellany of terms used in grouping accidents at sea was referred to in Chapter 2 suggesting that the lack of uniform classification of the data renders it difficult to compare studies. Table 17 (see also table 3, page 21) shows a selection of studies and their associated causal groupings as defined by the researchers. It is evident that different causal groupings have been proposed in different industries. The tables show that the causal groupings are generally too broad to provide sufficient detail for practitioners to develop accident reducing strategies.

Drury (1983) suggested that causal analysis generally focus on the human element, equipment/technology and the environment, perhaps with less attention to the task. Task analysis is a recognised technique for analysing human factors identifying the interaction between people, machines and the environment. This technique assumes that the operator brings to the task certain capabilities which are affected by age, gender and other factors, e.g., ship type and trading patterns (referred to in Chapter 4).

STUDY	The Human Element in Shipping Casualties(a)	Studies on Ship Casualties in the Baltic Sea 1979-1981(b)	Determinants and Background Variables of Human Factor Incidents and Accidents(c)	Accidents at sea: Multiple Causes and Impossible Consequences(d)	Promoting Safety in the Oil Industry - General Failure Types(f)	A Review of Flightcrew-involved, major accidents of U.S. air carriers, 1978 through 1990(6)	A Methodological framework for root cause analysis of human errors(g)
Year	1982	1984	1986	1987	1993	1994	1995
Type	All Shipping accidents	All Shipping Accidents	Aviation Accidents	All Shipping Accidents	Oil Industry	Aviation Industry	Aviation Industry
Causal Groups	Knowledge Experience Judgement Communication Rule Violation Use of Equipment Organisation Uncertain/Other	Environmental Conditions Technical Deficiencies Human Factors and Actions	Critical Situation Internal Condition External Condition	Cognitive System Social System Situational System	Hardware Design Maintenance Management Operating Procedures Error-enforcing Conditions Housekeeping Incompatible goals Communication Organisation Training Defence Management	Primary Errors: Aircraft handling Communication Navigational Procedural Resource Management Situational Awareness Systems Operations Tactical Decision Secondary Errors: Monitoring/ Challenging	System-related Person-related

a) Quinn P.T. & Scott S.M., (1982), The Human Element in Shipping Casualties, 2T 550/551/552, The Tavistock Institute of Human Relations, London

b) Tuovinen P., Kostilainen V. & Hämäläinen A., (1984), Studies on Ship Casualties in the Baltic Sea 1979-1981, Baltic Sea Environment Proceedings No 11, Helsinki Commission,

c) Gerbert K. & Kemmler R., (1986), The Causes of Causes: Determinants and Background Variables of Human Factor Incidents and Accidents, Ergonomics, 29, 11, 1439-1453

d) Wagenaar W.A. & Groeneweg J., (1987), Accidents at sea: Multiple Causes and Impossible Consequences, International Journal of Man-Machine Studies, 27, 587-598

f) Wagenaar W.A., Groeneweg J., Hudson P.T.W. & Reason J., (1993), Promoting Safety in the Oil Industry, Ergonomics Society, 7.1-7.24

g) National Transportation Safety Board, (1994), A Review of Flightcrew-Involved, Major Accidents of U.S. Air carriers 1978 through 1990, Report No: PB94-917001

h) Pedrali M. & Cojazzi G., (1995), A Methodological framework for root cause analysis of human errors, in Fuller R., et al., (eds), Human Factors in Aviation Operations, Proceedings of the 21st Conference of the European Association for Aviation Psychology, Vol. 3, pp 143-148, Avebury Aviation, England

Table 17 Selection of studies and their associated causal groupings

5.4.3 Classification of human factors in the navigational system

Leonard and Rajan (1995) recently suggested a classification framework for human factors' issues that should be addressed when developing a safety management system (shown in table 18).

- **COMMUNICATION**
  - Open Two-way Communication
  - Safety Information
  - Incident Reporting
  - Maintenance
- **ORGANISATIONAL PRESSURES**
  - Operation
  - Overload and Fatigue
  - Selection
  - Maintenance
- **PROCEDURES AND STANDARDS**
  - Organisation
  - Design Procedures
  - Incident Reporting
  - Emergency and Safety
  - Deck
  - Engineering
- **TRAINING**
  - Team Training
  - Emergency Training
  - Organisation of Training
  - Training of All Personnel
  - Specific Training
- **RESOURCES**
  - Economic
  - Equipment
  - Safety Equipment
  - Maintenance
- **PHYSICAL WORK ENVIRONMENT**
  - Physical Environment
  - Equipment Design
- **ALLOCATION OF RESPONSIBILITIES**
  - Organisation
  - Change

Table 18 Outline of human factors to be addressed when looking at Safety Management Systems in the marine environment (Leonard and Rajan, 1995)

Existing causal groupings and classification frameworks are useful for identifying and categorising what happened, i.e., the origin and/or type of decision or task that led to the accident. From a practical point of view, to facilitate procedures to prevent further accidents, where it happened is considered a stepping stone to further examining why it happened.

Figure 21 shows how the analysis of the chain of events leading to a collisions and groundings at sea can be divided into three consecutive steps.

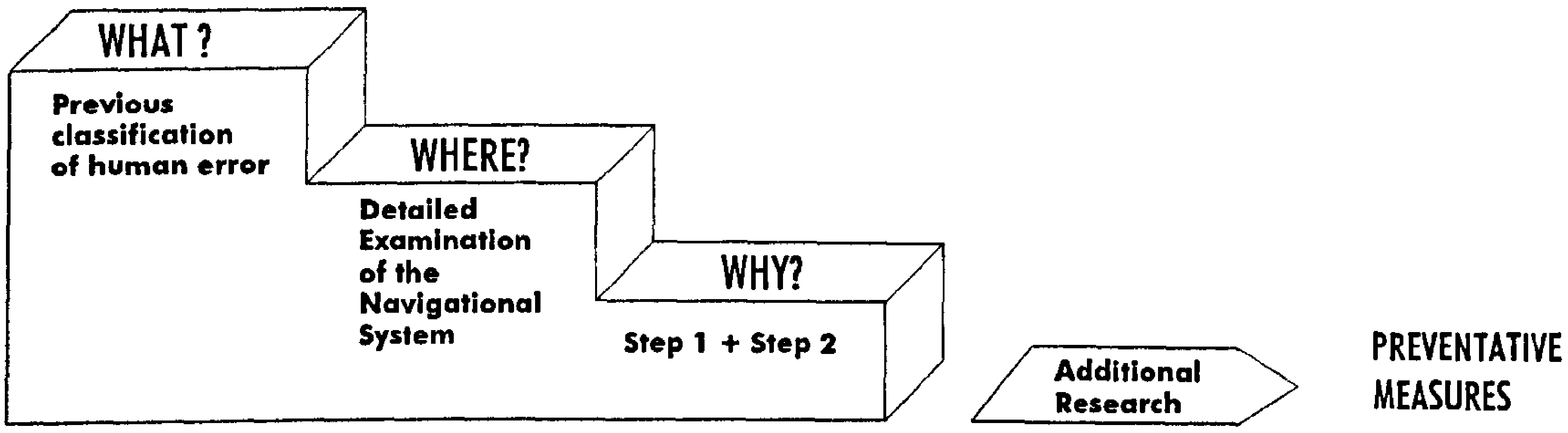


Figure 21 **Three steps to preventing groundings and collisions at sea**

This research focuses on situations on the ship's bridge WHERE problems occurred, i.e., situations which may have provided pathways that resulted in a grounding or collision. The data sources included in this research are:

(1) Active, i.e., the origin of the underlying information has been classified before data collection. This allows more specific and variable data to be collected. Active sources include personal surveys, observations and simulator experiments, or;

(2) Passive, i.e., the underlying information cannot be modified to conform exactly to later classification or categorisation of data. Passive sources include accident reports, confidential incident reports (MARS) and other unchangeable data collections (DAMA).

The questionnaire used in this research was expected to act as a pilot study to learn whether:

1. Active data can be split into modules that can be integrated into the framework of the working environment of the ship's bridge. This would then provide a basis for comparing the results of future studies.

2. There was a willingness to participate in more comprehensive research and if it was possible to collect data worldwide. This would result in a more representative sample of worldwide shipping, i.e., including ship/cargo types and trading patterns.

Passive sources will be used as the primary source of data in this research. The aim is to collect comprehensive data to establish a classification system which focuses on human factors on the ship's bridge.

Previous studies have largely focused on elements that may induce 'operator error' thus creating an impression that the accident is primarily caused by the operator on the ship's bridge. The intention here is to focus on the working environment of the ship's bridge acknowledging the complexity of the navigational system.

5.4.4 Comparison of data collection techniques

At this stage evaluating the data collection techniques employed in this research against each other is not possible. It is nevertheless considered useful to compare them against five criteria established by Gurpreet & Kirwan (1997) (table 19):

1. Comprehensiveness

   Comprehensiveness of data includes (a) accuracy of identifying significant situations and problem areas, i.e., those that have most significant impact on risk, (b) the breadth of coverage of these factors which relate to ships/cargo types and trading patterns and (c) the ability to identify all possible situations and problem areas within the navigational system.

2. Consistency of data collection

   The degree in which situations and problem areas can produce similar, if not identical results. Consistency is related to accuracy.

3. Usefulness of results for understanding human factors on the ship's bridge

   Usefulness of determining situations and problem areas in specifying accident prevention measures within the navigational system.

4. Resource usage

   Resource demands, i.e., time, manpower and cost involved.

5. Richness of data in meaningful terms (providing a better understanding of human factors, etc.).

	Comprehensiveness	Consistency	Usefulness of results	Resources usage	Richness of Data
Personal Observation	High	High*	Moderate	High	High
Post Accident Analysis	Moderate	Moderate	High	Moderate	High
Statistical Analysis of Computerised Accident Records	Low	Low/Moderate	Moderate	Low	Low
Analysis of Voluntary Incident Reports	Low	Low	Moderate	Moderate	Moderate
Survey using Questionnaire	Moderate/ High	Moderate	High	Moderate	High

* When the same observer

Table 19 Comparison of data collection techniques (adapted from Gurpreet & Kirwan, 1997)

Table 19 shows that Post Accident Analysis and Survey using Questionnaire can provide an attractive balance between Resource Usage and Richness of Data. Additional sources are likely to increase the quality of the data.

5.5 Organising the data

It was expected that analysing and comparing data collected from four different types of sources would be difficult. At the same time it was considered that including data from more than one source would provide a better representation of specific problem areas within the working environment of the ship's bridge.

The DAMA data was provided on a diskette and therefore had already been classified. The other data sources, Accident Reports, MARS Reports and own survey were classified by the author. Each classification scheme is explained below.

5.5.1 DAMA casualty codes

The DAMA database applies a generic coding system for causes of all types of marine accidents. This coding system is divided into 7 main categories A-G, shown in table 20.

Main Group	Definition
A	External conditions (weather, currents, etc.)
B	Ship construction and position of onboard equipment
C	Technical faults concerning equipment onboard the ship
D	Physical environment and design of equipment
E	Loading, unloading and safeguarding cargo and bunkers
F	Communication, organisation, procedures and routines
G	Human factors

Table 20 DAMA codes for definition of accident causes (Sjöfartsinspektionen, 1996)

Each main group has been categorised into a number of more detailed causes. Table 21 shows the breakdown of definitions for group G - Human Factors.

Coding systems, such as DAMA (see also table 17) tend to provide a broader classification system which can be useful for general statistical analyses of accidents at sea. It appears that the DAMA data has not been analysed in any depth previously. However, the coding system was recently applied to a framework for developing an historic risk and validation model for European coastal waters (Caridis, Desypris, Panagakos, Psaraftis & Ventikos, 1997).

Examining the studies referred to previously in this Chapter, it became clear that the probable risk reduction measures proposed, e.g., improved training, do not state which aspects of training should be considered. Chapter 3 showed that there are many aspects of maritime education and continuing training. More specific detail is therefore required to ensure that any improvements in maritime education and continuing training has the desired effect of reducing accidents.

CODE	DAMA definition of human factors (G)
G02	Insufficient competence for the task
G03	Poor planning
G04	Insufficient acknowledgment of available alarms
G05	Did not use alternative navigation aids
G06	Did not use available navigation aids
G07	Inadequate position fixing. Did not plot DR
G08	Misjudged course/speed/intentions of other ship
G09	Misjudged course/speed/intentions of own ship
G10	Tried to carry out manouevre despite unfavourable conditions
G11	Did not stay starboard in the fairway
G12	Excessive speed
G13	Special circumstances (illness, fatigue, long working hours)
G14	Fell asleep during watch
G15	Alcohol or other intoxicants
G16	Other circumstances influencing human factors
G17	Negligent/inappropriate handling
G18	Inattentiveness
G19	Human behaviour
G20	Error of judgement (general)

Table 21 Additional breakdown of causes relating to human factors (Sjöfartsinspektionen, 1996)

5.5.2 Development of a marine human factors classification scheme based on 'Catalysts'

As previously referred to in Chapter 1, in the aftermath of an accident at sea, there is a tendency to look for someone to blame. This often results in focusing on specific errors, perhaps overlooking the situation or problem area that may provide a pathway to the accident. The following summary from an accident report illustrates this point.

The Malaysian cargo vessel the *Alam Tenggiri* collided with the fishing vessel the *Galaxy* early in the morning of 6 September 1996 off High Peak Island, Queensland, Australia. The *Alam Tenggiri* was overtaking the *Galaxy* on a similar course and had the duty to stay clear of the fishing vessel. The report into the collision between the *Galaxy* and the *Alam Tenggiri* shows that they were probably converging at an angle of about 20°(Marine Incident Investigation Unit, 1996).

The report concludes that the 2nd Mate on the *Alam Tenggiri* did not make full and effective appraisal of the situation and the risk of collision. The ship was equipped with radar, ARPA and a separate look-out as required by the COLREGS 72 (Rule 5). Knowing that the 2nd Mate did not appraise the situation and risk of collision correctly does not explain why he failed to avoid the collision. The report shows that he was well aware of the other vessel approximately 80 minutes before impact. Based on some of the causal groupings shown in Table 17 (page 134) the actions of the 2nd Mate could be grouped under causes shown in Table 22.

Reference	Causal Groups
(A)	Rule Violation/Use of equipment
(B)	Human Factors and Actions
(C)	Cognitive and Situational System
(D)	Navigational/Situational

(A) Quinn P.T. & Scott S.M., (1982), The Human Element in Shipping Casualties, 2T 550/551/552, The Tavistock Institute of Human Relations, London

(B) Tuovinen P., Kostilainen V. & Hämäläinen A., (1984), Studies on Ship Casualties in the Baltic Sea 1979-1981, Baltic Sea Environment Proceedings No 11, Helsinki Commission,

(C) Wagenaar W.A. & Groeneweg J., (1987), Accidents at sea: Multiple Causes and Impossible Consequences, International Journal of Man-Machine Studies, 27, 587-598

(D) Wagenaar W.A., Groeneweg J., Hudson P.T.W. & Reason J., (1993), Promoting Safety in the Oil Industry, Ergonomics Society, 7.1-7.24

Table 22 Causal groupings of 2nd Mate's actions

Table 22 shows that the existing causal groupings provide broad groups e.g., Human Factors and Actions. Thus it is not readily evident what preventive measures could be taken to reduce the number of such accidents in the future. Following an exhaustive review of the data, it is suggested that factors could be classified according to a series of 'Catalysts', i.e., factors in a chain of events that may provide a pathway for an accident to occur. The concept allows one or more 'Catalysts' to be assigned to each accident. This concept is discussed and developed in more detail in sections 5.5.3 to 5.5.4 in this Chapter.

5.5.3 Process of developing a marine human factors classification system

The process of developing an alternative classification system focused initially on Accident Reports, followed by examining whether this system could be applied to the MARS reports. The examination of the Accident Reports involved four steps:

(1) A small selection of accident reports (approximately 20) were initially examined to evaluate the level of detail available in these reports. The initial sample indicated that sufficient information was available providing detail of specific problem areas on the ship's bridge.

(2) The next step focused on the situation or problem area, i.e., a 'Catalyst' that appeared to play a central role, whether directly causative or not, according to the report. The 'Catalysts' provide specific examples of problem areas, thus adding a third layer of detail to a more general classification system as shown by the DAMA coding scheme. The situations and problem areas were determined by recording them carefully, rather than being derived directly from the conclusions of the report.

(3) The 'Catalysts' were initially recorded under a number of 'Catalyst' Types (eventually 16). These were assigned as and when it appeared a new 'Catalyst' Type would make the perception of the 'Catalysts' clearer. The resulting array of 'Catalyst' Types provides a rudimentary description of general human factors within the working environment of the ship's bridge.

(4) The 'Catalyst' Types were consequently grouped within five 'Catalyst' Groups to present a functional marine human factor's classification system. The components were finally coded in a three-layer system and presented in table format (shown in table 23):

• **'Catalysts'** were assigned a combination of a letter (referring to the 'Catalyst' Group) and a number.	e.g., (A1) Assumed other vessel's intentions
	↓
• **'Catalyst' Types,** were assigned a number from 1-16	e.g., 1 Assumptions
	↓
• **'CATALYST' GROUPS** were assigned a letter from A-F	e.g., A HUMAN PERFORMANCE

Figure 22 illustrates how the method of defining 'Catalysts' followed a bottom-up process, i.e., examples of 'Catalyst' were first extracted from the accident reports and then arranged under an appropriate 'Catalyst' Type. These were then arranged within 5 'Catalyst' Groups.

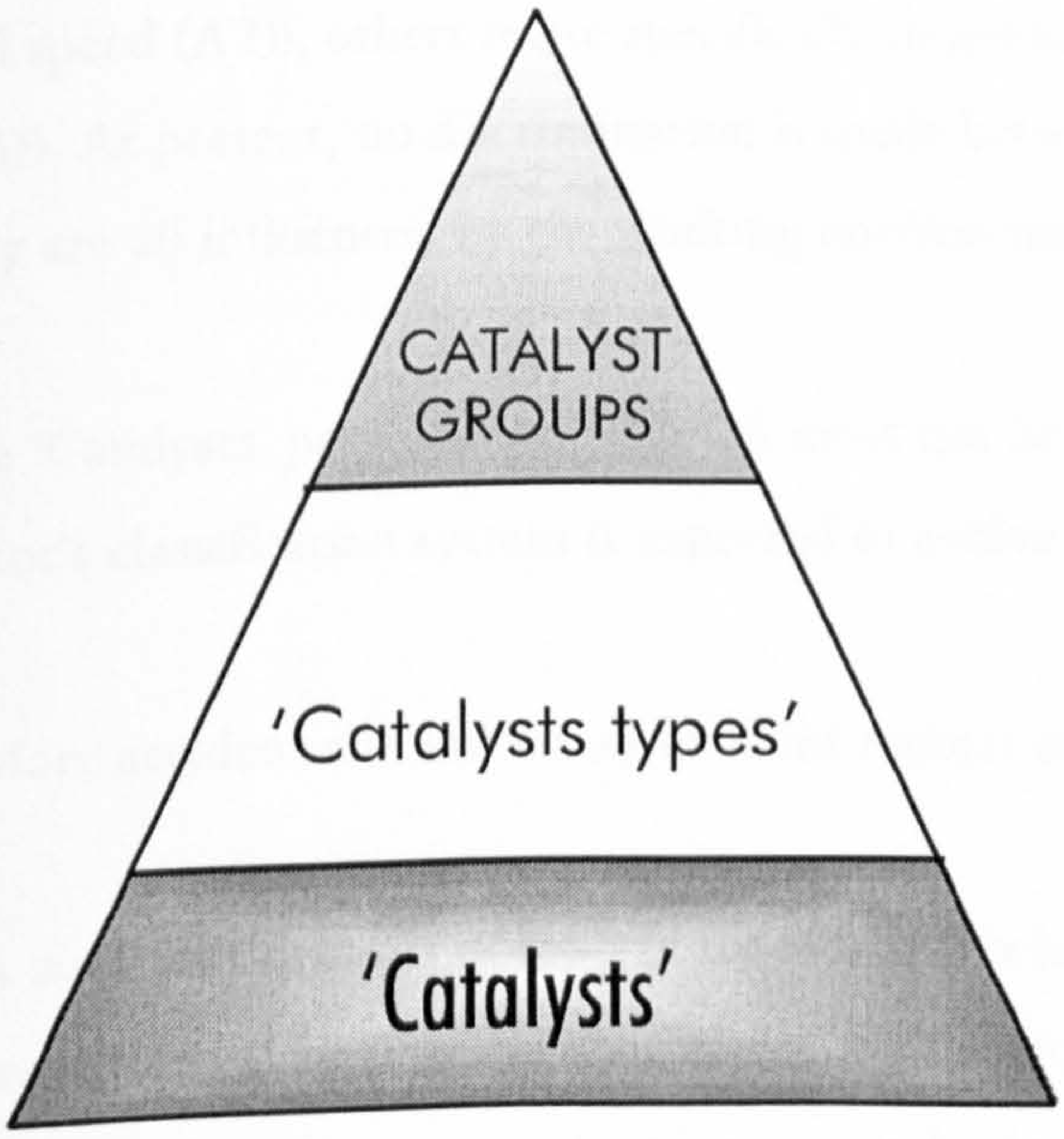


Figure 22 Defining 'Catalysts' based on a bottom-up process

The process for examining the MARS reports followed the method applied to the accident reports. The MARS reports were, however, initially divided into three navigation related categories, i.e., (1) crossing, (2) overtaking and (3) communications. 'Catalysts' were extracted using the above method and arranged under the same 'Catalyst' Types and 'Catalyst' Groups. As far as has been ascertained the MARS reports have not been analysed in this manner before.

The previous process for developing a marine human factors classification system shows that problems relating to TSS were evident only in the MARS reports. The author had limited access and only a small number of those related to an appropriate geographic area designated as TSS (e.g., Dover Straits).

5.5.4 The marine human factors classification system

The marine human factor's classification system based on the 'Catalysts' shown in table 23 is still subject to limitations, as are other classification schemes, e.g., the designation is arbitrary and subject to the researcher's perceptions and objectives.

Some 'Catalysts' relate only to collisions (e.g., No collision had both ship's maintained course and speed (A2)), others relate specifically to groundings (e.g., Mistook position/land marks (A3)). At present, no discrimination is made between types of accidents. It is considered that they are all influenced by the working environment of the ship's bridge.

The 'Catalysts' presented in table 23 must not be considered final. The marine human factor's classification system is expected to evolve as:

- More accident and voluntary incident reports are analysed in the same manner
- A sufficient number of reports are available which will allow focusing on specific traffic areas limited by physical constraints, e.g., narrow straits, or specific areas within the working environment such as integrated bridges.

GROUP A HUMAN PERFORMANCE

Type 1. Assumptions

A1 Assumed other vessel's intentions

Type 2. Error of Judgement

A2 No collision had both ship's maintained course and speed
A3 Mistook position/land marks
A4 Incorrect change of course/Passing too close
A5 Failed to assess course and manoeuvre of other vessel
A6 Did not fully assess the situation

Type 3. TSS (MARS reports only)

A7 Incorrect heading

GROUP B ENGINEERING/DESIGN

Type 4. Automatic steering/Auto pilot

B1 Auto Pilot /Gyro Error
B2 Autopilot response affected by external conditions

Type 5. Bridge/Ship layout

B3 Restricted view forward
B4 Position of equipment - Bridge Layout

Type 6. Manuals/Documentation

B5 Manuals in foreign language/Poor manuals
B6 Drawings not 'as fitted'
B7 Manuals only for individual components, not the complete system

Type 7. Mechanical & Manoeuvring

B8 Total Black out
B9 Unexpected manoeuvring characteristics

Type 8. Technology - Other

B10 Echo sounder not in use

Type 9. User Interface

GROUP C BRIDGE PROCEDURES

Type 10. Bridge Resource Management

C1 Poor communication between Bridge Team members
C2 Did not monitor other actions of other Bridge Team members
C3 Master's orders not complied with

Type 11. Communications

C4 Agreed manoeuvre (VHF) before near miss or collision
C5 Did not exchange information with other vessel/Unable to contact other vessel
C6 VHF agreement resulted in incorrect manoeuvre/not agreeable advice
C7 VTS did not provide information/advised delay
C8 Poor VHF transmission
C9 Use of different VHF channels by different classes of ship
C10 'Different language'
C11 'Same language'
C12 Failed to impart urgency
C13 No sound signals

Type 12. Charts/Passage Planning

C14 Poor passage planning
C15 Failure to use adequate charts/Did not appreciate warnings on chart

GROUP D SAFE MANNING

Type 13. Bridge Manning

D1 W1 - Bridge Unmanned/No Look-out
D2 Fell asleep - more than one on the bridge
D3 W1 - Distraction caused by VHF
D4 Long Pilotage

GROUP E NAVIGATION CONTROL

Type 14. No Radar Involved - Visual Look-out

E1 Difficult to distinguish external navigation aids
E2 Failed to see due to impaired vision forward
E3 Did not see other ship

Type 15. Position Discrepancy

E4 Position not fixed accurately
E5 Relied on radar bearings, etc.
E6 Using GPS as sole position fixing method

Type 16. Radar

E7 No radar parallel indexing used/incorrect use of radar parallel indexing
E8 Failed to plot course/speed of other vessel/made decisions based on initial data
E9 Blind sector
E10 Did not see other ship
E11 Other radar related
E12 Radar off

GROUP F OTHER

F1 Exhibiting inappropriate lights
F2 Operational demands
F3 Pilot did not act professionally (speed)
F4 Master did not follow advice
F5 Other

Table 23 Proposed arrangement of 'Catalysts' grouped under 16 'Catalysts' Types.

5.5.5 Classifying Survey Data

To ensure complete confidentiality the first step was to remove all information that might identify of the respondent, e.g., respondent's and the ship's name. The responses were then assigned consecutive numbers and related to the distribution channel, e.g., 01/NI.

The classification system for the first section (Personal/Ship Details) is based on two coding systems:

1. Numeric, e.g., age brackets, time on ship, number of languages, etc.
2. Labels, e.g., mother tongue, trading area, ship types, etc.

The other sections are based on responses that generally can be computed numerically, e.g., YES/NO, Yourself/Other Person answers. Additionally the responses provide useful information in the form of separate statements by the respondents.

5.5.6 Evaluation of the data sources

It was generally possible to fit the 'Catalysts' derived from both Accident and MARS reports within the 'Catalyst' Types and 'Catalyst' Groups shown in table 23. This permits one set of data to support another set of data. Additionally, a 'Catalyst' Group OTHER (F) was adopted to facilitate 'Catalysts' which at present do not fit any of the previous 'Catalysts' but are considered of sufficient value to be included.

The DAMA data was provided on a diskette and thus already classified. Some human factors' definitions (see table 21, page 140) are similar to some of the 'Catalysts' or 'Catalyst' Types but they cannot be compared directly. Nevertheless, DAMA provides useful supporting data, e.g., Time of Day, Light Conditions, Human Element, Steering and Bridge Manning.

The purpose of the questionnaire data was to provide additional information expected to be difficult to obtain through other sources. The questions were presented as clearly as practicable, combining answers in the same table, when deemed it would provide a clearer picture of a specific activity. The survey aimed at respondents from different backgrounds so as to build up a 'profile' which would represent not only a 'typical' navigating officer, but also reflect different ship types, experience, language skills, flags of registries etc.

5.6 Conclusion

This Chapter examined techniques for carrying out practical research into human factors on the ship's bridge. As a result five sources of readily available information were chosen: (1) Personal observation; (2) Official Accident Reports; (3) MARS; (4) DAMA and (5) Own survey using a questionnaire. The process of developing a marine human factor's classification scheme from the analysis of accident reports is explained. It is based on combining the technique of defining causal factors and task analysis into 'Catalysts'. These were defined as factors in a chain of events that may provide a pathway for a collision or grounding. The classification of the DAMA data and questionnaire was explained.

CHAPTER 6

DATA PROCESSING AND PRESENTATION

6.1 Introduction

Absolute safety in terms of no collisions or groundings occurring cannot be achieved unless ships opt to stay in port at all times. This is unlikely to occur and thus the question must be whether situations which may result in future accidents can be identified.

Wagenaar et al., (1987) suggested that many accidents at sea appear to result from highly complex coincidences which could rarely be foreseen by the people involved. The previous chapters have shown that the unpredictability of accidents is the result of a large number of causes and spread of information among the participants. The nature of errors made suggests a lack of understanding rather than lack of motivation or inclination.

This Chapter focuses on data processing and interpretation of the data introduced in Chapter 5. The data is presented in table format followed by a brief examination of the figures. The DAMA data is presented in section 6.3, the Accident and MARS data in section 6.4. and the survey data is presented in section 6.5.

6.2 Presentation of data

The four sources presented in Chapter 5 provide comparable and supporting information. Accident reports and DAMA data represent factual data, i.e., they are based on documented accident investigations. The MARS reports represent imprecise data, i.e., the incidents have not been verified. These sources provide historical data, whereas data obtained through the survey represents 'current' data. Although this has not been verified independently, it would appear justified to assume that it contributes toward a valid representation of the mariner's working environment.

The data are presented in a tabular form and are intended to be viewed as descriptive, rather than analytical. Until more data is collected, it is considered that a visual representation is likely to provide the most useful perspective of the role of the human element in the navigational system.

The data obtained from Accident and MARS Reports are based on the same classification system (referred to in Chapter 5, see also table 23, page 145) and can therefore be considered in parallel.

6.3 The DAMA data

The classification of the DAMA data was explained in Chapter 5. The main grouping of the DAMA data shown in table 24 suggests that human factors was attributed as the major cause of collisions and groundings. This was followed by external conditions. It should be noted that the complete DAMA database includes all accidents, but only those involving collisions and groundings were extracted for this research.

Definition of Main Group	Total
Human factors	590
External conditions (weather, currents, etc.)	417
Technical faults concerning equipment onboard the ship	58
Communication, organisation, procedures and routines	24
Physical environment and design of equipment	9
Ship construction and position of onboard equipment	3

Table 24 Total number of attributed factors for accidents in the DAMA Main Group

Examining the definitions in the Main Group additional detail of causes attributed to human factors are provided, e.g., 18 accidents involved falling asleep during watchkeeping (table 25). At present, combining the DAMA data with the Accident Report data is not feasible because they include the same period and may overlap. Thus an accident could have been recorded in the DAMA data and in the accident reports employed in this research.

DAMA Definition of Causes - Human Element	Code	No of Ships
Other circumstances influencing human factors	G16	145
Human behaviour	G19	130
Error of judgement (general)	G20	64
Misjudged course/speed/intentions of own ship	G09	43
Inattentiveness	G18	40
Poor planning	G03	22
Misjudged course/speed/intentions of other ship	G08	19
Fell asleep during watch	G14	18
Tried to carry out manouevre despite unfavourable conditions	G10	18
Excessive speed	G12	17
Did not use available navigation aids	G06	15
Negligent/inappropriate handling	G17	14
Inadequate position fixing. Did not plot DR	G07	11
Alcohol or other intoxicants	G15	11
Did not stay starboard in the fairway	G11	8
Special circumstances (illness, fatigue, long working hours)	G13	5
Did not use alternative navigation aids	G05	4
Insufficient acknowledgment of available alarms	G04	3
Insufficient competence for the task	G02	2

Table 25 Total number of ships for the accident causes relating to the human element

The apparently low number (11) of occurrences where the presence of alcohol or drugs had been determined may reflect the fact that many ships today are totally 'dry', i.e., they carry no alcohol onboard. This could be a result of the grounding of the *Exxon Valdez* in April 1989 (discussed further in Chapter 7) which increased the awareness in particular of alcohol consumption onboard ships.

In addition it should be noted that the figures indicating obvious incompetence are relatively low, only 5 occurrences. The figures for 'fell asleep during watch' do not state whether a look-out was posted on the bridge.

The DAMA data in table 26 shows that many groundings occurred when the Master/Mate was alone on the bridge. This could reflect the impact of smaller crews. Again it also appears that the bridge was unmanned frequently.

BRIDGE MANNING	COL	GR
Mate/Master alone	43	130
Mate + look-out	23	30
Mate + helmsman	4	4
Mate + look-out + helmsman	3	3
Mater + Mate	8	13
Mater + Mate + Pilot (poss. others)	18	25
Master + Mater + one man (minimum)	12	21
Master + Pilot or Mate + Pilot	16	16
Bridge Unmanned	24	13

KEY: COL = Collisions GR = Groundings

Table 26 Number of persons on the ship's bridge when the accident occurred

Table 27 shows that in most accidents the ship was steered manually by the helmsman. It is generally considered that a ship responds faster and better to manual course changes and is thus the preferred mode of steering in confined areas.

STEERING	COL	GR
Manually by helmsman	101	180
Manually by Master, Mate or other single navigating officer	14	40
Manually using remote control	13	15
Automatic steering	35	44

KEY: COL = Collisions GR = Groundings

Table 27 Type of steering when the accident occurred

6.4 The accident report and MARS data

The collection and classification of the data obtained from Accident and MARS reports was explained in Chapter 5.

Applying the concept of 'Catalysts', this data will be examined in three stages:

(1) the total number of 'Catalysts' within the 'Catalyst' Groups,
(2) the total number of 'Catalysts' within each 'Catalyst' Type, and;
(3) breakdown of 'Catalysts' within each 'Catalyst' Group.

6.4.1 Total number of 'Catalysts' within 'Catalyst' Groups

The five 'Catalyst' Groups provide a framework for human factors on the ship's bridge. Table 28 shows the total number of 'Catalysts' extracted from Accident and MARS Reports in descending order within the main groups. 'Catalyst' Types may occur only once within each data set, or only within one data set. The Group OTHER (F) was set part from the main groups.

'CATALYST' GROUP	Total No of 'Catalysts' Accident & MARS Reports
BRIDGE PROCEDURES	134
HUMAN PERFORMANCE	91
NAVIGATION CONTROL	63
ENGINEERING/DESIGN	50
SAFE MANNING	15
TOTAL	353
OTHER	*29*

Table 28 Total number of 'Catalysts' extracted from Accident and MARS Reports

Table 28 shows the uppermost layer of the marine human factors classification system suggesting that organising the data into broad groups is not especially informative on its own. It was, nevertheless, deemed useful to group the 'Catalysts' into such broad sets to make it easier to appreciate major problem areas on the ship's bridge. This is because humans have a limited capacity for the amount of short-term information that they can receive, process and remember (Miller, 1956). These particular 'Catalyst' Groups were adopted to show the characteristics of human factors on the ship's bridge.

The 'Catalyst' Groups can be superimposed onto figure 8 (page 44) illustrating the major factors influencing the human element on the ship's bridge. Figure 23 illustrates the combined figure.

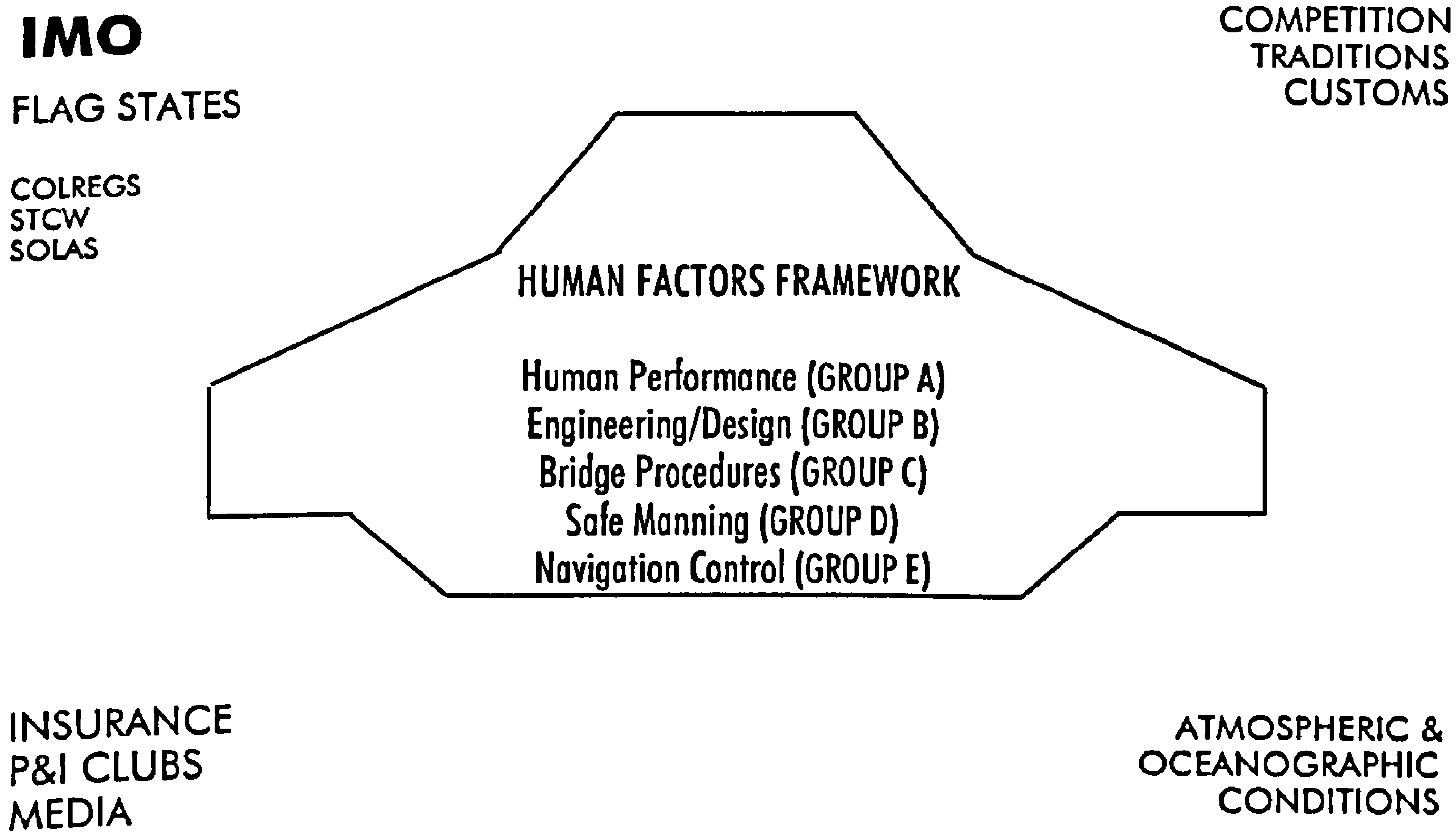


Figure 23 'Catalyst' Groups shown as an integrated part of the working environment of the ship's bridge

6.4.2 Total number of 'Catalyst' Types

'Catalyst' Types were designated broadly to illustrate more precisely the working environment of the ship's bridge. Table 29 shows a breakdown of 'Catalyst' Types indicating the second layer of the marine human factors classification system.

'CATALYST TYPE'	No of AR	No of MR	TOTAL
Communications	22	59	81
Error of Judgement	23	50	73
Bridge Resource Management	36	1	37
Radar	33	2	35
Other	*19*	*10*	*29*
User Interface	15	3	18
Charts/Passage Planning	14	2	16
No Radar - Visual Lookout	11	4	15
Bridge Manning	12	3	15
Position discrepancy	12	1	13
Assumptions	9	3	12
Bridge/Ship Layout	9	1	10
Automatic Steering/Auto Pilot	7		7
Manuals/Documentation	4	2	6
TSS		6	6
Technology - Other	5		5
Mechanical & Manoeuvring	4		4

Key: AR = Accident Reports MR = MARS Reports

Table 29 Total number of 'Catalyst' Types

As expected major problem areas include Communication, Error of Judgement and Bridge Resource Management. Here it should be acknowledged that MARS reports are based on incidents which did not lead to an accident.

Details relating directly to problem areas such as the Radar/ARPA or automatic steering have not been isolated to this extent previously. This table shows that such data was predominantly collected from accident reports and thus can be considered factual. The categories 'Radar' and 'No radar' should be considered simultaneously. The Radar/ARPA can be used to confirm a ship or landmark which has already been observed visually. Correspondingly, a ship or landmark which has been observed by radar can often be confirmed visually.

6.4.3 Breakdown of 'Catalysts' within 'Catalyst' Groups

Examining table 29 it becomes clear that a detailed breakdown into different 'Catalyst' Types still does not provide sufficient information to fully define situations or problem areas on the ship's bridge. To show the third layer in the marine human factors classification system 'Catalysts' were further isolated within the 'Catalyst' Groups' as shown in tables 30 to 34.

6.4.3.1 Human Performance

The 'Catalysts' within the Human Performance Group (shown in table 30) relate predominantly to the interaction between human behaviour and 'ordinary practice of seamanship', e.g., changing course incorrectly/passing too close (A4).

According to Kalaranta (1992) there appears to be no concise definition of ordinary practice of seamanship but he suggests that it is an abstract term which encompasses the theory and experience of all shipboard activities. This term is also included in the COLREGS 72 Rule 2 (a). It is generally considered either from a practical/ traditional or a legal point of view.

'Catalysts'		AR	MR	TOTAL
A5	Failed to assess course and manoeuvre of other vessel	1	37	38
A4	Incorrect change of course/Passing too close	8	13	21
A1	Assumed other vessel's intentions	9	3	12
A3	Mistook position/land marks	11	1	12
A6	Did not fully assess the situation	7		7
A7	Incorrect heading in TSS		5	5
A2	No collision had both ship's maintained course and speed	4		4

Key: AR = Accident Reports MR = MARS Reports

Table 30 Number of 'Catalysts' related to Human Performance

The most common 'Catalyst' "Failed to assess course and manouevre of other vessel" (A5) suggests that collisions can be, and are avoided, when the navigating officer on the other ship takes evasive action as permitted under Rule 2 of the COLREGS 72.

Assumptions are often based on insufficient data which may be a result of not knowing or appreciating the limitations of navigation aids or not cross-referencing data. "Assuming the other vessel's intentions" (A1) or "assuming a position/landmark" (A3) may lead to a collision or grounding. Once an incorrect assumption has been made, the risk that all future decisions are incorrect is much higher. The longer the chain of incorrect assumptions the more difficult it may be to recover the situation. These areas of concern must therefore be emphasised throughout an officer's training.

Although not a unique observation, it should be noted that there are situations where a collision would not have occurred had both ships maintained course and speed (A2). A well-known example is the collision between the *Stockholm* and the *Andrea Doria* in 1956. It was concluded that the main cause of this collision was that both officers accepted an inadequate passing distance in open waters (Cahill, 1983).

6.4.3.2 Engineering/design

Unlike in the aviation industry, ships are rarely designed or built according to a unique type or class. Even ships built as a series at the same shipyard for the same owner may differ considerably (Anon., 1998b). Ships rarely remain the same during their full working life. They are often remodelled to reflect changes in trading patterns, e.g., a ship may be built to operate as a passenger ro-ro ferry for a particular route and later remodelled to become a cruise ship. Such alterations, and regular equipment upgrades, may result in a great variety of electronic bridge aids fitted on ships' bridges.

Such changes may result in 'Catalysts' becoming linked, e.g., the officer may have to read and understand how the navigation aids operate perhaps during a total black out (especially if this occurs during the hours of darkness when reading a manual by flashlight is not recommended - personal observation). Poor manuals and 'drawings not as fitted' are likely to increase the risk of error during such occurrences.

'Catalysts" within the Engineering/Design Group are shown in table 31.

'Catalysts'		AR	MR	TOTAL
B4	Position of equipment - Bridge Layout	7	1	8
B5	Manuals in foreign language/Poor manuals	4	2	6
B3	Restricted view forward	4		4
B1	Auto Pilot /Gyro Error	4		4
B8	Total Black out	4		4
B2	Autopilot response affected by external conditions	3		3
B10	Echo sounder not in use	3		3
B6	Drawings not 'as fitted'	2		2
B9	Unexpected manoeuvring characteristics	1		1
B7	Manuals only for individual components, not the complete system	1		1

Key: AR = Accident Reports MR = MARS Reports

Table 31 'Catalysts' related to Engineering/Design

An operating manual on its own neither causes, nor prevents, accidents at sea. Nevertheless, if an officer is unable to use the equipment as intended, he may unintentionally place the ship at risk. The quality of manuals has not been examined in any detail and as yet, there are no human factors' standards available. Manuals may be poorly designed and suffer from poor translations which could exacerbate any developing situation. Although modern bridge systems are fitted as integrated systems, individual components are often designed and available as separate units. As a result manuals may be provided for each individual component, but lack an overview of the capabilities of the integrated system.

Designing a ship's bridge that would be perfectly suited for all navigating officers would be impossible ("Position of equipment/Bridge layout" (B4)). This is because each person thinks differently and has different anthropometric characteristics. The increasing mixture of officers from Western and Eastern countries may, however, increase the risk of error due to anthropometric differences among populations of the world.

Kennedy (1972) suggested that it was customary to design for the central 90 percent of the population in the United States Air force, i.e., from the 5th percentile to the 95 percentile. For stature this means a range from 167.3 cm to 187.7 cm. The same figures for the Vietnamese population range from approximately 151.5 cm to approximately 169.5 cm. His research suggests that bridge equipment designed for a Western population may obscure the vision of an Asian officer (or other shorter person), and vice versa.

Good all-round visibility on the ship's bridge is essential for safe navigation. Aircraft are generally designed for a specific population, e.g., American citizens, whereas ships' bridges increasingly have to fit a mix of populations. The human body can adjust to an inadequately designed system. However, poor position of bridge equipment or restricted view forward can increase the risk of collisions and groundings (see e.g., 'Catalysts' B3 and B4).

6.4.3.3 Bridge Procedures

Table 32 shows 'Catalysts' related to Bridge Procedures. The Master of a ship is in the unenviable position of being responsible for the actions of other crew members without necessarily being able to ensure his instructions are complied with. Ships may have a high turnover of officers and the Master rarely has control of the standards of the training of the officers. When an officer arrives on the ship, he may have to familiarise himself with the ship and bridge layout while carrying out his normal duties.

A key to safe navigation is planning the passage from berth to berth (C14) and using the correct charts (C15). Ships may have to make sudden port changes and as a result may not carry adequate or correct charts. Until recently ships have traditionally carried paper charts, which must be corrected regularly. Electronic charts were developed to offer a less time-consuming method to correct them and provide assistance for passage planning. These types of charts are based on traditional paper charts, e.g., published by the UK Hydrographic Office. The benefit of reproducing existing paper charts in electronic format is that they are familiar to the officer. As a result the officer can, when needed, more easily change from a paper to electronic format. Nevertheless, for a successful transition from paper to electronic charts the navigating officer must understand the basic concept of chart work.

'Catalysts'	AR	MR	TOTAL
C5 Did not exchange information with other vessel/Unable to contact other vessel	2	28	30
C1 Poor communication between Bridge Team members	22	1	23
C7 VTS did not provide information/advised delay	8	7	15
C2 Did not monitor other actions of other Bridge Team members	12		12
C4 Agreed manoeuvre (VHF) before near miss or collision	5	6	11
C15 Failure to use adequate charts/Did not appreciate warnings on chart	9	2	11
C10 Different language	4	6	10
C6 VHF agreement resulted in incorrect manoeuvre/not agreeable advice		9	9
C14 Poor passage planning	7	2	9
C3 Master's orders not complied with	3		3
C11 Same language	3		3
C13 No sound signals	2		2
C8 Poor VHF transmission	1	1	2
C9 Use of different VHF channels by different classes of ship	1		1

Key: AR = Accident Reports MR = MARS Reports

Table 32 'Catalysts' related to Bridge Procedures

Electronic Chart Display and Information System (ECDIS) defines a system which is acceptable as a primary navigation aid. An ECDIS system should provide full capability for chart work, route planning and monitoring (Smeaton, Dinely & Tucker, 1994). Assuming that the officer is familiar with basic chart work and passage planning, using ECDIS systems is likely to reduce his workload. However, unless the officer understands the basic concept of charts and passage planning, ECDIS will not provide the intended additional safety feature. Because the ship is displayed on the chart in real time, an officer may become complacent and neglect to verify the position of the ship using other available means. Ships fitted with electronic charts as their primary means of passage planning and position fixing are presently undergoing trials approved by interested maritime administrations (Anon., 1997b).

A chart also provides information that can assist monitoring the actions of other bridge team members. Communication between bridge team members (C1) and monitoring the actions of other Bridge Team members (C2) was referred to in Chapter 4. It appears that traditionally each member of the bridge team focuses mainly on his own actions. When a pilot arrives onboard there is generally inadequate communication between the bridge team members and the pilot.

Most ships experience delays at some point during their voyages, e.g., the pilot is not available when expected. Personal observation by the author suggests that a sudden delay raises the navigating officer's stress level, perhaps partly, because the risk of the ship reaching a point of 'no return' increases rapidly.

Assuming that being able to contact another ship by VHF would automatically increase safety at sea is natural. This assumption has, in part, led to the development of transponders (referred to in Chapter 4). The 'Catalysts' in the MARS reports in particular (C5 and C6) show that contact by VHF may not always provide an agreeable resolution to a developing situation. In fact, several near misses and collisions have occurred despite an agreement of a manouevre by VHF (C4).

6.4.3.4 Safe Manning

Table 33 shows 'Catalysts' related to safe manning (referred to in Chapter 3). Some arguments for employing a traditional lookout have been that: (1) the presence of the lookout will prevent the officer from falling asleep, and (2) the lookout can wake up the officer if he does fall asleep. It should be noted that there were four occurrences of 'Catalyst' "Fell asleep-more than one person on the bridge" (D2). This suggests that the previous arguments for employing the lookout may not be as valid as assumed.

'Catalysts'		AR	MR	TOTAL
D1	W1 - No Look-out/Bridge Unmanned	5	6	11
D4	Long Pilotage	5		5
D2	Fell asleep - more than one on the bridge	4		4
D3	W1 - Distraction caused by VHF		1	1

KEY: AR = Accident Reports MR = MARS Reports

Table 33 'Catalysts' related to Safe Manning

6.4.3.5 Navigation Control

Table 34 shows 'Catalysts' related to Navigation Control. A risk of collision is ... "deemed to exist if the compass bearing of an approaching vessel does not appreciable change" (Rule 7 (d) of COLREGS 72). Occasionally the officer fails to see the other ship either visually or, by radar. It could be assumed that this is mostly due to failing to keep a proper look-out but, it could also be due to "Blind sector on the radar" (E9) or "Failed to see due to impaired vision forward" (E2).

'Catalysts'		AR	MR	TOTAL
E4	Position not fixed accurately	12		12
E8	Failed to plot course/speed of other vessel/made decisions based on initial data	11	1	12
E11	Other radar related	9		9
E7	No radar parallel indexing used/incorrect use of radar parallel indexing	8		8
E3	Did not see other ship - no radar	6	1	7
E10	Did not see other ship - radar	6		6
E1	Difficult to distinguish external navigation aids	2	3	5
E12	Radar off	2	1	3
E2	Failed to see due to impaired vision forward	3		3
E5	Relied on radar bearings, etc.	2		2
E9	Blind sector on Radar	2		2
E6	Using GPS as sole position fixing method		1	1

Table 34 'Catalysts' related to Navigation Control

6.5 The survey data

The questionnaire and the coding of the data were explained in Chapter 5. The number of responses (32 in total) does not allow for conclusive statistical analysis. The aim of the survey was to provide additional data and, to this end, the richness of the detail is regarded as valuable. The figures have been cross-tabulated when considered constructive to provide a better representation of the working environment of the ship's bridge (see e.g., table 59, page 175).

The figures obtained through the survey are presented in tables 35 to 68.

6.5.1 Personal & Ship Details

Age	Masters	First Officers	2nd Officers	3rd Officers
25-30	1		4	3
31-40	4	2	3	
41-45	5		1	
46-50	4			
>50	5			

Table 35 Age of Respondents

Table 36 shows that most Masters had more than 10 years of experience, reflecting the age figures in table 35.

Years Certificate	< 5	6 - 10	11 - 15	20 - 25	26 - 30	31 - 35
Master		3	3	7	1	5
1st Officer		1	1			
2nd Officer	3	5				

Table 36 Watchkeeping experience in years

Mother Tongue	No of responses
English	12
Bilingual	4
Other	16

Table 37 Mother Tongue

Bearing in mind that the questionnaire was conducted in English it is not surprising that most respondents would know English (table 38) although several officers knew more than one language. This table also suggests that most of the people who speak English as their mother tongue do not speak any other language.

Mother Tongue	Number of other languages	No of responses
English	None	10
English	1 other language	2
Other Mother Tongue	1 other language & English 1 other language & other	131
Other Mother Tongue	2 other languages	4
Other Mother Tongue	> 2 other languages	2

Table 38 Number of other languages known by respondents

The spread of nationalities in table 39 shows 11 Nationalities of which 2 were dual citizens. This suggests that it is possible to reach officers from many different countries for research purposes. The number of Korean responses reflects the distribution channel of nautical schools.

NATIONALITY	Number of responses	NATIONALITY	Number of responses
KOR	9	CRO	1
USA	6	SWI	1
UK	5	SYR	1

NATIONALITY	Number of responses	NATIONALITY	Number of responses
HOL	4	ITA	1
IND	2	AUS	1
NOR	1		

Table 39 Nationality of respondents

Figures for the Certification/Rank ratio in table 40 for the lower ranks suggest that officers may have a different (lower) certification than their rank, e.g., 3rd officer employed as 2nd officer. This may reflect a linguistic problem, i.e., the respondent did not understand the difference between the words. Alternatively, it may validate research which suggests that there is an increasing shortage of qualified officers worldwide compelling shipowners to employ unqualified officers (Grey, 1997). These figures should also be considered in conjunction with figures reported by the annual report of Paris Memorandum of Understanding on Port State Control showing that in 1996 a total number of 699 deficient certificates of competency were found (MOU, 1996).

CERTIFICATION	RANK	Number of responses
1st Officer	2nd Officer	2
2nd Officer	2nd Officer	3
3rd Officer	2nd Officer	3
2nd Officer	3rd Officer	1
2nd Officer	1st Officer	4
Master	1st Officer	1
Master	Master	18

Table 40 Certification/Rank ratio

The figures in table 41 suggest that on more than half of the ships crew members use at least two languages.

	NUMBER OF CREW MEMBERS ON THE SHIP							
Number of languages	< 10	11-15	16-20	21-25	26-30	> 31	> 100	TOTAL
1		1	3	3	1	1		9
2		1	4	4	1			10
3	1		2		1	1	1	6
4			1				1	2
>5					1	1	1	3

Table 41 Number of different languages spoken/Number of crew members on the ship

It appears from table 42 that most of the officers have spent less than 12 months on their current ship. There is a risk that the officers may not be sufficiently familiar with the ship should a critical situation occur. This is particularly important should there be a serious incident which requires team work from the whole crew, e.g., a fire.

TIME ON SHIP	Number of responses
< 6 Months	11
6-12 months	7
1-5 years	8
> 5 years	4

Table 42 Period on present ship

Coastal trading is characterised by short voyages and short port-turn-around times. This creates a very intensive work schedule and could increase fatigue. Deep-sea trading may offer some relief during voyages crossing large bodies of water, e.g., the Atlantic. Although navigation duties may be less demanding , there is an increased risk of boredom. Arriving into an area of high density traffic, e.g., the English Channel, will also require a mental readjustment to cope with increased traffic increasing the risk of error.

TRADING AREA	Number of Ships
Coastal	10
Deep Sea	21
Deep Sea/Coastal	1

Table 43 Trading Area

Table 44 includes 14 different ship types, including a pipe laying vessel, tug and utility vessel. These ship types reflect, among others, the physical environments of the trading areas, e.g., port specialisation and vessel manoeuvrability.

SHIP TYPE	Number of responses	SHIP TYPE	Number of responses
Oil tanker	7	Forest Product	1
Container	6	Car Carrier	1
Bulk Carrier	5	LPG Carrier	1
Passenger	2	Chemical Tanker	1
Ro-Ro	2	Pipe laying	1
Semi-Submersible	1	Container/Ro-Ro	1
Tug	1	Utility Vessel	1

Table 44 Ship types

Table 45 suggests that the flag of registry does not necessarily indicate the standard of the crew members. It should also not be assumed that all officers from non-traditional maritime countries are poorly trained, or indeed trained in their country of origin.

RESPONDENT NATIONALITY	REGISTRY OF SHIP	Number of ships
Non Traditional Maritime Country	FOC	12
Traditional Maritime Country	FOC	7
Non Traditional Maritime Country	Traditional Maritime Country	1
Traditional Maritime Country	Traditional Maritime Country	12

Table 45 Nationality of officer versus flag of ship

6.5.2 Man-machine interface and Equipment Failure/manuals

The first two questions in the section covering Man-machine interface were modelled on research carried out by the Engineering Division of the United States Air Force in 1947 (Fitts & Jones 1947 a/b). Fitts and Jones suggested that it would be possible to eliminate many so called "pilot-error" accidents by designing equipment according to human requirements.

A careful literature review indicated that such studies in the shipping industry are not available to the public. It was therefore considered that the questionnaire should include these two questions. Considering the nature of shipping, e.g., the lack of uniform design of ships' bridges and navigation aids, it was not expected that sufficient data could be collected through this survey, to make firm conclusions. Nevertheless, based on this research, a future larger scale study is likely to yield the required information. Such data could provide the basis for improved, user-centred guidelines for the design of controls, displays and alarms of electronic bridge aids.

The third question examined the number of mistakes caused by language difficulties. This was included to reflect the common assumption that the lack of a common native language may result in mistakes.

6.5.2.1 *Q1 Any mistakes reading or interpreting bridge equipment*

Any mistakes reading or interpreting bridge equipment		No of responses	Total No of responses
NO		14	14
YES	Both	2	18
	Other Person	13	
	Yourself	3	

Table 46 Mistakes in reading or interpreting equipment

Table 47 shows that mistakes are generally made only once or twice, suggesting perhaps that the operator 'learned' from his mistake.

Number of times mistake was reported	No of responses
1-2	8
3-5	4
Many	2

Table 47 Number of reported mistakes in reading or interpreting bridge equipment

Table 48 suggests that navigating officers frequently make mistakes, particularly when reading or interpreting the radar/ARPA.

TYPE OF EQUIPMENT	Number of responses
RADAR/ARPA	12
OTHER TECHNOLOGY	5

Table 48 Type of Bridge Equipment

6.5.2.2 *Q2 Any mistakes in operating any bridge equipment*

Any mistakes in operating any bridge equipment?		No of responses	Total No of responses
NO		13	13
YES	Both	2	18
	Other Person	13	
	Yourself	3	

Table 49 Mistakes in operating bridge equipment

Table 50 suggests that Radar/ARPA and GPS appear to attract most problems when operating bridge equipment. GPS has increased in popularity and is now common on many commercial ships.

TYPE OF EQUIPMENT	Number of responses
Radar/ARPA	7
GPS	6
OTHER TECHNOLOGY	6

Table 50 Type of Bridge Equipment

How many times did it occur?	No of responses
1-2	9
3-5	4
> 6	4

Table 51 Number of times of making mistakes in operating bridge equipment

6.5.2.3 *Q3 Number of mistakes caused by language difficulties*

Mistakes caused by misinterpretation were reported by approximately 50% of the respondents (table 52). To determine who made the mistake is not necessarily simple, i.e., it is a matter of interpretation. For example, a situation may develop where person A assumes that person B has done as expected and acts accordingly.

Number of mistakes caused by language difficulties		No of responses	Total No of responses
NO		14	14
YES	Both	3	15
	Other Person	12	

Table 52 Mistakes caused by language difficulties

Languages involved:

7 responses of 2 languages involved, of which one English
1 response of two languages involved, neither English
3 responses of three languages involved

Obviously the more languages are involved the greater the likelihood that even simple instructions may be misunderstood.

6.5.2.4 Q4 Failure of any bridge equipment

Failure of any bridge equipment?	No of responses
NO	6
YES	26

Table 53 Failure of bridge equipment

Table 54 shows the type of equipment that failed. In comparison, the figures for Haapio's study (1991) presented in table 55 shows the responses to the question whether the pilot had experienced equipment failure that greatly affected the manoeuvrability of the vessel. This study focused on the training requirements for Finnish marine pilots.

TYPE OF EQUIPMENT	Number of responses
Radar/ARPA	13
GPS	7
Gyro	4
OTHER TECHNOLOGY	

Table 54 Bridge aid failure types

TYPE OF EQUIPMENT	Failures as % number of responses
Radar/ARPA	51%
Rudder	40%
Gyro	44%
Main Engine	59%

These figures do not add up to 100% as more than one type of equipment was recorded in many cases.

Table 55 Bridge aid failure types from Haapio's study (1991)

Not surprisingly equipment cannot always be repaired during the voyage as shown in table 56. This could be, e.g., because: (1) the crew members are unable to diagnose the problem, (2) the ship may not carry spare parts, e.g., chips or motherboards or (3) the ship does not carry crew members proficient in repairing the equipment.

Was it repaired during the voyage?	No of responses
NO	18
YES	14

Table 56 Experience of bridge aid repair

Table 57 suggests that basic seamanship and manual navigation skills are still required on modern ships. Traditional navigation is more labour intensive and the possibility of equipment failure should be considered when approving the safe manning certificate. It should also be noted that initial navigation skills acquired through basic training can deteriorate quickly unless practised regularly.

Reversion mode used	No of responses
Other Radar	4
Other ARPA	3
Magnetic compass	2
Manual Entry	2
Other methods	6

Table 57 Reversion mode for bridge aid failures

6.5.2.5 *Q 5 - Q7 Manuals*

Table 58 shows that most of the respondents consider that they have sufficient information to operate the equipment. The respondents who have had to consult manuals to operate equipment mostly found that these may be difficult to use or understand. The quality and ease of understanding manuals is perhaps more important at sea where there may be no one to ask for clarification.

UNDERSTANDING MANUALS	NO	YES
Do you have sufficient information to operate all bridge equipment?	4	28
Do you fully understand the manuals?	9	23
Have you consulted manuals?	8	24
Were the manuals easy to use?	10	11

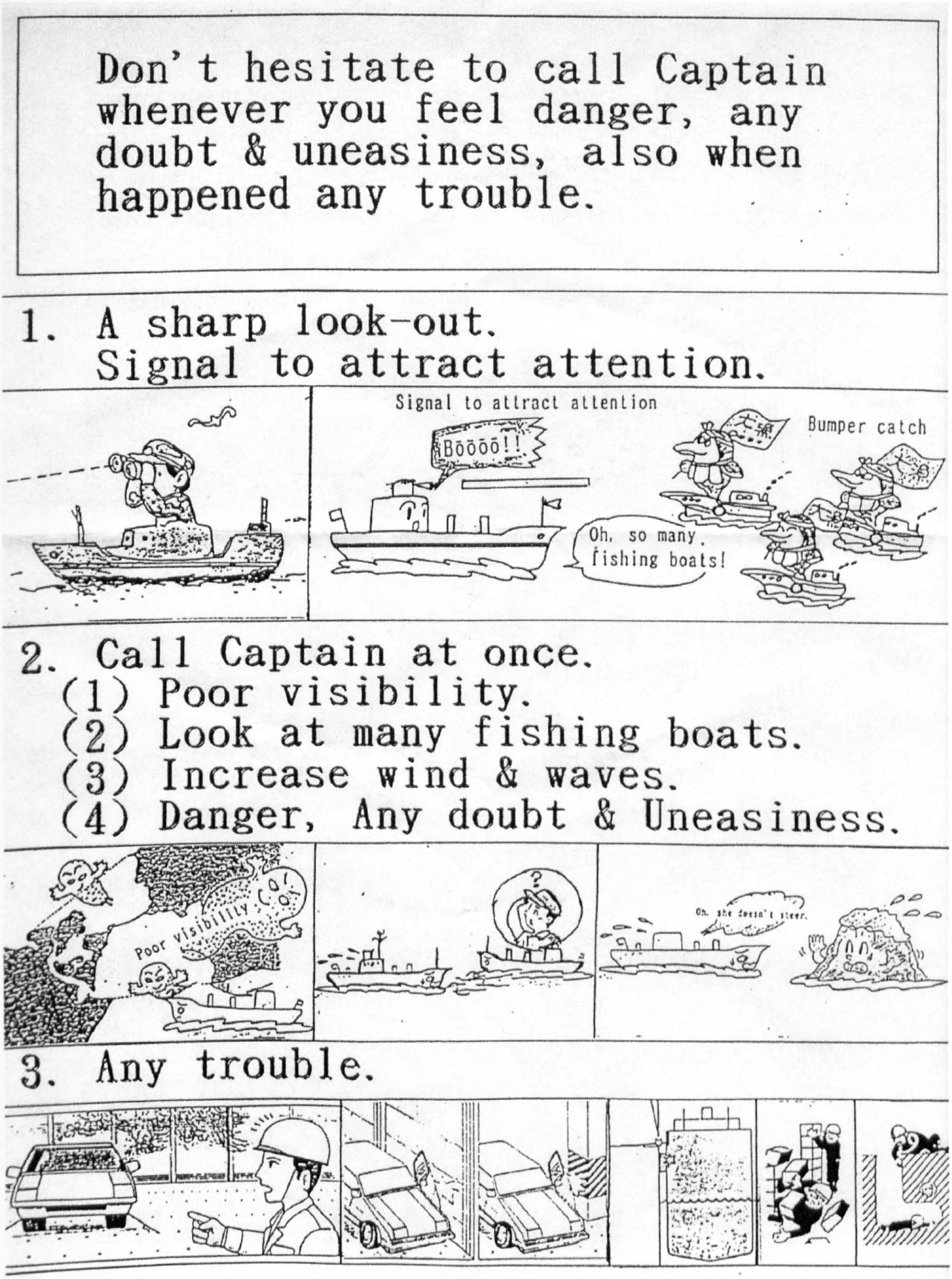
Table 58 Understanding manuals

6.5.2.6 *Q 8 Memory Aids*

Most people use some type of memory aids, e.g., post-it notes, in their daily lives to remind them of what to do, or perhaps not to do. On ships' bridges such memory aids may be regular instructions, e.g., Master's Standing Orders. Alternatively, memory aids can be used to assist in operating equipment, e.g., check lists.

Personal observations by the author during ship visits suggest that officers may also create lists and diagrams on laminated boards that can be wiped clean and reused repeatedly. On one ship the crew kept a continuous record of ship movements provided by the VTS. On another ship the crew had laminated a diagram of the 31 shipping forecast zones around the British Isles. They recorded onto a tape the shipping forecast broadcast by the BBC. Finally they marked visually the wind speed and direction using arrows (and letters) and numbers (in knots). This provided the next watchkeeper with a quick visual reference of the weather forecast.

An example of a memory aid to the Master's Standing Orders is shown in Figure 24. It was displayed on a car carrier with a Japanese Master and Filipino crew. It is completely understandable to any navigating officer despite not being grammatically correct English. Its 'comic' content and being displayed prominently on the ship's bridge is likely to be more effective than just the written Standing Orders.



Don't hesitate to call Captain whenever you feel danger, any doubt & uneasiness, also when happened any trouble.

1. A sharp look-out.
   Signal to attract attention.

2. Call Captain at once.
   (1) Poor visibility.
   (2) Look at many fishing boats.
   (3) Increase wind & waves.
   (4) Danger, Any doubt & Uneasiness.

3. Any trouble.

Figure 24 Example of a memory aid (provided by Captain W.J. Corbett, 1998)

6.5.3 Accident reporting

Incident reporting is presently attracting increasing attention in the shipping industry, e.g., the USCG is currently developing a national Incident Reporting System (Docket Management Facility, 1998). MARS is the only international voluntary reporting scheme at present. Many IFSMA members are also members of the Nautical Institute and therefore are expected to be familiar with the scheme. The consensus of the respondents is that officers should be encouraged to send in voluntary incident reports (table 59).

	Have you heard of MARS?		Have you sent in a report?		Should officers be encouraged to send in reports?	
SOURCE	YES	NO	YES	NO	YES	NO
IFSMA	8	1	1	7	9	
Internet		1		1	1	
Nautical Schools	8	5	1	6	10	3

Table 59 Knowledge of MARS

6.5.4 Simulator Training

6.5.4.1 Q12 Have you undertaken simulator training?

Have you undertaken simulator training?	No of responses
NO	4
YES	28

Table 60 Previous simulator training

TYPE OF COURSE	Number of responses
ARPA/Radar Collision Avoidance	17
Ship handling	5
Other courses	4

Table 61 Simulator course types

TYPE OF COURSES SIMULATORS ARE BEST USED FOR	Number of responses
BRM/Ship handling	8
Radar/ARPA - Collision Avoidance	4
Other courses	3

Table 62 Principal applications for simulators

6.5.5 *Q15 How often should refresher simulator courses in collision avoidance be undertaken?*

Table 63 suggests that refresher courses should be undertaken every 3 to 4 years. This differs somewhat from Haapio's study (1991) suggesting that ship handling courses should be arranged for pilots every 2-3 years.

How often should refresher simulator courses in collision avoidance be undertaken?	Number of responses
Once a year	5
Every 2 years	1
Every 3 years	7
Every 4 years	7
Every 5years	4
No need	3
Other	3

Table 63 Interval between collision avoidance refresher courses

6.5.5.1 Q15 How Long should it be?

Table 64 suggests that the length of the simulator course should be approximately 2-3 days. This is slightly shorter than Haapio's study (1991) suggested for ship handling courses. Ship handling and collision avoidance require similar, but not identical, training.

Most important, however, respondents generally agreed on the necessity for refresher courses in Radar/ARPA and collision avoidance.

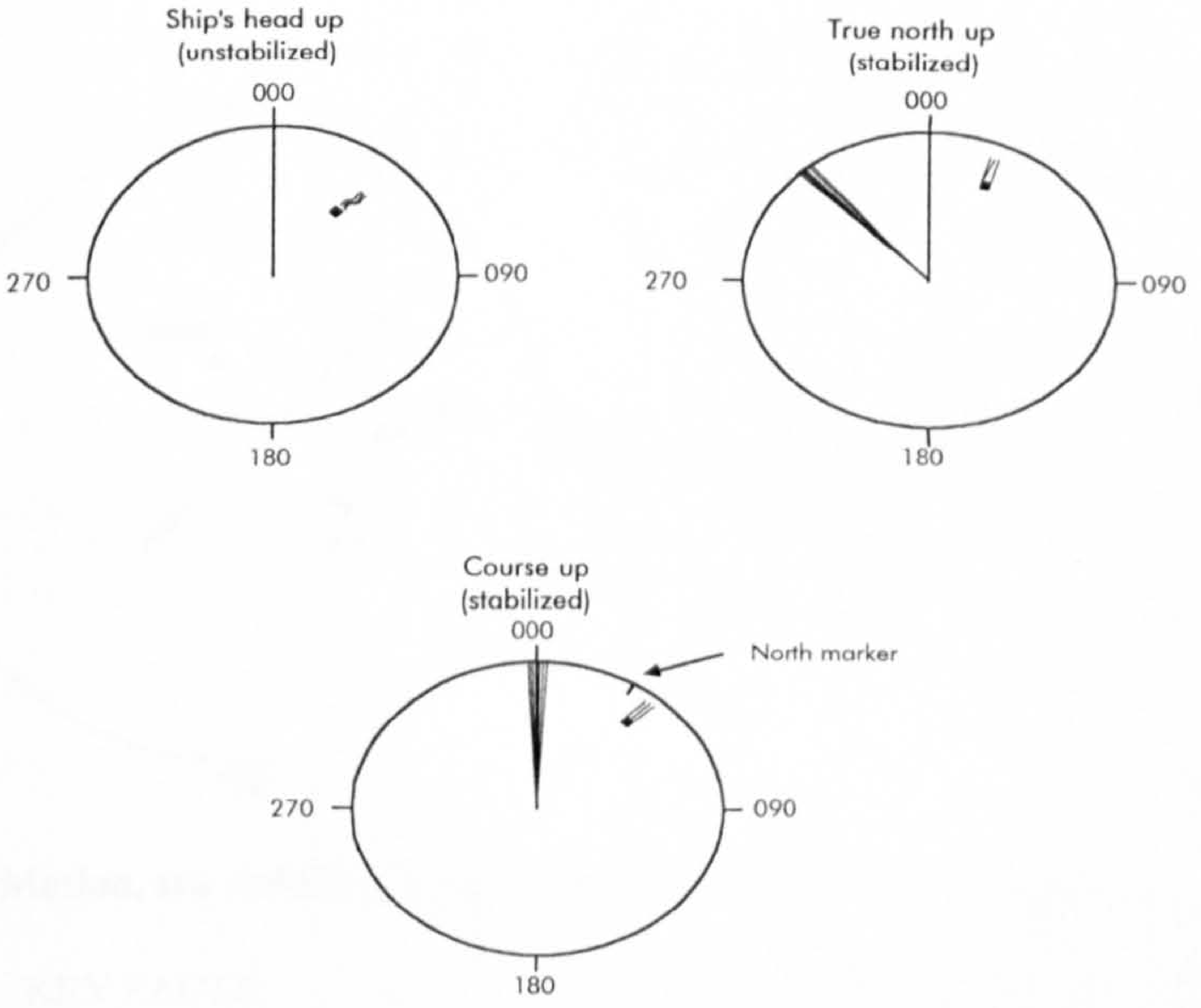
How long should it be?	Number of responses
1 day	1
2 days	8
3 days	10
≥5 days	8
None	2
Other	1

Table 64 Length of simulator course

6.5.6 Radar/ARPA

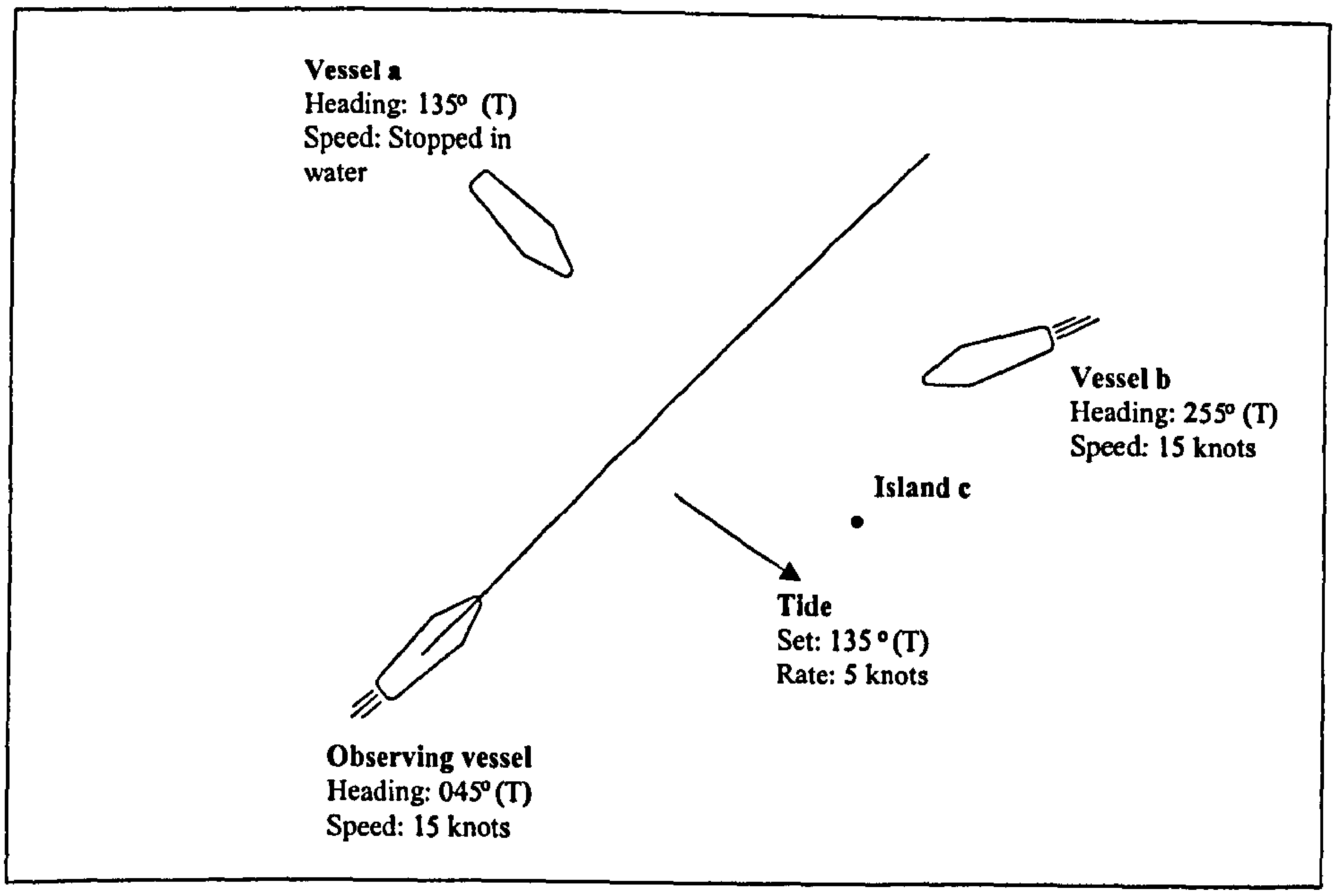
6.5.6.1 Q16 Which radar/ARPA course heading do you prefer?

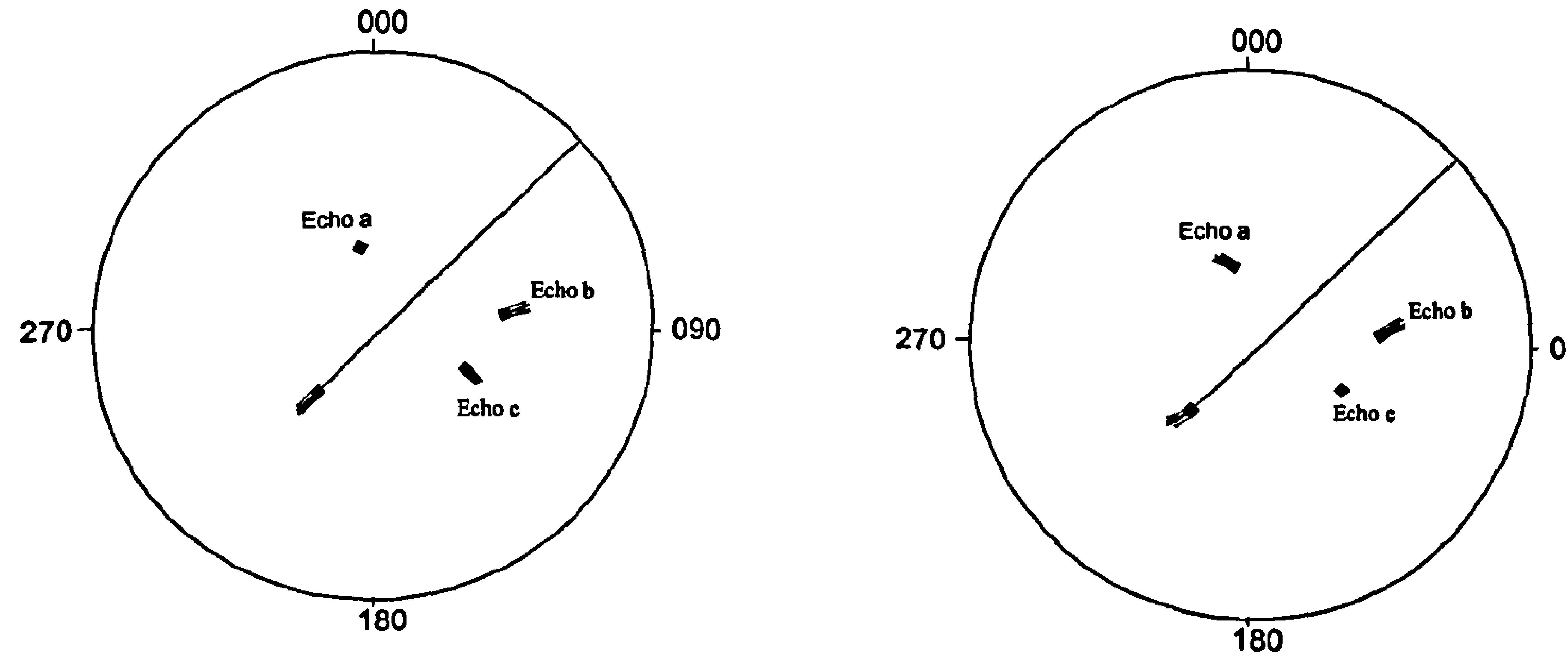
The basic features of the radar/ARPA are course heading (orientation) and mode (stabilization). Figure 25 shows that the radar/ARPA screen provides a different image to the human eye depending on the selected course heading and mode. The significant feature for the eye is whether the screen corresponds with the wheelhouse window view or the chart. The selection of a course heading is generally based on personal preference which may be based on initial training.



Feature	ORIENTATION *Ship's head up, unstabilized*	*True north up, stabilized*	*Course up, stabilized*
Blurring when observing vessel yaws or alters course	Yes: can produce very serious masking	None	None
Measurement of bearings	Awkward and slow	Straightforward	Straightforward
Compatibility with reflection plottter	Very limited	Straightforward	Straightforward
Angular disruption of target trails when observing vessel yaws or alters course	Yes: can be dangerously misleading	None	None
Corresponds with wheelhouse window view	Perfect	Not Obvous	Virtually perfect except after large course change
Corresponds with chart	Not obvious	Perfect	Not obvious

Figure 25 Comparison of radar course headings (derived from Bole et al., 1992)





True Motion, sea stabilized presentation

KEY FACTS

The echo of a stationary target in the water remains stationary on the screen

The echo of a moving target through the water will move across the screen in a direction and rate which corresponds with its motion through the water

The echo of a land target or a target at anchor will move across the sceen in a direction reciprocal to that of the tide, at a rate equal to the tide

True Motion, ground stabilized presentation

KEY FACTS

The echo of a stationary target in the water will move across the screen in a direction and at a rate corresponding ot that of the tide

The echo of a moving target through the water will move across the screen in a direction and rate which corresponds with its movement over the ground.

The echo of a land target or a target at anchor, will remain stationary on the screen

Figure 26 Comparison of sea and ground stabilized presentation (derived from Bole et al., 1992)

Which course heading do you prefer?	No of responses
Course Up	2
Ship's Head Up	3
True North	26

Table 65 Radar course orientation

6.5.6.2 *Q17 Which radar/ARPA mode do you prefer?*

The radar/ARPA picture presents the movement of echoes with respect to a chosen reference. The amount of information that can be obtained by viewing such echo movement as indicated by the afterglow trails is limited. To fully appreciate an encounter with other vessels, systematic observation of detected echoes is essential. However, picture presentation can assist by providing an image that the human eye can appreciate correctly immediately. The significant difference between ground and sea stabilization is that a ground stabilized presentation does not display the headings of moving targets. This is illustrated in figure 26 and it should be noted that in a ground stabilized presentation the echo movement will not indicate the heading of a moving target. This is an essential information required to apply the COLREGS 72 correctly (Bole et al., 1992).

The possibility of superimposing ECDIS and radar/ARPA pictures has resulted in discussions on whether ground stabilization, the natural presentation mode for ECDIS or sea stabilization, the natural radar/ARPA mode for collision avoidance decision making should be employed (see e.g., Deutsche Gesellschaft für Ortung und Navigation, 1993; Smeaton et al., 1994). Nevertheless, it has generally been accepted that a sea stabilized presentation reduces the risk of collision. The survey shows that the preferred mode of presentation is sea stabilized (table 66). Accident reports do not generally include information on what mode the radar/ARPA displayed and it is thus not possible at present to assess to what extent the mode of presentation may have induced a collision or grounding.

Which mode do you prefer to use?	No of responses
Both	3
Ground Stabilized	5
Sea Stabilized	16

Table 66 Preferred mode

6.5.7 Watch One

Although IMO has so far only approved trials for the evaluation of the Watch One concept, it should be noted that classification societies continue to approve Watch One ships (DNV, 1998). It is expected that the number of approved Watch One ships will increase in the future and it is thus appropriate to continue to explore the safety of the Watch One concept.

	Is the ship designed/classified as W1?	Is it operated as W1?
NO	27	25
YES	4	5
Don't know		1

Table 67 Classification of ship

Table 33 (page 162) suggests that a dedicated look-out does not necessarily increase the safety of the ship, i.e., prevent the accident. During normal navigation duties on a W1 bridge the workload of the navigating officer may be too low to fully occupy an additional person. The increasing complexity of modern navigation aids, together with new or additional duties, e.g., GMDSS, may on the other hand, at times increase the workload substantially. Thus there may not be a demand for a dedicated look-out but for supplementary navigation assistance available when needed. For instance, during a black out one person is needed to concentrate on the navigation of the ship and another person (e.g., the Master) to examine the situation and determine subsequent actions.

How often is it operated as W1?	Number of responses
Never	1
Occasionally	5
Regularly	3

Table 68 Typical operation of ship

6.6 Conclusion

The data presented in this Chapter should be viewed as cogwheels interacting within a complex and imperfect system. Thus any changes, e.g., the introduction of new rules will affect other areas of the system, e.g., training, design of user-interfaces and manuals.

The DAMA data confirmed the need for exploring an alternative classification system in the marine environment which focuses on human factors. The data was presented in table format followed by a brief examination of the figures. The data from the Accident and MARS reports were considered as primary data and in parallel and the DAMA and questionnaire data was considered supporting data. Each set of data provides a unique insight into the various components of the working environment of the ship's bridge.

It was concluded that organising the primary data only into broad groups or categories would provide limited practical value. Consequently, the 'Catalysts' from the Accident and MARS reports were broken down within the main groups (tables 30 to 34) providing the basis for a three-layer classification system. This data is intended to be viewed as descriptive rather than analytical.

Since it was established that the questionnaire would provide primarily supporting data the figures were shown in a tabular form. It is suggested that the data provides an improved representation of the working environment on the ship's bridge.

CHAPTER 7

GENERAL DISCUSSION ON HUMAN FACTORS ON THE SHIP'S BRIDGE

7.1 Human Factors and Safety at Sea

The employment of seafarers is increasingly transient, for example, the navigating officer employed on Ship A today may be employed on Ship B tomorrow bringing his training, skills and experience with him. The role of human factors on the ship's bridge is expected increasingly to affect the shipping industry worldwide.

The data presented in Chapter 6 was largely considered in isolation within the proposed marine human factors' framework, i.e., Human Performance, Engineering/Design, Bridge Procedures, Safe Manning and Navigation Control. The main objective was to examine whether meaningful information in form of 'Catalysts' could be isolated from a combination of data sources. However, contemplating the results within the broader context of the working environment of the ship's bridge seems appropriate.

In this exploratory study, a summary of typical 'Catalysts' is expected to provide an improved indication of the most relevant problem areas within the working environment of the ship's bridge. These 'Catalysts' will continue to develop and may be modified following any changes in the working environment, e.g., High Speed Ships (HSS) or changes in the COLREGS 72.

The aim is to develop awareness of the 'Catalysts' and how they affect the navigating officer. The objective, at this stage, is to encourage further research thus ensuring that the human element does not invalidate the intended effect of remedial proposals (e.g., introducing new technology or rules/regulations).

The focus of this research is to develop a marine human factors classification system which will improve future analysis of collisions and groundings. It is expected that the increased knowledge provided by the detail of human factors in form of 'Catalysts' can additionally, for example, be applied to examine 'human error' on the ship's bridge and improve the IMO rule making process (e.g., re-examining the Watch One concept).

7.2 Applying the Marine Human Factors Classification System to the analysis of collisions and groundings

The 'Catalysts' (referred to in table 23, page 145) form the basis of the marine human factors classification system proposed in this research. The 'Catalyst' concept focuses on situations and problem areas on the ship's bridge and provides a method for collecting human factors data systematically from accident reports. Although the resulting marine human factors classification system would be specific to the working environment of the ship's bridge it would be expected that the principle could be employed for the examination of other types of accidents.

The 'Catalysts' grouped within specific 'Catalyst' Types were derived through isolating the immediate chain of events culminating in the accident. 'Catalysts' are not considered a feature of an isolated event but arise from the context of the working environment.

The classification system provides a recording technique that describes human factors in a more functional manner.

To illustrate the advantages of the Marine Human Factors Classification system the groundings of the *Exxon Valdez* and the *Sea Empress* are examined as case studies. A significant characteristic of both groundings is that the period from the moment of 'no return' to the impact is very short, only approximately 20-25 minutes.

Case Study: The Exxon Valdez

The grounding of the *Exxon Valdez* (NTSB, 1990) attracted worldwide attention from the media, much of which focused on the master of the ship. The fully laden U.S. oil tanker the *Exxon Valdez* grounded on Bligh Reef in Prince William Sound, Alaska on March 24, 1989 resulting in the largest oil spill in U.S. history. The official report published by the National Transportation Safety Board (NTSB) argued, among other things, that the intoxication of the master was a major factor in causing the accident. This notion was based essentially on the results of speech analysis. The report and the ensuing media attention are likely to have ensured that in the public mind the blame remains with the master (Faith, 1998).

It is not intended here to argue the merits of the technique of speech analysis for the determination of possible intoxication, nor to criticise a very comprehensive and thorough report, but to examine factors affecting the human element that perhaps received less attention. There is, for example, another possible explanation to the master's speech patterns, i.e., that it resulted from a deep emotional shock caused by the grounding itself, particularly as the master was not onboard the bridge at the time immediately before the grounding.

Consequently, his performance is likely to have had a lesser, direct effect, on the outcome of the events. This fact does not exonerate his behaviour, but draws attention to other factors which may also be relevant, e.g., why did he feel sufficiently confident to leave the third mate in charge? It should be noted that the third mate had served 6 trips on the *Exxon Valdez* with this master and one trip with a relief master. He had also served previously about two years as third mate on five other Exxon vessels.

Other data extracted from the *Exxon Valdez* report shows that the Vessel Traffic Centre (VTC) agreed to the diversion from the traffic lanes to avoid ice which eventually led to the grounding on Bligh Reef. This was an accepted practice as evidenced by the tankers, the *Arco Juneau* and the *Brooklyn,* which deviated around the ice, the evening before and the same morning, respectively.

Examination of the interaction of the human element and the steering control system of the ship is considered essential from a human factor's point of view. The *Exxon Valdez* was equipped with a centralised multi-computer integrated steering control system. Four steering modes were available: (1) Helm, or hand steering (2) Gyro, or automatic pilot (3) NAV mode and (4) Rate-of-turn mode.

The main events leading to the grounding are summarised in Table 69. The summary shows that the total time from when the master left the bridge until the grounding was only approximately 20-25 minutes.

A simple human factors' analysis of the summary indicates that there are at least two possible reasons for the third mate's inability to bring the vessel safely around the ice: (1) he began the swing to starboard too late, or (2) that the autopilot was still engaged and therefore the helmsman's application of the helm did not engage the rudder.

		Comments
1	The master asked the helmsman to steer 180° and engage the automatic pilot. The helmsman pressed the gyro button to engage the automatic pilot.	*Why did he leave it on automatic? How long did he intend to steer it on automatic?* Time 23.39
2	When the helmsman was relieved he advised the third mate that the vessel was steering on automatic pilot.	*Why didn't 3M query the decision to operate the vessel on automatic?*
3	The third mate acknowledged this but did not expect this as the vessel was not normally operated in automatic mode when navigating in traffic lanes. He did not discuss this with the master.	Time 23.50
4	The third mate decided not to call the second mate as scheduled but he decided to remain on watch until the vessel was clear of ice.	*Was 3M over confident? Was it typical?*
	The master asked the mate whether he felt 'comfortable' to continue on his own to which the mate replied that he did.	*Master accepted 3M's response.*
5	The third mate then went to the steering stand and pushed the hand steering button. The helmsman claims he observed the indicator illuminated showing it was engaged. The helmsman offered two different versions (1) he was unable to recall whether it was in automatic when he arrived on the bridge and (2) that it was in gyro mode and when he was going to push the hand steering button the third made pushed the button as well.	*Conflicting information on whether the manual helm was engaged. When in auto mode the steering wheel is electrically disconnected and may be turned without affecting the steering or causing any alarms to sound!* Time 23.55
6	The third mate ordered the helmsman to put the rudder to right 10° - he did not recall watching the rudder angle indicator to ensure that the rudder was actually applied.	*3M did not confirm visually the rudder angle*
7	He phoned the master to inform he had started to turn the vessel. He was standing with his back to the rudder indicator. The master asked whether the second mate had arrived on the bridge. He was informed that the second mate had not been called.	*3M was unable to confirm visually the rudder angle.*
8	The third mate then went to the port radar to check ranges and noticed that the vessel had not moved to the right and the heading had not changed.	
9	The third mate then ordered rudder increase to right 20° and then hard right rudder.	
10	He then called the master and said 'I think we are in serious trouble'.	Time 00.05

Table 69 Summary of the events leading to the grounding of the Exxon Valdez

The NTSB report states that carrying out the proposed manoeuvre involved careful navigation and frequent position fixing. The Master had made more than 100 trips through the Prince William Sound which may have resulted in a certain degree of complacency and over confidence. He may not have realised that the third mate did not have sufficient experience to carry out the proposed manoeuvre on his own. On the other hand, the master also expected the third mate to hand over the watch to the second mate. It should also be noted that according to Exxon company regulations, the master or chief mate should have been in charge of the watch, when the vessel was navigating through confined or busy waters.

Examining the above scenario from a human factor's point of view, the following should be considered:

(1) Design of User interface - the course recorder suggests that the steering may have remained in gyro mode. The steering could easily be switched between gyro and helm without providing appropriate feedback (e.g., sound or light). The report does not state clearly the extent of sleep deprivation, but it is accepted that fatigue can result in substantial decline in performance (Neville et al., 1994). Thus if the third mate was fatigued, he was more likely to make a mistake, i.e., not note consciously whether the autopilot had switched to manual helm as intended.

(2) Manning - the *Exxon Valdez* operated with a reduced crew complement approved by the Coast Guard. The minimum crew requirements had been established for the Valdez-Panamanian trade but the vessel was now operating regularly between Valdez and ports in California. This trade may have been more demanding due to more frequent port calls, and it is possible that re-evaluation of the manning requirements would have been useful in reducing the risk of fatigue.

(3) Onboard supervision and management - traditionally training has focused mainly on navigation and other shipboard skills and to a lesser degree on formal training in managing people, understanding human factors, fatigue management, evaluating other crew members' experience/skills or managing reduced crew complements.

Applying the marine human factors classification scheme to the grounding of the *Exxon Valdez* suggested two main 'Catalysts' (shown in table 70):

Problem/Situational Area	'Catalyst'
It was possible to turn the wheel when in auto mode with no effect on steering and no alarm	*User interface*
The master left 3rd Mate alone in charge of the watch	*Did not fully assess the situation*

Table 70 'Catalysts' extracted from the *Exxon Valdez* Report

The accident report of the *Exxon Valdez* does not suggest directly that the interaction of the human element and the steering control system may have been a problem area. Further examination of all the accident reports examined in this research show that there were 5 other incidents where the design of the user-interface of the steering control system had been a problem area (e.g., the autopilot changeover could be operated by the helmsman without knowledge of the pilot or the autopilot did not sound an alarm when the turn was not carried out when operated in NAV mode).

These findings do not detract from the official report. Rather, they extend the possible conclusions in a subtle manner and extract additional useful information. This brief analysis also shows how a move away from 'blame seeking' to an attempt to identify underlying causes can stimulate future progress in general and detailed design of bridge equipment and management procedures.

A better interface with adequate audio and/or visual warnings would have reduced the risk of making such a mistake.

Case Study: Sea Empress

The *Sea Empress* grounded off the Middle Channel Rocks in the approaches to Milford Haven on 15 February 1996 (MAIB 1997). A pilot was on board when the vessel was entering the Haven via the West Channel. The *Sea Empress* was manned with a total crew of 27, all Russian nationals. She was delivered in 1993 and the master had been in command of the vessel since she was new.

Applying a similar human factor's analysis referred to previously in this Chapter, a summary of the accident scenario for the grounding of the *Sea Empress* indicates that (1) the pilot was unable to bring her around to follow the leading lights and (2) the bridge team did not appreciate the danger of the developing situation (shown in table 71) .

		Comments
1	End of sea passage, steering 022°. Engine from bridge control.	Time 19.05
2	Course altered to 012° towards boarding area requested by the Pilot	Time 19.10
3	Pilot boarded. The Sea Empress was heading 010°. Main engine dead slow ahead.	*Master and Pilot did not discuss passage plan.* Time 19.40
4	The master, chief officer and helmsman were on the bridge.	
5	The pilot ordered full ahead, turn to starboard to course approx. 060° (hard-a-starboard)	Time 19.44
	The pilot ordered progressive changes to port, by about 5° at a time until the vessel was heading 035°. Speed ca. 10 kts. The pilot was satisfied with the helmsman.	*The pilot did not realise the effect of the tide. Gave small course orders, rather than helm order of at least 10 or 15°.* *Why did the master not query the pilot's course orders of only 5°?* Time 19.55
6	When the Sea Empress was 2-3 cables from the Channel Entrance the pilot saw from the changing aspects of the Outer Leading lights that there was a set to the east and ordered course change of 5° to port.	*The Chief Officer assumed that the pilot was taking a compromise shorter course to the entrance to save time.*
7	The pilot saw the Outer Leading lights close and then open to the east.	*The pilot realises that the vessel is off course*
8	The helmsman reported that the vessel was not steering.	Time 20.07

Table 71 Summary of the events leading to the grounding of the Sea Empress

It should be noted that the crew had prepared a detailed passage plan to follow the leading lights at 022°. This was based on a previous visit by the master in a large tanker to Milford Haven, and all other available information. It could be speculated that had the vessel followed the prepared passage plan the vessel may not have grounded.

Examining the above scenario from a human factor's point of view the following should be considered:

(1) Master/Pilot relationship - it appears that there is a tendency for pilots and crew members not to communicate the intended passage. This is true even when the crew have prepared a berth-to-berth passage plan.

(2) Navigational supervision - the *Sea Empress* had a fully qualified/trained crew but it appears that neither the chief officer nor the master had the necessary skills to monitor and observe other crew members' or pilot's actions with the view to take control before the point of 'no return'.

(3) Pilot training regarding specific geographic areas and local conditions (e.g., tides, currents) is not within the scope of this research and therefore not considered in any detail here.

Applying the marine human factors classification scheme to the grounding of the *Sea Empress* suggested two principal 'Catalysts' (shown in Table 72):

Problem/Situational Area	'Catalyst'
Did not agree a passage plan, assumed pilot's intentions	Poor communication between Bridge Team members
Pilot ordered course to steer, rather than helm order	'Same Language'

Table 72 'Catalyst' Types extracted from the *Sea Empress* Report

The preferred latest time to embark the pilot was 1930 hours to ensure that the *Sea Empress* would be alongside the Texaco Refinery Jetty by the predicted low water time of 2130 hours. The pilot did not board until 1940 hours and according to Port records the *Sea Empress* entered the West Channel about 15 minutes later than any previous tanker of that size. This fact was unknown to the pilot at the time. This delay was not considered a critical factor as extra time was provided by the period of slack water off the jetty before the tide turned.

The analysis of the accident report of the *Sea Empress* shows that the interaction between the pilot and the crew members may be a problem area. A further examination of the available data shows that, within the category of Bridge Resource Management, there were 5 additional accidents directly involving poor interaction between the pilot and crew.

The role of a common language in accidents at sea has attracted much attention from the shipping community. Although the crew members and the pilot were of a different nationality, verbal communication appears not to have been a problem. The problem area was therefore assigned to 'same language' allowing a more detailed examination of the meaning of the words used. When the pilot gave course change orders, the amount of helm applied and rate of turn to the new course were left to the helmsman's discretion. The helmsman's priority may have been to avoid an excessive swing. Giving a larger helm order (10-15°) may have brought the vessel around to the required course more precisely. It appears that course and helm orders can have different messages which may give rise to erroneous assignments of meanings.

7.2.1 General observations on the case studies

After the accident, the first priority, is generally to develop measures that will ensure that a similar accident cannot occur again. To this end the accident is generally viewed singularly, i.e., what recommendations for system improvements can be proposed based on the investigation of a single accident such as the grounding of *Exxon Valdez*.

Research is needed to provide information to improve management of the theory and practice of safety at sea. Accidents grouped together provide a broader base for analysing common denominators and perhaps trends and the effectiveness of preventive measures over a period of time. The more detailed investigation, the more useful data it can provide. The type of information available from a singular accident was outlined in the above example.

Analysis of accident groups is generally based on the final reports which may have several disadvantages:

- The report is edited and relevant data may not be included
- Data may be missing perhaps because its importance was not realised during the investigation
- Lack of consistency, e.g., time of accident, number of people onboard the bridge, etc. may not have been recorded in each individual report

7.3 The Marine Human Factors Classification System and 'Human Error'

The SHELL concept was discussed briefly in Chapter 4 examining the scope of human factors in aviation safety. It was suggested that is be applicable to the marine environment. The 'Catalysts' extracted from the two case studies show that Liveware, i.e., the navigating officer, is central in a marine safety system (Table 73)

'Catalyst'	SHELL
User Interface	L-H
Did not fully assess the situation	L-L
Poor communication between the Bridge Team members	L-L
'Same Language'	L-L

Table 73 'Catalysts' extracted from the case studies and their corresponding SHELL label

It is expected that all the 'Catalysts' fit within the SHELL model thus verifying that it provides a useful mental representation of human factors in the marine environment.

Reason (1990a) suggests that latent failures in complex technological systems are analogous to resident pathogens in the human body. This analogy stresses the importance of causal factors present in the system before an accident sequence actually begins. At any one time, each complex system will have within it a certain number of latent failures, whose effects are not immediately apparent but that can serve to promote both unsafe acts and to weaken its defence mechanisms (see also figure 4, page 9).

For the pathogen metaphor to have any value, it is necessary to demonstrate clear causal connections between indicators relating to the seriousness of the system and accident liability across a wide range of complex systems and in a variety of accident conditions. Accidents have multiple causes and the occurrence of an accident is not simply determined by the sheer number of causal factors in the system. Their adverse effects have to find a window of opportunity to pass through the various levels of the system and, most particularly through the defences themselves. There are a large number of random variables involved.

The case studies of the *Exxon Valdez* and the *Sea Empress* presented here, show that 'Catalysts' provide specific detail relating to the working environment of the ship's bridge, e.g., the design of user-interface of autopilots or monitoring bridge team members. Consequently the marine human factors classification system provides additional information which is expected to improve the analysis of accidents when adopting accepted human factors research techniques and 'human error' classification systems.

7.4 The IMO rule making process

The IMO provides the framework for safety at sea and it is increasingly recognising the significance of the role of human factors in accidents. To support the rule making process IMO has recently adopted interim guidelines for the application of a Human Element Analysis Process (HEAP) (IMO, 1998). The HEAP is a practical tool designed to address the role of the human element in maritime safety. A flowchart listing a series of questions that should be considered to address appropriately the human element in the regulatory development process has been introduced (Figure 27).

The modified HEAP chart applies only to the working environment of the ship's bridge and the affected areas (Technical, Manning, Training, Management and Work Environment) in the original flowchart have therefore been substituted to include the five 'Catalyst' Groups referred to in Chapter 5. The flowchart is expected to assist in focusing on the most appropriate human factors when developing new rules or guidelines.

For example, the number of crew members has increasingly become an important focal point in shipping safety. As a measure to drive down costs, the Watch One concept was introduced and has been discussed and debated during the last decade in both the IMO and the nautical press (referred to in Chapter 3). The main argument regarding the safety of the concept is that it is safe if the bridge is designed according to strict guidelines. The counter argument is that it is an unsafe practice under any circumstances.

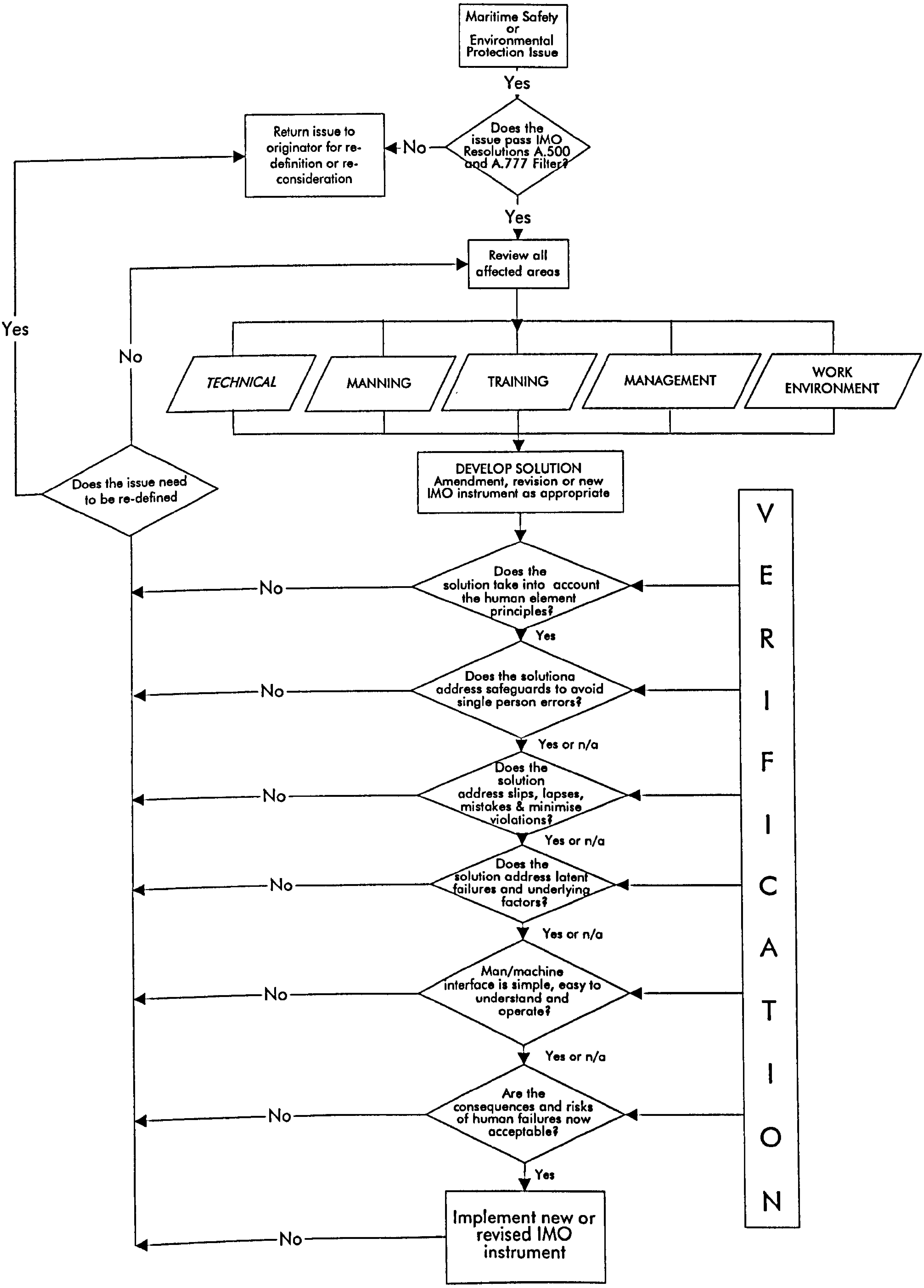


Figure 27 Flowchart for analysing the human element (IMO, 1998)

The introduction of the concept of 'Catalysts' as components of a marine human factors classification system presents additional detail and would thus improve the proposed HEAP model. Figure 28 shows a modified flowchart incorporating the concept of 'Catalysts'. The two flowcharts complement each other.

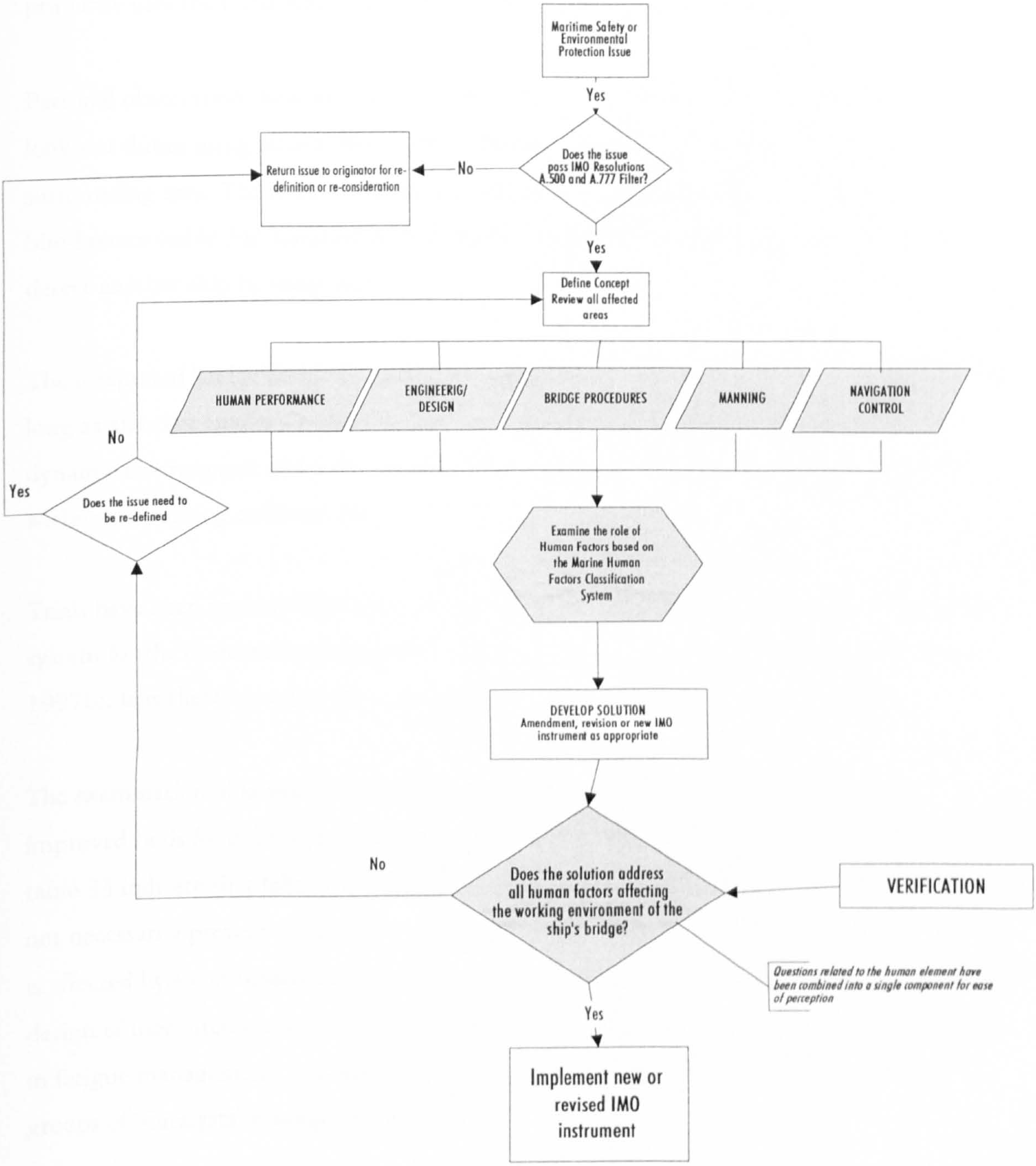


Figure 28 **Modified HEAP Flowchart applied to the IMO Rule-Making Process relating to safety of navigation**

The safety aspect of the Watch One concept has been considered in several recent reports (Hansen & Pedersen, 1998; Wikman, 1997; Schraagen, Breda van & Rasker, 1997). Advocates for the concept generally assume that the bridge can be designed so that a solitary watchkeeper has the same amount of time to look out, as a dedicated look-out on a conventional bridge. This is partly based on the assumption that the navigating officer primarily uses the radar/ARPA to look out during the hours of darkness.

Personal observation, however, suggests that the prudent navigating officer performs his look-out duties using all available means, for example, using binoculars to scan the surrounding area. The research presented here further suggests that the radar may have a blind sector (table 34/ 'Catalyst' E9) and unless the officer is fully aware of it, he may not detect another ship by radar alone.

The integrated bridge design has many labour-saving features and may be considered safe as long as all other factors are assumed to remain unchanged. However, ships operate in a dynamic environment and safety is influenced by the interaction of the navigating officer within his working environment.

Trials have been approved for ships using electronic charts as part of their main navigation system for the evaluation of integrated bridge systems and the Watch One concept (Anon., 1997b). It is therefore appropriate to continue to explore the safety of this concept.

The examination of human factors as defined by the individual 'Catalyst' provides an improved basis for developing safer solutions. For example, the 'Catalysts' D1 & D2 shown in table 33 indicate that falling asleep on the bridge is a problem, but an additional person does not necessarily prevent the accident. This suggests that the safety of the Watch One concept is affected by a combination of factors, some which can be managed through regulation (e.g., design of user interfaces or manuals) and others which demand other solutions, e.g., training in fatigue management. A simple procedure for examining the concept of individual or groups of 'Catalysts' is suggested in Figure 29.

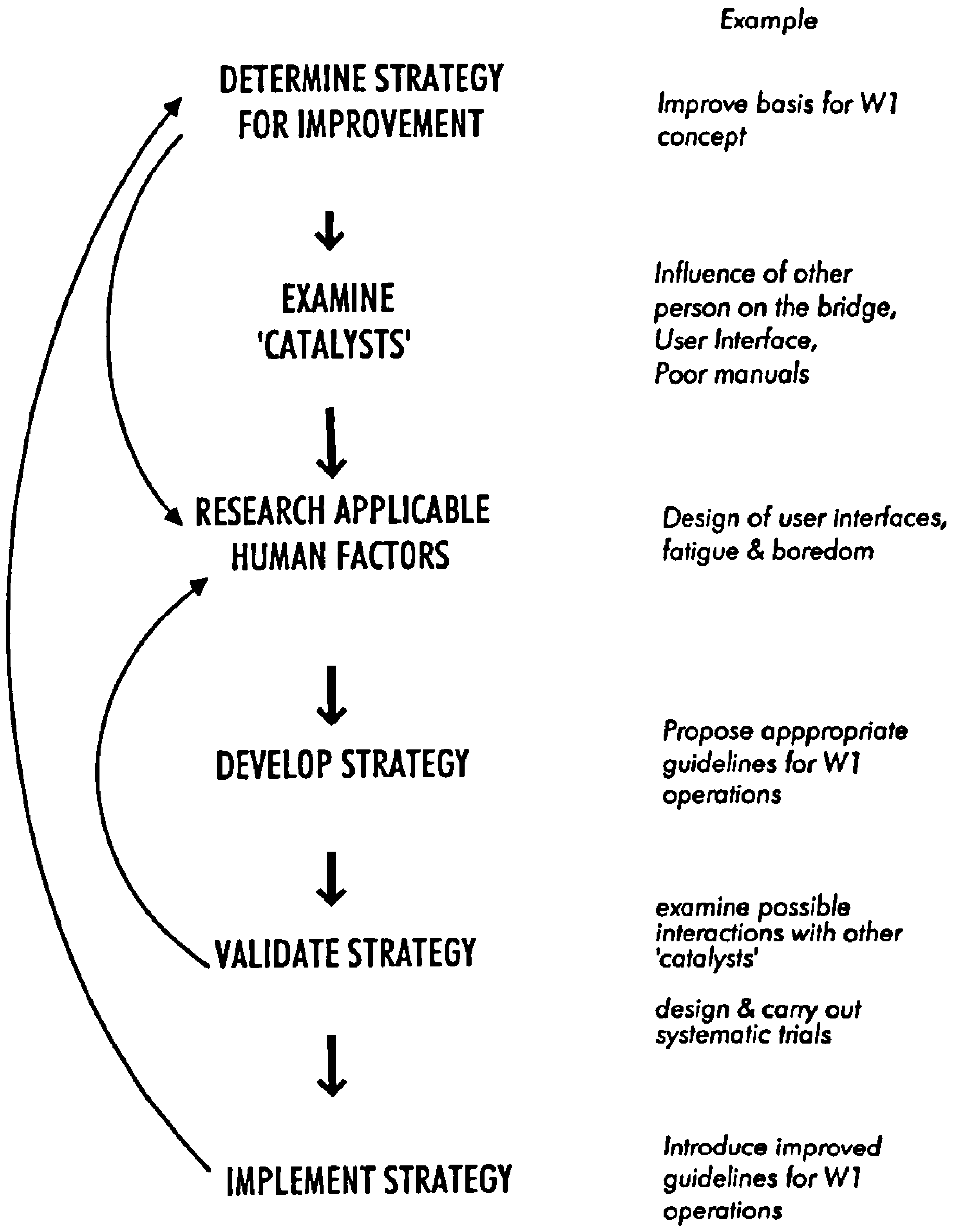


Figure 29 **Suggested procedure for examining the concept of individual or groups of 'Catalysts'**

Safe navigation under all operational conditions must be the starting point for the evaluation of the safety of the Watch One concept. Labour-saving features of the bridge design should be encouraged, but this must not be at the expense of introducing other possible 'error inducing' features, e.g., insufficient training or poor user interfaces. This leads to the conclusion that the safety of the Watch One concept in particular would benefit from an introduction of some form of a human factors validation of bridge design.

7.5 The concept of 'catalysts' and organisational errors

Analysis of collisions and groundings has traditionally focused on the 'sharp end' on the ship's bridge, i.e., the navigating officers. Chapter 1, however, shows how human failures on ships' bridges may result from decisions made by top-level decision makers (see further figure 4 and page 9 to 10). Such organisational errors can result in an increased likelihood of operator error through an active or latent failure pathway. On the ship's bridge an active failure pathway originates in top-level decisions and proceeds via error-producing and/or violation-promoting conditions to unsafe acts committed by the bridge team. A latent failure pathway leads directly from the organisational processes to deficiencies in the defences of the system (Reason, 1995).

These are illustrated in figure 30 stressing the differences between the active and latent failure pathways in accidents (see also figure 11, page 65).

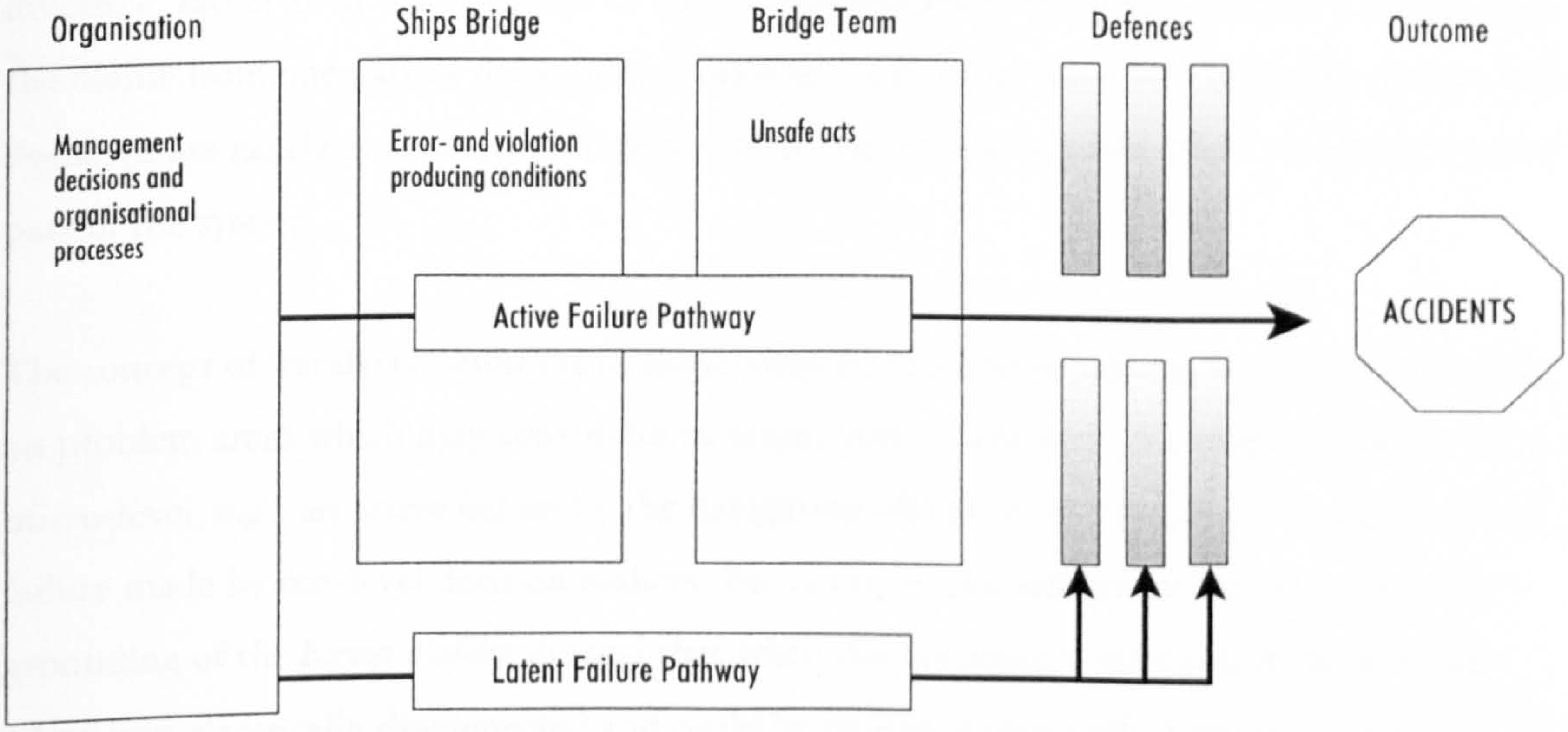


Figure 30 **Stressing the differences between active and latent failure pathways as applicable to the ship's bridge (derived from Reason, 1995)**

As an example of organisational errors, the report into the near miss between the *Woodside I* (a ferry) and the *Tussle* (a tug) showed a number of latent and active failures (see further page 10). This report showed how the accident sequence began with failures at an organisational level (e.g., the lack of a policy for minimum operating standards for navigation equipment fitted on the organisation's ferries). Such management and operational decisions are often influenced by financial, economic and/or political factors. Latent failures created by management decisions or organisational processes may be then transmitted along an active failure pathway to create local conditions increasing the probability of unsafe acts (e.g., failure by the navigating officers to report to the Vessel Traffic Services before leaving the port).

Reason (1995) suggests that technological advances, particularly in regard to engineered safety features, have made many hazardous systems largely safe against single human or mechanical failures. As a result, breaching the 'defences in-depth' requires an unlikely combination of several contributing factors. Each factor is necessary to cause the accident. Additionally, increased automation provides greater opportunities for the accumulation of latent failures within the system as a whole.

For illustration, figure 30 shows how the navigating officer on the ship's bridge is the inheritor, rather than the instigator of an accident sequence. However, the aim is not to shift the blame from one part of the system to another. It must be acknowledged that designs and decisions are nearly always a compromise which may have a negative effect on safety in some part of the system.

The concept of 'catalysts' attempts to move away from a blame seeking strategy by focusing on problem areas which may contribute to unsafe acts. These may be considered either on a micro-level, e.g., an active failure by the navigating officer or on a macro-level, e.g., a latent failure made by top-level decision makers. For example, the analysis of the report into the grounding of the *Exxon Valdez* showed that when the autopilot was engaged the steering wheel was electrically disconnected and could be turned without affecting the steering or causing any alarms to sound (see table 69, page 187). The poor design of the user-interface of the autopilot (which did not indicate whether or not the autopilot was engaged) may have acted as a local trigger and increased the likelihood of an unsafe mode error by the navigating officer.

The analysis of the report into the grounding of the *Sea Empress* suggests that the systems' defences were breached through the latent failure pathway (see table 71, page 190). In this case management decisions and the organisational framework must bear responsibility for not providing sufficient human factors training for bridge team members.

The reduction of accidents at sea requires the identification of local triggers (i.e., error and violation producing conditions) and latent failures (i.e., inadequate defences) that may increase the risk of a collision or grounding. The detail provided by the 'catalyst' approach should assist in examining the potential for active and latent failures specifically on the ship's bridge. Safety management should make use of such knowledge of problem areas to improve factors such as design, hardware, training, operating procedures, etc.

7.6 Conclusion

This Chapter examined the benefits of applying the marine human factors classification system to analysing collisions and groundings. A brief examination of the groundings of the *Exxon Valdez* and the *Sea Empress* demonstrated that a non blame seeking approach can provide additional information through the extraction of 'Catalysts'.

It was concluded that the 'Catalysts' extracted from the two groundings examined as case studies would fit the mental representation provided by SHELL (referred to in Chapter 3). It is expected that all the 'Catalysts' would fit within this model.

The additional information provided by the 'Catalysts' is expected to improve the analysis of collisions and groundings. They can also assist in examining the potential for active and latent failures specifically on the ship's bridge. However, the time period between the accident and the publication of the final report can be several years and therefore the benefits of the extracted information may be less constructive in developing practical preventive measures.

Management of safety at sea is embodied in the organisational framework provided by the IMO. Human factors have been recognised through the application of HEAP. This Chapter discussed the application, proposed a modified HEAP flowchart and examined the Watch One concept. It was concluded that it can be used to improve the safety of the concept by taking into account factors affecting human element through future training requirements and design requirements.

CHAPTER 8

CONCLUSIONS

8.1 The role of human factors in managing safety at sea

Progress in safety at sea has been marred, to some extent, by a historic reluctance within the shipping community to accept change. For example, when lighthouses were first developed in the 1780's in Scotland as aids to navigation, the engineers found themselves challenging the prejudices of the mariners, whom those lights were supposed to save (Bathurst, 1999). Frequently shipowners have objected to proposed legislation, e.g., Plimsoll Lines, because they considered the measures uneconomic. Many a time, progress in safety at sea has resulted from a major accident, e.g., SOLAS was introduced in the aftermath of the sinking of the *Titanic*.

A brief review of safety at sea (see Chapter 1) showed that collisions and groundings inevitably result in an economic loss. Figure 3 (page 7) suggests that some costs may be hidden, viz. pollution liability (e.g., the *Exxon Valdez*). It has recently been estimated that the annual cost of mutual claims arising from collisions and groundings resulting from navigational errors totals around US$500 million (Anderson, 1999). The lack of worldwide annual statistics on collisions and groundings, and readily available sources for detailed costs, add to the difficulties in determining trends and assessing the effectiveness of preventive measures.

Human behaviour can have a significant effect on whether preventative measures will have the intended effect . An increased awareness of human factors on the ship's bridge can thus assist in developing strategies for managing safety at sea with the aim of reducing the number of navigation related accidents.

8.2 Human factors on the ship's bridge

The existing literature was examined (see Chapter 2) and it was suggested that it does not provide an acceptable procedure for determining the impact of human factors on the ship's bridge (see also Appendix B). Nevertheless, substantial research into human factors is available, particularly in the aviation, nuclear and automobile industries. This limited availability of human factors' research specifically related to the ship's bridge played a significant role in determining the course of this research. It was also suggested that the specific characteristics of the marine environment must be considered before applying any results directly to the human element on the ship's bridge.

'Human error' was discussed briefly in Chapter 2 and the examination of a recent study of shipping accidents (Merenkulkulaitos 1997) reinforces the current belief that 'human error' is a major cause of accidents at sea. However, it does not suggest specific measures that could be adopted to reduce future accidents. It was concluded that the available HEI techniques, when used in isolation, have at present, limited practical value for exploring 'human error' on the ship's bridge. It was suggested that there was a need to obtain a better understanding of the working environment to improve the effect of current and future research techniques.

Every working environment is different, defined by factors such as the organisational/regulatory framework and the physical environment. Consequently a review of (1) the organisational framework and (2) the navigational system, as part of an integrated working environment was outlined. This showed that the organisational framework is based primarily on Conventions and Resolutions adopted by the IMO. It is generally accepted that although the IMO has no enforcing powers it plays an important role as the overall guardian of safety at sea. This review concluded that the navigating officer has little direct influence on the working environment of the ship's bridge (see Chapter 3).

Collision avoidance is considered an inevitable part of safe navigation. The influence of the original the Rules of the Road at Sea on the COLREGS 72 was discussed. It was suggested that the early rules focused on legal aspects, perhaps lessening their practical value as a tool for avoiding collisions. This historical review concluded that this legacy may have affected the current COLREGS 72, potentially resulting in navigating officers interpreting the rules differently during the time leading to a collision.

The Watch One concept has attracted much attention in the past few decades. A brief review of the concept concluded that, at present, the available studies provide inconclusive evidence of the safety of the Watch One concept.

Based on the outline of the working environment of the ship's bridge a descriptive memory aid for human factors (SHELL) was examined and it was suggested that it could be adapted for use in the marine environment. To this end, it showed how the organisational framework is divided into two parts (a) the Physical environment of the Ship's Bridge and (b) the Navigational System of the Ship's Bridge (figure 16, page 84). It is suggested that this modified SHELL diagram illustrates better the role of the human element in the working environment, thus providing an improved model for future studies into human factors on the ship's bridge.

Human factors relevant to the working environment were then outlined in Chapter 4, i.e., the design of hardware and related information processing, learning processes, maritime education and training and communication.

Communication is a complex issue and safe communication at sea is often assumed to be primarily by using the same mother tongue between crew members. This assumption was considered too simplistic and consequently the term communication was explained in more detail. It is expected that this will provide a useful framework for all aspects of communication at sea.

Health related factors may influence the behaviour of the navigating officer and increase the risk of a collision or grounding. Fatigue and boredom were considered to have the greatest impact and were examined in more detail in Chapter 4.

8.3 The development of the marine human factors classification system

Navigation is human voluntary activity and thus subject to 'human error'. It is not assumed that all 'human errors' can be eliminated but that, by moving away from a blame seeking strategy, additional detail from readily available data sources can be obtained.

Consequently a pre-classified database, DAMA, was analysed and this analysis suggested that the broad coding scheme provided only limited information on specific human factors on the ship's bridge (referred to in Chapter 5). Nevertheless, the figures show that the human element has been attributed as a cause in the majority of the accidents. Factors such as fatigue or long working hours (see table 21, G13- Special circumstances) may be difficult to recognise and the figures may thus not have been appropriately categorised. This is likely to add to the difficulty examining the pre-classified database.

Accident reports were expected to provide more detailed information on collisions and groundings. Official accident reports were obtained from several different countries (see table 15, page 127) to afford a better representation of worldwide shipping e.g., trading patterns

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and ship/cargo types. The analysis of the reports concluded that they provided a balanced collection of a variety of geographic conditions, e.g., restricted waters.

The important concept to emerge from this research is the three-layer classification system, i.e., the human factors classification system using the 'Catalyst' concept, as opposed to the broader classification systems generally used previously (see e.g., table 17, page 134). The third layer has the potential to reveal more information from existing data sources, thus providing more detail on accident and incident analysis. This was confirmed by applying the system to two brief cases studies, the groundings of the *Exxon Valdez* and the *Sea Empress*.

It is anticipated that the increased knowledge offered by the marine human factors classification system presented in this study, will assist people, individually or collectively, in assuming their responsibility in managing safety at sea. In addition this research provides a basis for increasing human factors awareness among those affected by accidents at sea, including seafarers, designers, engineers, legislators, accountants, ship managers, the public and media.

The proposed marine human factor's classification system is based on designating problem areas on the ship's bridge as 'Catalysts'. These were defined as factors in chains of events that may provide a pathway for a collision or grounding. The process of developing this system from accident reports was explained in Chapter 5. The 'Catalysts' were initially grouped within 16 'Catalyst' Types. These were then grouped within five 'Catalyst' Groups forming a simple framework for human factors on the ship's bridge (table 23, page 145 and figure 23, page 154). It is expected that this marine human factors' classification system can be used in the analysis of:

1. A broad worldwide sample of accident or voluntary Incident Reports (e.g., as in this research), and;

2. A specific sample limited by a geographic area or restricted by a specific time limit, e.g., accidents investigated by a specific organisation;

3. To classify voluntary incident reports (MARS reports). This would provide the following:

a) An alternative and additional human factors data source that can be used to compare and contrast with data collected from other sources;

b) It assures the active navigating officer that he makes a valuable contribution to human factors research thus affording him an incentive to continue doing so.

The data was presented in a tabular form and intended to be viewed as descriptive, rather than analytical, i.e., to show patterns of 'Catalysts' (see Chapter 6). Until more data is available, it is considered that a visual representation is likely to provide a more useful perspective of the role of the human element in the navigational system.

A questionnaire was developed to improve the understanding of the working environment of the ship's bridge. The number of returned survey results was not sufficient to provide a representative sample of navigating officers and ship/cargo types engaged in worldwide trade. The results as shown in tabular form, nevertheless, provide additional background information to offer an improved representation of the working environment on the ship's bridge. For example, in view of expected future changes in the marine environment, e.g., increasing number of High Speed Ships, it is particularly important that ship/cargo types and trading patterns are considered during the development stage of the projects.

To this end it is suggested that the sections from the questionnaire requesting Personal and Ship details can be used as a format for standardising future studies (see Appendix D). A combination of, for example Type of Ship/Type of Cargo/Trading area would allow future studies to be compared and possible trends noted. In addition, the ability to cross reference with details such as linguistic proficiency and time spent on the ship may allow studies to be analysed in a more effective manner.

The four data sources discussed previously were examined individually using a non blame seeking strategy. It is suggested that this strategy provided an improved basis for collecting additional human factors information from readily available data sources. In addition, the accident and MARS reports were coded using a similar approach. Tables 30 to 34 show that this was a sound choice, e.g., 'Catalyst' C6 in table 32 confirms that agreeing a manoeuvre by VHF may not have the intended result. It demonstrates that the MARS data when coded appropriately can provide additional information.

Although the marine human factors classification system proposed here has not been verified independently, it would appear justified to assume that, together with the DAMA and questionnaire data, it could contribute toward a valid representation of the mariner's working environment.

8.4 Practical value of the Marine Human Factors Classification System

The detail provided by the 'Catalysts' is expected to encourage those responsible for safety at sea to employ foresight rather than wait for the accident to occur. Reason (1990a) noted that when an accident occurs human involvement is evident on many other levels, including during the design and manufacture of bridge equipment, training, inspections and the development of rules and regulations (see figure 4, page 9). The role of human factors in safe navigation is thus as much the concern of the organisational framework, as it is an individual responsibility.

It is expected that each decision making level will benefit from the detail provided by the proposed marine human factors' classification system. For example, on the highest level of decision making, the awareness of an increased risk of 'human error' due to poor user-interfaces and manuals would allow IMO to develop, in addition to technical standards, human factors standards for user-interfaces and manuals. On the lowest level, the navigating officer could be advised of common unsafe acts which increase the risk of collision or grounding, e.g., if the radar has a blind sector and the officer may not see the other vessel in time (E9); failing to plot course/speed of the other vessel could result in a collision (E8) etc. (table 34, page 162)

By adopting a similar systematic approach to examining accident reports, the principle of the marine human factors' classification system could be used to analyse accidents in other working environments, e.g., personal injury on the ship.

It must be recognised that there is more than one definitive strategy to preventing collisions and groundings at sea. There is not expected to be a single best recommendation, nor a single dominant dimension on which to focus. The key to preventing collisions and groundings is to understand the theory and limitations of the individual components and how they interact within the entire navigational system on the ship's bridge.

8.5 The future of human factors in the marine environment

International shipping is characterised by the notion of the freedom of the high seas and a regulatory framework based primarily on Conventions and Resolutions adopted by the IMO. Since IMO has no enforcing powers, implementation and administration is through national legislation introduced by the Member States. In essence, this means that a ship can operate legally to a different standard depending on where she is registered. The organisational framework thus creates a critical financial climate through fierce competition. However, a sound financial basis is essential to improve safety at sea.

The Member States can play a significant part in administering a safe environment for ships, e.g., funding provided by the governments is important. For example, the National Oceanographic and Atmospheric Administration (NOAA) provides the data for accurate and up-to-date information on US waters but their funding has decreased in recent years (American Association of Port Authorities, 1999). On the other hand, the USCG is expected to introduce new regulations that would provide tangible benefits, e.g., reduced Port State inspections to ships expected to have few defects (Shuker, 1999). Such a policy would provide actual economic benefits to quality owners and would reduce costs by reducing the number of inspections on ships that pose little threat to U.S. waters.

The importance of human factors has been recognised in the marine environment but has not attracted the widespread attention that it has in other industries, particularly in aviation. Research and accident investigations in the marine environment often result in exclusive and restricted reports with limited or no access for the public.

At present the sharing of knowledge and information is limited within the operational shipping community. Nevertheless, several maritime administrations, notably Australia, Canada and the United States of America, already provide public access to information (e.g., complete accident reports) through their web sites. The use of the Internet is expected to increase, and eventually other maritime administrations and organisations may provide similar services to the shipping community worldwide. It is also expected that the navigating officer, when not at sea, will gradually have better access to the Internet (e.g., through public libraries, etc.). This would provide him with a tool that would allow him to obtain up-to-date information (e.g., voluntary incident reports or changes in rules and regulations).

It is anticipated that this research will provide a stimulus for the industry to focus on human factors on the ship's bridge. However, to achieve this, the entire community, i.e., the private and the public sectors, must accept responsibility and encourage open access to information relating to human factors.

8.6 Recommendations for further work

Human factors' research into accidents at sea has something of a 'Cinderella' status. In the same way 'Cinderella' did not get a new gown for the ball, funds have predominantly been granted for research into engineering/design and organisational/regulatory aspects of safety at sea (e.g., *Estonia*, *Herald of Free Enterpris*). Funding has been lacking perhaps because the results of human factors' research generally benefit the maritime community at large, rather than a particular company or organisation.

The present lack of a standard human factor's terminology in the marine environment limits the possibility of comparing different studies (e.g., analysis of accident investigations). It is concluded that limited progress in understanding human factors will be made until the shipping community:

- Focuses on standardisation and harmonisation of human factors/error terminology.
- Makes an effort to coordinate human factors research within the international research community. The added benefit is a reduction of duplication and cost of studies.

The research presented in this thesis provides a framework for standardising elements of human factors research. This would ensure that future research can be effectively compared. It is expected that further research will improve the framework presented here. The following suggestions are offered as topics for further research, but are deemed beyond the scope of the current investigation:

(1) Following from current research based on the questionnaire, investigate further problems associated with user-interfaces on ships' bridges (i.e., questions 1-3, Appendix D).

Additionally officers should be encouraged to notify specific details on poor design through the Internet. This could be modelled on the web site for "Bad Human Factors Designs" (http://www.baddesigns.com/). This site provides specific examples of poor designs which can assist equipment manufacturers to develop better user-centered interfaces.

(2) It is apparent that most ships carry the required manuals of various bridge aids that are installed onboard the ship's bridge. This research confirms that poorly designed manuals may (a) increase the risk of accidents because the officer did not know how to use the equipment correctly, and (b) lessen the officer's ability to recover from a known situation thus increasing the risk of collision or grounding. It is suggested that task analysis could provide a basis for developing a basic model for operating manuals, separating them from service, technical and functional operations manuals.

(3) Although Radar/ARPA and collision avoidance have attracted research (see Appendix B) there has been limited focus on the role of the navigating officer. The Radar/ARPA can be operated in three course headings and three modes resulting in different images on the radar screen (see Chapter 6, see also figures 25, page 178 and 26, page 179). It is suggested that additional research be carried out to establish how the navigating officer's interpretation is influenced by the different settings of the equipment. The background of the officer is considered important as his preference may depend on his initial training, e.g., if he learned to use North Up then he is more likely to continue doing so. It is also important to include Personal and Ship details, as referred to previously, so that cross referring may be carried out if necessary.

(4) Following from the research presented here, it would appear logical to develop a model for validating ships' bridges (traditional and Watch One) using appropriate human factors' research techniques to reduce risk of accident resulting from poor bridge layout and user-interfaces.

(5) The role of alarms and failure mode analysis was determined primarily through personal observation during ship visits. These were later confirmed through informal discussions. As a result a brief review of existing literature on alarm research was conducted (Appendix C). It shows that, as yet, no general research has been carried out on alarms on the ship's bridge unlike in the aviation, medical and other industries. It is suggested that accident investigators should attempt to note the possible role of alarms in individual accidents. During analysis of the accident, alarm related 'Catalysts' could be included within the alternative classification system under Engineering/Design by providing a new

heading. Additionally it is recommended that the following research is carried out without delay:

- Determine the minimum number of alarms on ships' bridges. This is expected to vary depending on ship/cargo type and type of bridge.
- Determine the function, i.e., emergency, primary or secondary, of alarms on ships' bridges.
- Determine the effectiveness of each alarm type on board ships' bridges, e.g., does the operator detect the warning, does he interpret the warning correctly, and does he take appropriate action.

8.7 Contribution to the marine environment

This research focused on collisions and groundings at sea, examining existing literature on human factors, safety at sea and accident and incident reports. This resulted in the development of a marine human factors classification system that provides a third layer of detail as opposed to conventional classification systems. A combination of different techniques, including analysis of accident and voluntary incident reports, a pre-classified data base, a questionnaire and personal observation provided the basis for developing this system.

The primary contribution of this research was to:

(1) Provide the shipping industry with a marine human factors classification system for the analysis of accident and voluntary incident reports (e.g., MARS). By standardising the classification of human factors on the ship's bridge it is expected that future studies could be more easily compared and, ultimately, the effectiveness of preventive measures evaluated.

(2) Establish individual 'Catalysts' which show detailed information of problem areas on the ship's bridge. These would provide a basis for developing specific research strategies for determining preventative measures.

(3) Provide a framework for the standardisation of collecting Personal/Ship details. This would assist in the comparison of future studies.

Additionally this research provides a convenient practical guide to (a) the working environment of the ship's bridge, and (b) different aspects of communication in the marine environment. This is expected to assist in future human factors' research.

The overall contribution of this research is to increase the awareness of specific human factors on the ship's bridge.

APPENDIX A

A GENERAL CLASSIFICATION SCHEME OR TAXONOMY OF DIFFERENT HUMAN FACTORS' METHODOLOGIES (Wilson and Corlett, 1990).

This table provides a frame of reference for all the methods used in the evaluation of research into human factors.

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

	Method			
Approach	Group	Subgroup	Technique	Measure/Outcome
Collection of information from/about people	Direct observation (laboratory or field)	Unobtrusive, participative, or visible	Human recording: checklists, rating, ranking, critical incident technique, charts (time, spatial, sequence, link)	Event frequency, sequence, Times, errors, accuracy, Overload, underload Descriptive, evaluative, diagnostic, measures of performance
			Hardware recording: video, film, tape, event recorder, *position/movement* recording, computer real time recording	
	Indirect Observation (laboratory or field	Psychometrics/scaling	Surveys, questionnaires, rating, ranking, scaling, diaries, critical incidents, yes-no checklists, group discussions, interviews	Attitudes, feelings; perceived effort, difficulties, advantages, disadvantages, preferences
	Perceptual/Cognitive performance	Ability testing	Mental or cognitive tests (e.g., general aptitude test battery) perceptual tests	Prediction of performance
		Psychophysics	Method of limits, method of average error, method of constant stimuli, e.g., aesthesiometer, hearing loss audiometry	Thresholds and levels of perception, sensitivity
	Knowledge Acquisition	Knowledge elicitation (from expert)	Interviews (structured, unstructured) protocol analysis (verbal, shadowing, behavioural), conceptual mapping, goal decomposition, automatic techniques	'Rules', reasoning, explanation

Continued

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

	Method			
Approach	Group	Subgroup	Technique	Measure/Outcome
		Other	Interpretation of records, standards, guidelines, criteria	
	Physical measurement	Anthropometry (static or dynamic)	Anthropometry, wall charts, video, photography, CODA, fitting trials, computer modelling	Dimensions, percentiles, other descriptive statistics
Collection of information from/about people	Physical measurement	bio mechanics	Dynamometer, strength gauges, goniometer	Values, descriptive statistics
		Performance	Eye movements, acuity	
	Physiological measurements		ECG, EEG, EMG, ERP, O_2 Uptake, GSR pupil diameter, etc.	
	Models	Computer, mechanical, conceptual, mathematical		
Evaluation of human-machine system- performance or consequence (actual or potential)	Task Analysis (TA)		Hierarchal TA, tabular TA, ability requirements analysis, TA for knowledge description, link analysis, cognitive TA, formal mappings (e.g., TAG), job analysis charts	Consequence of task, task sequences, times, probable error rates
	Archives, databases, published information		Production, activity, quality control or personnel records, standards, guidelines, etc.	Output, times, quality, etc. Absenteeism, labour turnover, health data
	Interface evaluation	User trials	Techniques of direct and indirect observation, and physical performance measurement-individual or groups	Time, reaction times Accuracy, errors Opinions, attitudes, responses Physical fit Workload, stress

Continued

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

Approach	Method			Measure/Outcome
	Group	Subgroup	Technique	
		User models, formal mapping	GOMS, CLG, TAG, etc.	
		Expert analysis	Walkthrough, checklists	
		Prototyping	Rapid prototyping, story boarding	
		Introspection	Techniques for protocol analysis	
		Evaluation environment	CAFÉ OF EVE	
Evaluation of human-machine system- performance or consequence (actual or potential)	Electronic monitoring		On-line (performance) record, gripe button	
	Work system analysis	All		
	Text Analysis		Readability formulae (Gunning, Fog, Flesh, etc.), cloze procedures; judgements (rate/rank, etc.), protocol analysis; scan/read tests	Normative scores. ratings
	Models	Task network (SAINT, Siegel-Wolf, etc.), control theoretic, micro process (HOS, etc), cognitive (GOMS, etc.)		Performance predictions
	Simulation	Mathematical, computer, including CAD (e.g., SAMMIE), Physical mock-up, walkthrough		
	Human Reliability Analysis	Error Analysis	SHERPA, GEMS, PHECA, etc.,	Errors, type, causes,
		Representation	Fault tree, action trees, etc.,	Descriptive and predictive charts,
		Quantification	THERP, HEART, SLIM, etc.	Human error probabilities
	Statistical Analysis		Signal Detection Theory	Performance measure

Continued

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

	Method			
Approach	Group	Subgroup	Technique	Measure/Outcome
	Method Study		Graphical analysis, charts, filming, micro motion, etc.	
	Accident Reporting and analyses		Archive records, reporting system, in-depth follow up interviews, site analysis, statistical analysis	Incidence, severity, epidemiology and aetiology
	Work measurement		Time study, activity analysis, synthetic analysis, electronic monitoring	Times, standards, task sequence and simultaneity
Evaluation of human-machine system- performance or consequence (actual or potential)	Cost-benefit analysis		Investment returns, productivity-life cost, revenue calculation; health and safety valuations	Financial return
	Textual analysis		Parsing, etc.	
	Self recording		Gripe button, diary, event recorder	Problems, incidents
Analysis of work activity demand	Introspection (+ protocol analysis)	Concurrent and retrospective	Hardware recording, debriefing, written record, diary, critical incidents, shadowing	Explicit content, implicit content, behaviour transitions, rules, knowledge
	Expert Analysis		*Checklist; walkthrough, Delphi, etc. method study* techniques, expert systems	
	Archives, data base		Medical records, accident records	Incidence, severity, risk factors

Continued

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

	Method			
Approach	Group	Subgroup	Technique	Measure/Outcome
	Physical workload		Indirect observation, e.g., Borg scale, Performance records, secondary or alternative tasks of psychomotor performance, physical changes (e.g., shrinkometer)	Subjective ratings Performance decrement, etc.
	Posture analysis		Biomechanical (mathematical) models; optical methods (CODA, Selspot); paper and pencil (posture target, body part discomfort)	'Postures' to compare with criteria Opinions of discomfort, etc.
	Physiological	Measurement of fatigue, stress, function, etc.	HR, HR variability, O_2 uptake, air analysis, GSR, ECG, EMG, EEG, ERP	Objective data, to be interpreted against norms, criteria
	Mental workload measurement		Primary, secondary, alternative task, Subjective assessment (e.g., SWAT), physiological response	'Performance' decrement, Load (subjective or objective)
Analysis of work activity demand	Stress assessment		GSR, etc., indirect observation techniques (SACL, GWBQ, etc.)	
	Job and work attitude measurement		Techniques of indirect observation, especially rating scales, e.g., JDS, WLAS, etc.; informal group or individual interviews	Satisfaction, needs, important job characteristics
Physical environment assessment	Measurement by instrumentation		Light (illumination, glare, etc.), climate (temperature, humidity, air space, etc.), noise (sound intensity-weighted), vibration, workplace dimensions	measurements versus norms, comparisons

Continued

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

	Method			
Approach	Group	Subgroup	Technique	Measure/Outcome
	Subjective assessment		Psychophysical techniques, scaling, rating, surveys, etc.	Comfort, annoyance, acceptability
	Performance measures		Speech intelligigility index, work-rate, standard psychomotor and mental tests, etc.	'Scores'
	Modelling and simulation		Computer (e.g., SAMMIE), mechanical (manikins), mathematical	
	Response measures		Sweat rate, body temperature, heart rate, etc., hearing loss, etc.; visual acuity, contrast sensitivity, etc.; sensation loss (vibration), shrinkometer	Measurements versus norms Comparisons
	Archives, medical and accident records			Sickness, absence, injuries
Organisational environment assessment	Organisational analysis			
	Indirect observation		Rating, ranking, etc.; group participative methods	Attitudes, opinions, etc., 'Improvements'
Design and implementation	User tests		Direct and indirect observation	
	Expert analysis		Walkthroughs, audit	
	Creative techniques		Brainstorming, decision groups, focus groups	
	Participative methods		Design and follow-up groups, user representation involvement; 'education' in ergonomics	

Continued

General taxonomy of different human factors' methodologies (Wilson & Corlett 1990)

	Method			
Approach	Group	Subgroup	Technique	Measure/Outcome
	Evaluation environment		CAFÉ OF EVE	
Process promotion and dissemination	'Literature'			
	Participative methods		Ergonomic working groups, etc.; training	
	Cost-benefit analysis		Investment returns, health and safety valuations	

APPENDIX B

STUDIES, ETC ON HUMAN FACTORS WHICH MAY BE APPLICABLE TO THE MARINE ENVIRONMENT

Appendix B shows a summary of available literature in table format (referred to in Chapter 2). Entries refer in one direction to the aim of the study and in the other direction to the methods used. The numbers in the cells refer to the list of references which have been divided roughly into three categories: (1) Research carried out predominantly in the shipping industry (shown in **bold**), (2) Research into human factors in the aviation industry (shown in *italics*) and (3) General research into human factors (shown in normal font).

Studies, etc on human factors which may be applicable to the marine environment

MEANS / ENDS	POST ACC. INVESTIGATION	PERSONAL OBESRVATION	PERSONAL LOGS, ETC	LAB & SIMULATOR STUDIES	OBSERVATION OF VTS TRAFFIC	CONTROLLED EXPERIMENTS	MATHEMATICAL MODELS	SURVEYS / INTERVIEWS	PHYSIOLOGICAL DATA	MISC
NAVIGATION	1, 2, 3			4, 5, 6, 7, 8						
OMBO/W1		9		7				10		
FATIGUE			*11, 12*	13, 14		*11*, 13, 14			*12*	
VISUAL FACTORS				15		*16*, 17				
RADAR/ARPA	18			5, 19						
ECDIS				20, 21				20		22
BIBLIOGRAPHIES, SUMMARIES, REVIEWS	23, 24, 25, 26								27, 28	29, *30*, 31, 32
HUMAN ERROR	23, 24, 33, 34, 35, 36, 37, 38	39		37, 40		41, 42				
HUMAN FACTORS	33, 34, 43	43		4, 19, 21, 44, *45*, 46	47	41, 48, 49, 50, 51, 52		53, *43*		54, 55, 56
VTS				57,	59,					
COLLISION AVOIDANCE	3, 18, 25, 58, 59, 60			5, 6, 20, 44, 61, 62, 63, 64, 65, 66			61, 64, 67, 67, 68, 69, 70	65,		57, 71
WORK LOAD				*45*, 21				72, 73		
TRAINING				47, 74, 75, 76, 77				78		
USER INTERFACE				47, 79		80, 81, 82		55, 83, *84*		

KEY: BOLD = Shipping *ITALICS* = Aviation NORMAL = Other

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APPENDIX C

ALARM STUDIES

ALARM STUDIES

This Appendix provides a brief literature review relating to existing alarm studies (referred to in Chapter 4). These studies refer only to this table and are grouped according to their main subject area.

MAIN SUBJECT AREA	STUDY
Auditory Warning	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Voice Warning	14, 15
Text Warning	16
Urgency Scaling	8, 17, 18
Alarm Information/Handling	19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33
Alarm Systems	34, 35, 36, 37, 38, 39

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APPENDIX D

SURVEY INTO HUMAN FACTORS RELATING TO NAVIGATION

Survey into Human Factors Relating to Navigation

ALL RESPONSES WILL BE TREATED IN STRICTEST CONFIDENCE

NOTES TO RESPONDENTS

- Please try to answer all questions as clearly as possible.
- Please give as complete details as possible, including name of ship and other details which assist in distinguishing one incident from another. Please include any sketches and/or photographs which may be helpful to illustrate the problem.
- It is always difficult to estimate the space needed to answer some of the questions and therefore there may be at times too little space allocated. Please feel free to continue using additional sheets referring to the Question Number to enable you to give as complete details as possible.

* * * * * * * *

PERSONAL DETAILS

Name ____________________ Age ________

Rank ____________________ Watchkeeping Experience _____ Years _____ Months

Nationality ____________________ Mother Tongue(s) ____________________

____

____

Which other languages do you speak fluently ____________________

At which nautical colleage(s) did you undertake your main training (name and country)

____

____

____

____

DETAILS OF YOUR CURRENT SHIP

Name of Current Ship ____________ Port of Registry ____________

Type of Ship ____________ Type of Cargo ____________

LOA ________ m/feet Beam ________ m/feet Gross Tonnage ________ GRT

Trading Area/Route ____________

How long have you been on your present ship? ______ Years ______ Months

Total number of crew ________

Number of Navigating Officers, excluding the Master ________

What languages do the crew members speak as their mother tongues?

No of Crew Members	Language

MAN-MACHINE INTERFACE

Q 1 Would you please describe in detail **any error** that you have made on any ship in the previous 12 months in **reading or interpreting** any bridge equipment (GPS, Radar, ARPA, etc,) or describe such an error made by another navigating officer whom you were watching at the time.

Type of equipment ____________

Was the error made by YOURSELF ☐
OTHER PERSON ☐

Approximate number of times this particular error has been observed ____ times

Further details ______________________________

____

____

____

____

____

____

____

____

Q 2 Would you please describe in detail **any error** that you have made on any ship in the previous 12 months **operating any bridge equipment** (GPS, Radar, ARPA, etc.) or describe such an error made by another person whom you were watching at the time.

Type of equipment ______________________________

Was the error made by YOURSELF ☐
OTHER PERSON ☐

Approximate number of times this particular error has been observed ______ times

Further details ______________________________

____

____

____

____

____

____

____

____

____

Q 3 Would you please describe in detail **any error** that was made by yourself on any ship in the previous 12 months which was **caused by any language difficulties.**

Language(s) involved ______________________________

Was the error made by YOURSELF ☐
OTHER PERSON ☐

Further details ______________________________

____

____

____

____

____

____

____

EQUIPMENT FAILURE/MANUALS

Q4 Would you please describe in detail a **failure of any bridge equipment** (GPS, Radar, ARPA, etc.) on any ship in the previous 12 months

Type of equipment? ______________________________

How did it fail? ______________________________

Was it repaired during the voyage? YES ☐
NO ☐

What reversion mode did you use?______________________________

____

____

____

____

Q 5 Do you have **sufficient information** on your present ship detailing the **operation** of all bridge equipment?

YES ☐
NO ☐

If NO, what other information would you like to have? ______________________________

____

____

____

____

Q 6 Do you fully **understand the manuals** relating to the bridge equipment on your present ship?

YES ☐
NO ☐

If NO, please describe any problems it may have caused? ____________________

____

____

____

____

Q 7 Have you had to **consult any manual(s)** to enable you to operate any of the bridge equipment on your present ship?

YES ☐
NO ☐

If YES, name the equipment (type/manufacturer/model) ____________________

____

If YES, did you find the manuals easy to use? YES ☐
NO ☐
N/A ☐

If NO in what way do you think that they could be made easier to use? ____________________

____

____

____

Q 8 Have you, or any other crew member, made up **specific memory aids** in response to an error which occurred on the bridge (i.e. written notes, check lists, etc.)

YES ☐
NO ☐

If YES, please give details ____________________

____

____

____

____

____

ACCIDENT REPORTING/NAUTICAL PUBLICATIONS

Q 9 Have you heard about the **Marine Accident Reporting System** (MARS - published in Seaways)?

YES ☐
NO ☐

If YES, have you ever sent a report to MARS?

YES ☐
NO ☐

Q 10 Do you think navigating officers should be **encouraged to send in confidential reports** of near-misses and other problems?

YES ☐
NO ☐

Q 11 Which nautical publication(s) do you have regular access to

Journal	Country of publication
________________	____________________________
________________	____________________________
________________	____________________________
________________	____________________________

TRAINING

Q 12 Have you undertaken any training using a simulator? YES ☐
NO ☐

If NO, would you like to undertake training using a simulator? YES ☐
NO ☐

If YES please give details (type of course, where and when)____________________

____

____

How well do you think that elements of the simulator course transferred to a real world situation ______________________________

____

____

Q 13 Which aspects of navigation training do you believe a **simulator can be best used for?**

____

____

____

____

Q 14 Which aspects of navigation training do you believe **cannot be substituted using a simulator?**__________________________________

____

____

____

____

____

____

Q 15 How often do you think that a simulator refresher course in collision avoidance should be undertaken?

Once a year ☐
Every 2 years ☐
Every 3 years ☐
Every 4 years ☐
Other ☐
No need ☐

How long should such a course be?
2 days ☐
3 days ☐
4 days ☐
5 days ☐
Other ______________

RADAR/ARPA

Q 16 In which course heading do you prefer to use the Radar/ARPA?

True North Up ☐
Course Up ☐
Ship's Head Up ☐

Why do you prefer this particular heading?____

____

____

____

Q 17 In which mode do you normally use the Radar/ARPA?

Sea Stabilized mode ☐
Ground Stabilized mode ☐

Why do you prefer this particular mode? ____

____

____

____

____

WATCH ONE/OMBO

Since IMO granted dispensation to conduct trials during which the Officer of the Navigational Watch Acts as the Sole Look-Out During Periods of Darkness in July 1991 many ships' bridges were designed or adapted to conform to the guidelines specified by the IMO. Since then IMO has terminated the trials but there is sufficient evidence that some ships still operate according to the trial guidelines.

It is an issue which has caused a lot of controversy in the shipping industry with views both for and against. To enable more research to be carried out into the safety aspects of this concept it is essential to find out how common the practice is at present.

* * * * * * * *

Is your present ship designed as/classified for Watch One/OMBO (allowing the navigating officer to act as the sole look-out in periods of darkness)?

YES ☐
NO ☐

Is it operated as Watch One/OMBO?

YES ☐

NO ☐

DO NOT WANT TO ANSWER ☐

If YES, how often? Regularly ☐
Occasonally ☐

Finally, please feel free to make any other comments which may be of relevance to any aspects of the prevention of collisions, groundings or near-misses.

Many thanks for your assistance with completing the questionnaire.

Would you please return the completed questionnaire, including any additional sheets, sketches, photographs to:

PRIVATE AND CONFIDENTIAL
M-B Moreton
Centre for Maritime and Offshore Operations
Liverpool John Moores University
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GLOSSARY

of more frequently used acronyms, abbreviations and terminology

Abaft the beam	Any bearing or direction between the beam of a ship and her stern
Able Seaman	A man able to perform all the duties of a seaman on board a ship
AIS	Automatic Identification System Transponder
Allision	Contact with a stationary object, e.g., a bridge
ARPA	Automatic Radar Plotting Aid
BRM	Bridge Resource Management
Cable	About one-tenth of a nautical mile
Classification Society	Organisation authorised to determine the seaworthiness of a ship by a survey based on her construction and the size (scantlings) of the materials used in her building.
COLREGS 72	International Regulations for Preventing Collisions at Sea 1972
CRM	Cockpit Resource Management
DAMA	Databank for Sikring af Maritime Operasjoner is a database developed in Norway for the reporting and compiling data on accidents at sea jointly with the other Nordic countries
DECCA	Medium frequency continuous-wave radio navigation system used for precise positioning within short range of transmitters
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
DR	Dead Reckoning, a position obtained by applying courses and distances made through the water from the last observed position
ECDIS	Electronic Chart Display Information System
EPIRB	Emergency Position Indicating Radio Beacon
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
FOC	Flag of Convenience
GEMS	Generic Error Modelling System
GLONASS	Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
GRT	Gross Registered Tonnes is the total of all the enclosed spaces within a ship, expressed in tons each of which is the equivalent of one hundred cubic feet
GT	Gross Tonnage, adopted by the International Tonnage Convention (1969), is the total of all internal spaces of a ship measured in cubic metres
HEI	Human Error Identification Technique
IACS	International Association of Classification Societies
IBS	Integrated Bridge System

IFSMA	International Federation of Ships Masters Association
ILO	International Labour Organisation
IMO	International Maritime Organization
Inmarsat	International Marine Satellite Organisation
ISM Code	International Safety Management Code
ITF	International Transport Workers Federation
Leading Lights	Lights set up on shore which, when brought into line with one another leads the ship along a marked channel
MARS	International Marine Accident Reporting Scheme
MOU	Memorandum of Understanding (often referred to as PSC)
NASA	National Aeronautics and Space Administration
NI	Nautical Institute
NIS	Norwegian International Shipping Registry
NOAA	National Oceanographic and Atmospheric Administration
NRT	Net Registered Tonnage is the total of all enclosed spaces within a ship available for cargo, expressed in tons each of which is equivalent to one hundred cubic feet
NT	Net Tonnage, adopted by the International Tonnage Convention (1969), is the total of all cargo compartments measured in cubic metres
NTSB	National Transportation Safety Board US
OMBO	One-Man-On-Bridge Opearation, a.k.a., Watch One
OOW	Officer of Watch
P & I Club	Protection and Indemnity Club
Plimsoll Line	A mark painted on the side of the ship indicating the draught levels to which the ship may be loaded for varying conditions of season and location. These were made compulsory in Britain under the conditions of the Merchant Shipping Act 1876 passed after a decade of parliamentary struggle conducted by Samuel Plimsoll.
Point	A division of the circumference of the compass card which is divided into 32 points, each of 11 ¼ degrees of arc. 2 points are 22 ½ degrees.
PSC	Port State Control
SAR	Search and Rescue
SHELL	Software, Hardware, Environment and Liveware represents the components with which human factors on the flight deck can be addressed
Sister Ship	Two or more vessels which are under the same beneficial ownership, therefore not necessarily identical (Hill 1989)
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention for Standards of Training, Certification and Watchkeeping
TSD	Total Sleep Deprivation
TSS	Traffic Separation Scheme
USCG	United States Coast Guard
VHF	Very High Frequency radio
VLCC	Very Large Crude Carrier

VTC/VTS	Vessel Traffic Centre/Service/System
Watch One/W1	Denotes an officer of watch acting as sole lookout during the hours of darkness (see IMO Circ. 566)

USEFUL WEB SITES

Federal Aviation Administration, U.S. = http://www.hf.faa.gov/

Human Factors and Ergonomics Society = http://hfes.org/

International Maritime Organization (IMO), UK = http://www.imo.org

Marine Incident Investigation Unit (MIIU), Australia = http://www.miiu.gov.au

Marine Accident Investigation Branch (MAIB) = http://www.open.gov.uk/maib/maibhome.htm

Maritime Links on the Net = http://w3.ime.net/~drwebb/maritime.html

Maritime and Coastguard Agency (MCA), UK = http://www.mcagency.org.uk/default.htm

NASA Ames Research Center's, U.S.= http://human-factors.arc.nasa.gov/

National Maritime Safety Reporting System (NMSIRS), US = http://www.marad.dot.gov/information/nmsirs

Royal Aeronautical Society UK = http://ourworld.compuserve.com/homepages/loftwork/menu.htm

System Concepts - Ergonomics in Practice = http://www.system-concepts.com/

The Ergonomics Society of the United Kingdom = http://www.ergonomics.org.uk/

The National Transportation Safety Board (NTSB), US = http://www.ntsb.gov

The Nautical Institute (NI), UK = http://www.nautinst.org/

The Royal Institute of Naval Architects (RINA), UK = http://www.rina.org.uk

Transportation Safety Board of Canada (TSB), Canada = http://bst-tsb.gc.ca/

U.S. Coast Guard R&DCenter, U.S. = http://www.rdc.uscg.mil/rdcpages/human_factors.html

U.S. Coast Guard, Prevention Through People (PTP), US = http://www.uscg.mil/hq/g-m/nmc/ptp

VETA (Non-profit Traffic Safety Organisation), Sweden = http://www.veta.se/

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