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Introducing Human Factors Into The Maritime Safety Framework

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Abstract

The paper begins by considering the importance of safety before establishing the role of human factors in accident claims. This situation is not helped by the different interpretations of the key terms used to refer to "safety", "risk", "hazard", the "safety case concept", "formal safety assessment (FSA)", etc. However, a clear understanding of the meaning of each of these terms is essential if advances are to be made in this important subject. The paper then goes on to outline the goal of the provider. Safety and human activities are then examined before a definition of the term safety is provided. A critical review of research studies is then given, followed by discussion of the meaning of the term human factors. The basis of the PAR Principle for use in safety assessment is then given. This principle relates prescriptiveness and responsibility and its application is illustrated by three examples. The key conclusion is that the most viable way of incorporating human factors for examining safety is the collaborative safety assessment approach.

1. Introduction

In recent years a number of maritime accidents involving loss of life and danger to the environment have attracted considerable public attention Examples of the former are the capsize of Ro-Ro passenger ferry *Herald of Free Enterprise* in March 1987 in the North Sea, and of the *Estonia* in the Baltic Sea in September 1994, and these tragedies have once again focused attention on the safety of this class of ship, see [1], [2]. Examples of the latter type of accident include the grounding of the *Exxon Valdez* in Alaska, USA [3], the *Braer* [4] in Shetland in 1993 and the *Sea Empress* at Milford Haven, in Wales [5], in February 1996.

Everyone is in total accord about the fact that such tragic accidents should not be allowed to occur. Views differ, however, as regards the *best* way of dealing with the problem since in practice <u>absolute</u> safety is something which cannot be achieved in any activity involving human beings.

In order to minimize the likelihood of confusion and assist the examination of this important subject, the key terms used are clearly defined wherever possible.

Many suggestions have been made on the causes of these accidents and by far the most significant parameters to be isolated have been human error, poor judgment or violations of accepted procedures. It is indeed generally accepted that human actions contribute to accidents but there is no consensus on the importance of this factor. By far the most meaningful statistics on it have been presented in the publications of the UK P&I Club of Insurers entitled *Analysis of Major Claims*. These reports are published each year and contain details of claims for the preceding five-year period, e.g., the 1992 report gives information for the period 1987 - 1991 - involving 1380 claims valued at US$724 million, see [6]. The results of the analysis are shown in Figure 1, and can be summarized as follows:

- Human error caused 60% of the total number of accidents. (Contributors included deck and engineer officers, crew and pilots, and shore staff),
- Structural and mechanical failure caused 19%,
- Equipment failure caused 11%,
- Other factors caused 10%.

Since human beings are involved in the design, installation and maintenance of structures and equipment it can be stated that they are responsible directly for 60% of all accident claims and indirectly for a further 30%. Data for other periods do not show any significant variation from these percentages.

The importance of human factors is thus evident and soundly based. The need is now for practical solutions to assist ship designers, operators and regulators to minimize their effects. Before a solution can be put forward, however, it is necessary to understand what is meant by the term "human factors" and how it relates to safety. It will then be possible to show the way in which safety assessment can best be done while taking into account the effects of human factors.

2. Scope

The paper will involve the following aspects:

- Consider the goal of ship operators; safety and human activities,
- Review research on human factors,
- Examine the relationship between human factors and safety assessment,
- Propose a new approach and illustrate its application,
- Discuss some of the key issues,
- Draw conclusions.

3. The Provider's Goal

In any marine project or business activity, it is essential to understand what the goal should be. It is also useful to recognize that relationships exist between client and provider, e.g., ship operators provide a service to shippers, but the ship operators are in their turn clients of shipbuilders. In general the goal of the provider can be stated as follows:

> To be competitive in meeting the client's specifications with solutions that are cost-effective at an acceptable level of safety.

This implies that in any project success in achieving the goal depends on meeting four separate sets of criteria simultaneously, i.e., competitiveness, specification, cost-effectiveness and safety. Competitiveness require the supplier to generate the desired level of profit and to meet the quality requirement. It is also dependent on timing, the number of other suppliers involved, and choice. Specification is a description of the product, process or service to be provided. The term *cost-effective* implies value for money and incorporates customer expectation. It is the requirement for an *acceptable level of safety* which calls for special attention, in particular, with regard to its relationship with human factors and practical usage.

4. Safety and Human Activities

The importance of safety is appreciated by everyone but *safety* is a very broad concept and the understandings of its actual meaning tend to vary widely. It would therefore be helpful to have an agreed definition of the term. Typical definitions include:

Freedom from danger	Concise Oxford Dictionary
Not losing money:	Commercial statement.

Questionnaires that were circulated to a wide spectrum of engineers in industry, government departments and educational institutions revealed the following attitudes regarding the main features thought to be most closely associated with safety:

- Many practicing engineers believe safety is a matter of producing a design, project or service that satisfies statutory rules and regulations.
- Operators of ships tend to regard safety as *being able to follow operational procedures*.
- Most academics and researchers think that safety is achieved after a risk analysis of the situation or a reliability study has been carried out.

There is no doubt that safety involves all these factors and many others as well. The definition now adopted by a number of organizations and individuals is the following:

> Safety is a perceived quality which determines to what extent the management, engineering and operation of a system are free from danger to life, property and the environment. [7]

This means that safety is not a one-dimensional quality concerned solely with the outcome of engineering endeavors and decisions, but also involves management and operational aspects. Furthermore, all three aspects are closely associated with human behavior and human interaction with hardware, software, the work environment and the performance culture of an activity. It has to be recognized that it is human beings who determine policies, invest resources, design, maintain and operate systems.

5. Review of Research In Human Factors

It would be helpful to have an appreciation of the research done on human factors in relation to safety in maritime systems and some of the key issues addressed, and this will be considered under three headings, as follows:

5.1 The Terminology Used

There is a general problem relating to the terminology used in this subject and a tendency for people to use one word when their intended meaning is better represented by another term. Such a state of affairs does not help the effective communication of research findings to practitioners and also impedes further research. It is not possible in this paper to examine in detail all the issues that arise but two basic suggestions are given here.

Firstly, before significant terms are used in a report or publication their definition should be given.

Secondly, the critical terms used in a research publication should be listed and explained in a nomenclature section.

With regard to "critical terms", it would be useful to clarify the meaning of the term *risk*. Risk (R) is a function of Consequence (C) and Probability of Occurrence (P) of an event, incident, situation, etc. Thus, when the consequence of the event is extremely serious but the probability of its occurrence is very remote, it does not require a great deal of attention. However, if the probability of occurrence is high, even if the consequence is low, then something must be done about the matter. This is particularly relevant in cases involving human activities. It should be noted that when the consequence of failure is not acceptable, as with the operation of an aircraft (i.e., $C = 1$) then "risk" is equal to "probability of occurrence".

A specific cause of confusion is the use of the word *risk* in place of *hazard*.

There is also general confusion in some publications at present in the understanding and use of the term *safety case concept*,the assessment method called *Formal Safety Assessment*, and the UK Marine Safety Agency's proposal in 1993 to the International Maritime Organization for improving the development of statutory regulations called *FSA* (or Formal Safety Assessment.)

5.2 Research Done in the USA

In the USA, maritime-related research in this area is being actively carried out by members of the team led by Professor Bea of the University of California and their colleagues. Typical examples of their publications can be found in [8] to [11]. These studies addressed matters such as the classification of human and organization errors, system failures, and quality and reliability issues. Reports of theoretical work are supported by practical examples of how the techniques can be applied in practice to both offshore installations and ships. These studies have been very valuable in assisting the profession to acquire a better understanding of the importance of human factors in system failure situations, as opposed to purely technical problems. So far, however, they have not managed to integrate human factors with safety so that a practical methodology is developed. Other studies of interest have been published by Pate-Cornell [12].

5.3 Research Done in Europe

In Europe research studies have been performed both by individuals working closely with industrial companies and by researchers in funded projects. One example of the former is the work of Reason [13] which has provided insights into human error that have been applied in the context of ships and aircraft. Prof. Reason has also applied the results to the study of human-related accidents on offshore installations.

An example of a major funded project is the human factors research supported by the European Commission in 1992 under the Third Framework Program for Transport called EURET. Four major programs were initiated for the period 1992 to 1994. The one that is most relevant to the present paper was called the MASIS program. It was coordinated by Cetena, Italy, and involved four contractors and eight sub-contractors from Italy, Spain, Germany, the UK, France and Greece. The three major emphases were as follows:

- A systematic survey of factors influencing crew performance,
- Data gathering and analysis relating to human factors,
- Methods of improving man-ship interface.

There were twelve tasks covering topics such as:

- Acquiring and analyzing data on work done by crew members on board ship,
- Analyzing behavior of *standard-sized* crews with a view to achieving crew reduction,
- Ergonomics and professional qualifications,
- Effects on crew members of interference factors arising from ship/system,
- Human factors and the psychological and physical efficiency of the crew,
- Cost/benefit analysis of options.

These research studies provided valuable information and better understanding on a number of areas of human factors. The results of some of the tasks have been published by the researchers. For example, at the ISHFOB 95 Conference in Bremen, Germany, in 1995. [14], the following results were reported:

- The impact of new technology on the composition of crews today.
- The cause of human failures in sea accidents.
- Human error analysis and ship system reliability.
- Human factors as the key factors for ship efficiency and ship enhancement.

[15] is a paper reporting the results of research into the effects of vibration and noise on crew performance.

Other sponsored research work has been funded by the UK Engineering and Physical Research Council, and MTD Ltd has supported a study on human factors relating to ship bridge operation via examination of the comparative effects on crew performance of electronic displays versus paper charts.

5.4 Other Studies

It is known that other studies on human factors are taking place but the available publications provide very little insight into what is being examined. In this category can be included: studies on the use of Bridge Resource Management techniques aimed at reducing human error. Courses on these techniques include modules on cultural awareness, communication and briefing, emergencies and leadership [16], ergonomics of bridge design and operation, and the use of simulators to train seafarers in safety-related operations.

6. The Meaning of Human Factors

The term *human factors* is used in many contexts associated with the performance of tasks, in particular when safety is involved. There is, therefore, a need for a definition which can be used in practice. Before one is suggested, however, it would be useful to classify the various interpretations under three main headings, as follows:

6.1 Human Factors as an Ergonomics Discipline

The term *human factors* is used in the USA in relation to human actions and error, but in Europe the study of these is regarded as a discipline under the title *Ergonomics.* Typical definitions are:

- The scientific study of man in his working environment [17]
- The study of people at work and, in particular, their relationship with machines [18].

These studies provide useful insight into the key features being considered but do not indicate ways in which their results could be used in engineering situations.

6.2 Man-Machine Interface

With continuing advance in the application of computers to industrial functions such as flexible manufacturing systems and the use of robots, emphasis has shifted to man-machine interface or MMI. Sometimes the term *human engineering* is used instead of *human factors*. A popular definition is given by Chapanis as quoted in [19], as follows:

> Human factors discovers and applies information about human behavior, abilities, limitations and other characteristics to the design of tools, machines, systems, tasks, jobs and environments for productive, safe, comfortable and effective human use.

Such an understanding will assist practical application, but the emphasis is strongly on information processing.

6.3 Safety-Related Definitions

In the context of safety, the term has been defined by the UK Health and Safety Executive [20] as follows:

> The perceptual, mental and physical capabilities of people and the interaction of individuals with job and working environments, the influence of equipment and system design on human performance and, above all, the organizational characteristics which influence safety related behavior at work.

This is a very comprehensive definition which covers the human being's capabilities, job, and working environment. However, the definition does not make it clear how the various features mentioned can be integrated into a general methodology for practical usage.

7. A Practical Definition of Human Factors

In the light of the discussion in the foregoing section, a definition of human factors for practical use was suggested in 1993 by Kuo [21] and it is as follows:

> Human factors are concerned with the interfacing of a set of personal capabilities and characteristics with a combination of hardware, software, working environment and performance culture in the effective carrying out of a task.

Some of the terms in this definition require explanation:

- <u>Interfacing</u>: This means to match a set of requirements with a set of responses in order to meet an objective while taking into account the opportunities and constraints offered by elements of both sets.
- <u>Personal Capabilities</u>: These include both intellectual and physical capabilities. Intellectual capabilities cover competence, confidence and communication skills. Physical capabilities include health, fitness and human limitations.
- <u>Personal Characteristics</u>: These include such factors as personality, response to stress, attitudes, leadership ability and teamwork quality.
- <u>Performance Culture</u>: This term refers to how individuals have interpreted and put into practice in their work, the philosophy adopted by

the organization and is reflected in their attitude to issues such as quality and safety.

It should be noted that *personal capabilities* can generally be enhanced through the application of *training* which involves developing efficiency in doing a task through practicing proven or new methods. Training can help to reduce errors which are caused by a lack of knowledge or opportunity to practice. Improvements can also be made in communication skill, with particular emphasis on delivery and the interpreting of written forms and non-verbal forms such as body language. *Personal characteristics* on the other hand, have to be treated by other approaches in addition to training. Examples of such additional approaches would be the use of *education* to develop positive attitudes, introducing decision making procedures, generating a safety culture, identifying ways of coping with stress which affects people in different ways.

8. Approach Based on the PAR Principle

In order to combine the understanding of safety with the practical definition of human factors, it is clear that a new, and preferably generalized, approach would be needed to deal with this complex subject. Following examination a number of options such as quality management systems and the International Safety Management (ISM) Code, [22], however, it was possible to derive a generalized approach based on the PAR Principle (Prescriptiveness And Responsibility) for use in a wide range of human activities including those affecting the safety of a system, see Kuo [23].

In the light of analysis of accidents and other human activities, the PAR approach is based on the assumption that the crucial factor in these cases is the *level of responsibility* undertaken by the various parties involved. When this is linked to the *degree of prescriptiveness* and applied to a situation, it is possible to derive assessments that incorporate human factors.

The basis of this approach is explained in the safety context by means of descriptions of prescriptiveness and responsibility. *Prescriptiveness* refers to the amount of restriction applied to a human activity and, in practice, it can be represented by the stringency of specific rules and regulations. At one extreme there is the *formal* zone prescribing what individuals or organizations will and will not be legally permitted to do. A typical example would be the statutory regulations laid down by the Government on the speed limits for ships in certain seaways. At the other extreme is the *informal* zone where desirable requirements to be followed are outlined. A typical example would be the *house rules* or quality management systems which are enforced within a company but do not have legal status.

Responsibility in the present context refers to the obligation taken on by individuals, organizations or government bodies when carrying out specific activities or tasks, or when dealing with practical situations. At one extreme a single party can take on the total responsibility and others will have little or none, while at the other extreme no party carries very much responsibility at all An illustrative example would be the relative responsibilities of parents and young children. In practice, the level of responsibility accepted by an individual, organization or government body will lie somewhere between two extremes.

The PAR approach can best be explained with the aid of the sketch given in Figure 2.

8.1 Zone of Prescriptiveness (Figure 2a)

This shows that prescriptiveness is divided into the three broad zones of informal, collaborative and formal.

8.2 Prescriber's Regime (Figure 2b)

It can be seen that in the formal zone the prescriber has a very high level of responsibility but this decreases rapidly as the degree of prescriptiveness is decreased. The curve drops from the right hand side to the left hand side. It should also be noted that the provider has a very small role to play here.

8.3 Provider's Regime (Figure 2c)

In this case the provider has a very high level of responsibility in the informal zone but this decreases rapidly as the degree of prescriptiveness is increased. The curve drops from the left hand side to the right hand side, which is the exact opposite of its behavior in the Prescriber's Regime. In this situation the prescriber has little involvement in the regime.

8.4 Combined Regime (Figure 2d)

In this case the Prescriber's and Provider's Regimes have been merged to create the Combined Regime. The relevant curve is shown in the diagram together with those for each of the other two regimes. It will be noted that this curve is U-shaped. While this regime is an improvement on either of the other two, being a *compromise*, it is very likely that the different parties' shares of responsibility will be unclear, thus causing confusion.

8.5 Collaborative Regime (Figure 2e)

In order to overcome the drawbacks of the Combined Regime, a Collaborative Regime is proposed. This aims to increase the responsibility of all parties to a level that is As High As Reasonably Practicable i.e., the AHARP level.

The implications of the Collaborative Regime call for attention.

Firstly, when human beings are involved, formal assessments with a high level of responsibility for the prescriber are unlikely to be adhered to all the time unless the provider is actively involved. In the opposite situation, informal assessments are unlikely to be supported until there is greater involvement by the prescriber. Secondly, the drawbacks identified in the previous paragraph can be overcome by the collaborative approach, i.e., the operation should take place in the Collaborative Zone.

9. Practical Application of the PAR Principle

Three examples are used to illustrate the application of the PAR Principle.

<u>EXAMPLE 1: An Everyday Situation</u>
The problem is concerned with arriving at a system of flexible working hours in an office. In this case the total number of hours worked in a week is thirty-five and consideration of the various regimes yields four possible arrangements, as follows:

<u>Prescriber's Regime</u>: Everyone works for five days on a schedule of 0900 hours to 1700 with a one-hour lunch break between 1300 and 1400 hours. This is the traditional approach but it would be very inflexible for some office workers with family commitments.

<u>Provider's Regime</u>: Everyone can select their own schedule so long as the thirty-five hours per week are worked. In theory it is thus possible for someone to come in to the office on Tuesday at 0800 and complete the required thirty-five hours of work for the week by 2400 on Wednesday, with a one-hour break for every five hours worked. Clearly this arrangement is quite undesirable, both because interaction with colleagues would be difficult and because efficiency would decrease during the period worked.

<u>Combined Regime</u>: This regime would demand a five day week of seven hours a day but the staff can come and go in a flexible way so long as each day's time-requirement is met. Thus some people would work between 0700 and 1500 hours with a one-hour break, and others would work from 1400 to 2200 again with a one-hour break. This is a rather more flexible solution than either of the previous two, but its main drawback is again that effective staff interaction staff would be difficult.

<u>Collaborative Regime</u>: In this case the staff have to work for seven hours on each of the five week days and everyone is on-site during the core period of 1000 to 1600 hours. Some might choose to come in at 0800 hours and leave at 1600 and others might arrive at 1000 and leave at 1800. This arrangement provides sufficient flexibility for most purposes while ensuring that everyone is available during the "core" period. Implementation of such a regime would improve working relationships and team spirit, and reduce absenteeism.

<u>EXAMPLE 2: A Maritime Situation</u>
This situation is concerned with the roles of a ship's captain and a pilot when a large tanker is entering a harbor area for the first time to discharge its cargo. The area in question is under a preservation order because of its natural features and great beauty, and extra care must be taken in by every ship making its way to the oil terminal. Application of the various regimes would yield the following results:

<u>Prescriber's Regime</u>: Under this regime the regulations would demand that the pilot has the responsibility for "guiding" the captain who is taking the ship into the harbor. This regime is not adopted, as it involves the captain having very little responsibility.

<u>Provider's Regime</u>: In this situation the captain has total responsibility for the ship while the pilot is there for "comfort" purposes and is not expected to give advice unless it is sought. Thus, the pilot's responsibility is minimal. This is the regime in operation at present.

<u>Combined Regime</u>: To overcome the likelihood of errors occurring, this regime may assign joint responsibility to both captain and pilot so that each party has a duty to consult the other on critical decision. This could be an improvement on the previous two arrangements, provided good communication is developed between the parties concerned.

<u>Collaborative Regime</u>: Under this regime the captain and pilot will jointly consider the assignment before the tanker is allowed to approach the harbor area. The captain will provide data on the handling characteristics of the vessel and the pilot will provide data on the seabed and local weather conditions. Collaborative decisions will be made, e.g., to wait until the weather improves before proceeding into the harbor, or to use two tugs during the tanker's passage to the terminal, to help with maneuvering. It should be borne in mind that both the captain and the pilot will have the support of their organizations and will be in constant contact with their respective offices.

<u>EXAMPLE 3: The Structural Design of High Speed Craft</u>
In this case the task is to devise rules for the structural design of high speed craft (HSC) which will be used by builders after selecting the classification society which will register the vessel.

<u>Prescriber's Regime</u>: The rules will be prepared by the classification society on the basis of its acquired experience of the structural design of conventional ships; i.e., the prescriber has the responsibility. The published rules will be given to the builders to apply, when new designs of HSC are being considered.

Provider's Regime: The builders of HSC may have considerable experience of this type of ship and in this case they would devise an informal set of rules for deriving the thickness of plating and the sizes of stiffener to be used. This regime is a feasible possibility in view of both the present general lack of feedback on experience of HSC, and their wide variety. The responsibility here rests on the provider.

Combined Regime: In this case, in order to improve the structural design of projected HSC, prescribers would consult providers before and during the formulation of construction rules. This consultation could take the form of a Workshop, or an invitation to several builders to comment on the draft rules. The final version would have input from all the interested providers. Thus the sharing of responsibility would overcome the drawbacks of the previous two regimes.

Collaborative Regime: In this regime both prescribers and providers accept that at present there is only a limited amount of feedback available from operational experience of the wide range of HSC designs already in use. In order, therefore, to ensure the best structural design for any projected new HSC, they agree to collaborate in seeking better solutions. This collaboration could take the form of having a set of general rules for the structural design of HSC with flexibility for the providers to come up with alternatives based on operational data. The two parties will also systematically pool their available experience in a database. They will use this information to identify areas where potential structural failures could occur and then establish their risk levels. Structures with high risk levels would be given special attention so that efficient design procedures are devised for practical use. At the same time research into better design methods would be encouraged, or even jointly funded. In this way, responsibility is shared at the AHARP level.

10. Discussion

On the basis of the material presented, three topics deserve some brief consideration, as follows:

10.1 Incorporating Human Factors into Safety Assessment

That safety is a 3-D quality underpinned by human factors is something which must be clearly understood. Unless full weight is given to human behavior, decisions and actions, any solution will be likely to ignore parameters having ninety percent of the total influence on safety. At the same time, incorporating human factors into safety assessment is not a straightforward matter because different circumstances require different solutions. In general, for the reasons demonstrated by the examples in Section 9, it can be said that neither the formal nor the informal approach should be the basis for formulation of a safety assessment. Informal safety assessment leaves too much scope for providers and in highly competitive situations the responsible provider may not recognize the positive aspects of safety. Formal safety assessment does not actively involve the providers, and in the light of the influence of human factors, statutory regulations would not be able to cover the majority of situations effectively.

10.2 The Examples of Application

It was only possible to highlight here three illustrative examples of the application of the PAR Principle. In relation to the first one, it should be noted that the core time concept has already been implemented by a number of organizations adopting "flexitime". They have been using the PAR Principle without necessarily recognizing what it is. In the second example the approach presently in use, i.e., the Provider's Regime, can be shown to have serious weaknesses, such as lack of knowledge of the local scene. While the Combined Regime would be an improvement, there needs to be stronger incentives for the captain and pilot to make joint decisions. In this connection it should be noted that the Cockpit Resources Management (CRM) approach operated by many airlines, actively requires the captain and co-pilot to discuss all the relevant issues before arriving at a joint decision. Careful preparation and joint discussion before any decision is made, will enable the captain of a tanker and the port pilot to ensure a hazard-free arrival at the terminal. The third example shows both the importance and the benefits of having prescriber and provider work together on the structural design of HSC because of the present shortage of feedback on wave loads and the performance of the structure.

10.3 Future Developments

The adaptation of the safety case concept for the offshore industry on the UK continental shelf, as recommended by Lord Cullen following the tragic *Piper Alpha* accident [24], has led a number of people to advocate its adoption by the shipping industry as well. Reference [25] explains what is meant by the safety case concept and draws attention to issues and problems relating to its adoption by the industry, i.e., the vast store of shipping experience available, the international nature of shipping, and the need for the industry to make radical changes in attitude and behavior. There would, however, be merit in devising a collaborative safety case approach which could combine the strength of the safety case concept, maritime experience and the ability to incorporate human factors into safety assessment. Early research in this area by the author's team has produced very encouraging results on the practical feasibility of this approach.

11. Conclusions

The key conclusions to be drawn are:

a) It is essential to understand what is meant by the terms safety and human factors before advances can be made to devise a generalized safety methodology that could incorporate human factors and be applied in practice.

b) It is important to recognize that the human elements, as represented by personal capabilities and personal characteristics, require to be treated differently in safety matters in order to improve their interfaces with hardware, software, the working environment and performance culture.

c) The PAR Principle linked to collaborative safety assessment offers the most logical method of incorporating human factors into safety assessment.

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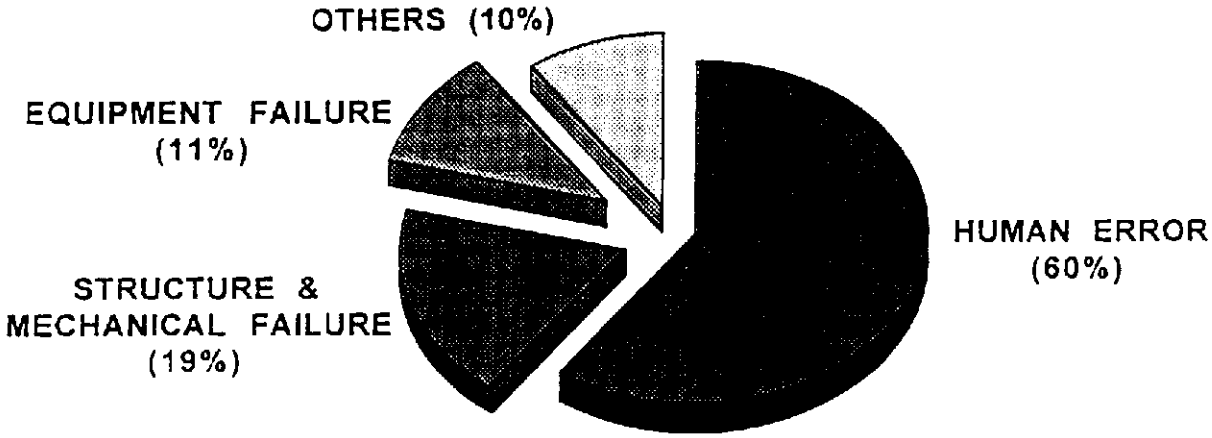

Figure 1

Main Causes of Ship Insurance Claims from 1985-91

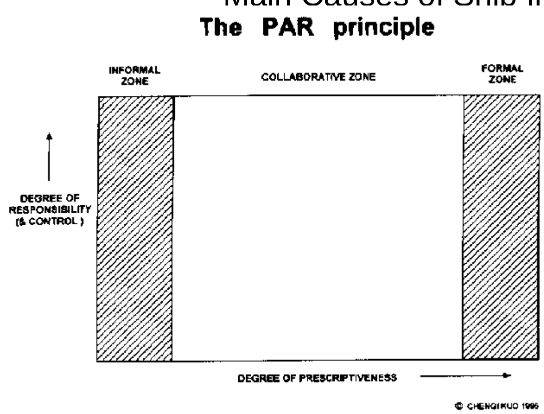

Figure 2a
Zone of Prescriptiveness

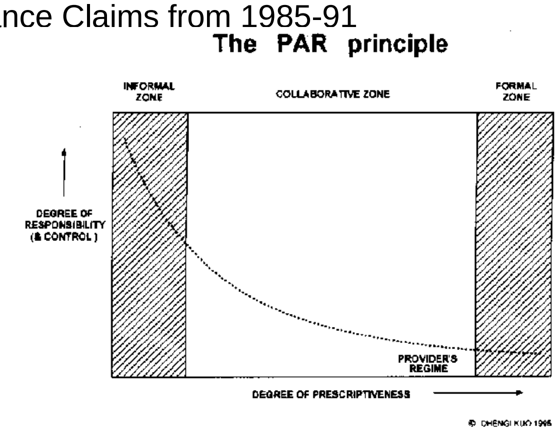

Figure 2c
Provider's Regime

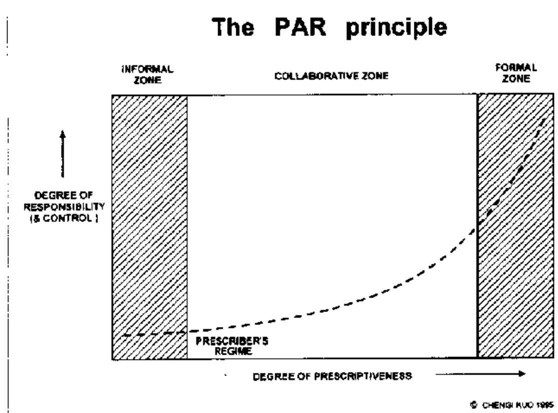

Figure 2b
Prescriber's Regime

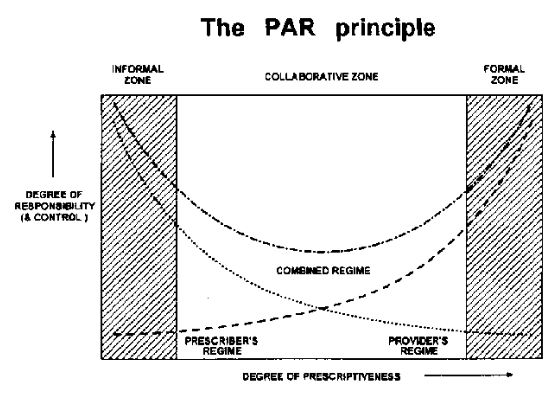

Figure 2d
Combined Regime

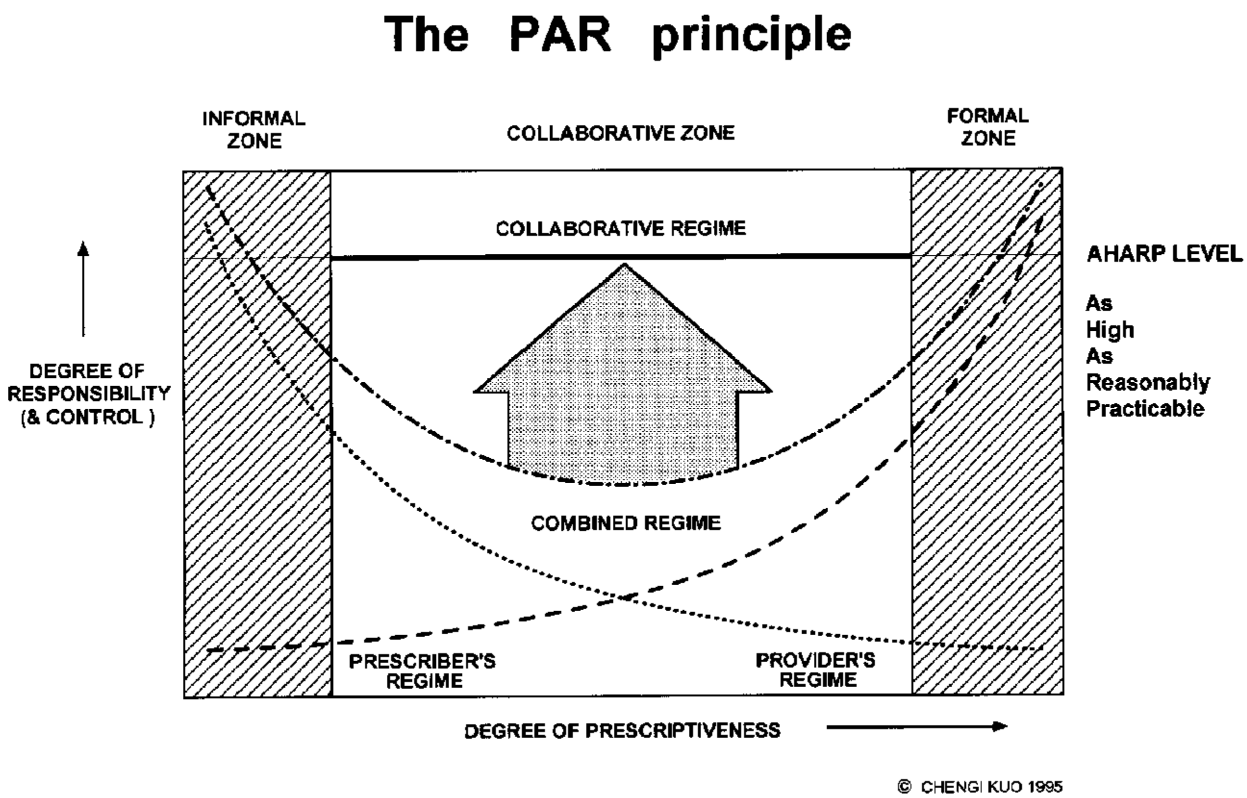

Figure 2e

Collaborative Regime

Discussion

by Robert Molloy
National Tranportation Safety Board

Thank you, Dr. Kuo, for an excellent introduction to the application of human factors in maritime safety. In discussing his presentation, I would like to examine three accidents that the Board has recently investigated. All three of these accidents involve automation that was designed to assist the human operator and prevent human error.

The first accident involved the collision of two Metrorail subway trains near Gaithersburg, Maryland. The accident occurred on a snowy night during the month of January. On this night, all of the trains in the metrorail system were being operated in automatic mode. In this mode, computers controlled the speed, acceleration, and braking for each train. However, due to the slippery conditions on the track, several trains had over-run stations in which they attempted to stop. These operators contacted the metro controllers for permission to operate their trains manually, but this permission was denied.

Train T-111, the accident train, had overshot the third to last station on its run. The operator informed the controller of this problem and requested manual operation but it was denied. The train then overshot the next station and informed the controller of this information. The controller then placed an automatic speed restriction on the train, but since the first train was past the station, the train defaulted to its highest speed — 75 mph. The operator informed the controller, and the controller placed a speed restriction that slowed the train. However, the train was still unable to stop at the last station and collided with a parked train 470 feet past the station — killing the operator. The Safety Board was unable to determine if the operator had tried to use the emergency braking.

Prior to the crash, Metro officials ordered trains to be operated in manual only in cases of emergency. This decision was based on two factors — first, manual braking put greater wear on the wheels and second, when humans were operating the train there was no back-up system. The Board listed as probable cause “the failure of Metro management to permit operating employees to use their own experience, knowledge, and judgment to make decisions regarding safety issues.” This accident provides an example of how safety cannot be prescribed from management without assistance from the operators working in the system. Had both management and the operators of the system collaborated on the operation of this system, then the accident may not have happened.

This accident also shows how human error can occur in the design of a system. The computer logic used to control the subway trains was developed for train scheduling and not safety. As a result, when a train did not properly receive instructions, it reverted to its default, in this case 75 mph, instead of reverting to a slower, safer speed.

The second accident I want to discuss is the grounding of the ROYAL MAJESTY in June of 1995. Prior to the grounding, and for nearly all the cruise, the ROYAL MAJESTY was being steered by an autopilot coupled to a Global Positioning System of GPS unit. During the cruise, the shield wire portion of the GPS antenna cable separated from its connection at the antenna. This failure resulted in the GPS unit transmitting dead-reckoning derived position data to the autopilot. Because DR-derived data do not account for the effect of wind, current, or sea conditions the autopilot was unable to keep its intended track. Over time, the distance between the intended course and the vessel’s actual position grew to 17 miles. The crew failed to notice the change in the GPS or its effect on the autopilot prior to grounding.

The grounding of the cruise ship ROYAL MAJESTY illustrates one of the difficulties in applying human factors research, or for that matter the PAR principle, to shipboard design. There are a number of agents involved in manufacturing a ship. The shipyard that built the ROYAL MAJESTY obtained an integrated bridge system from one manufacturer and a GPS unit from a second manufacturer. While both units may have been developed with sound human factor principles, they were not developed to function together as a system. Thus, when the GPS system switched from using satellite information to using dead-reckoning for position information, there was no clear indication of this switch on the integrated bridge system (IBS). The only indication of this mode switch was on the screen of the GPS unit located in the chart-room away from the IBS system. In addition, the auditory alarm indicating the switch was able to shut itself off only 1 second after activating.

The final accident I want to discuss is similar to the accident involving the ROYAL MAJESTY. In December, 1995, an American airlines 757 crashed into a mountain-side outside of Cali, Columbia. The pilots of the plane were executing an instrument approach to the Cali airport. The controller at the airport requested the pilots to proceed directly to ROZO - a navigation point that lined up with the runway. The pilots then programmed their autopilot to fly to that point. However, instead of programming ROZO, the pilots programmed ROMEO. This error was a simple one since pilots usually select waypoints using only the first letter. The FMS then lines up the nearest waypoints with that letter, and the crew selects the closest one. However, in this case the ROZO intersection was not selectable with only an R, thus it did not appear on the list. The plane then began to fly to this new waypoint without the crew becoming aware until just prior to impact. The whole flight toward this erroneous waypoint, the crew continued their descent.

In both the ROYAL MAJESTY accident and this accident, autopilots were in control and operators were monitoring. Both times the operators failed to detect their craft drifting off course. Further, both operators overtrusted the automation and received poor feedback from the automated systems. I bring this up to show that lessons can be learned from other modes of travel. The field of human factors has been around a long time. We should look beyond the human factors work conducted only in whatever area we are working. There are four things that I would like to say in summary:

1. The PAR principle can play a role insuring that systems are designed safely and addressing human factors concerns. I think the metrorail accident makes a clear case for this. However, I say this with one caveat. I believe that traditional human factors approaches have emphasized the importance for this communication between designers (prescribers) and users (providers). Thus, I believe that this system has already been in place albeit not always used.

2. The maritime industry can provide a difficult environment for ensuring good human factors design due to the number of separate agencies involved in the process.

3. Human factors has been around as an organized discipline since World War II. As such, we need to not limit ourselves to just research conducted in the maritime mode. Humans function in all modes of transportation and industry.

4. Finally, I want to emphasize the importance of designing for the operator not to replace the operator. Each of the accidents I described involved operators who were effectively removed from the control loop. In each case the operator had the final responsibility for insuring safety. This is as it should be, but we need to design systems that will help these operators, not bypass them. As the Coast Guard would say, we need to seek prevention through people.

by DeWitt Davis IV, Marine Consultant
Collaboration is a logical conclusion. But what about the illogical aspect of large social organizations or industries? There is an undefined, amorphous, illogical, irrational, disconnected, quality that needs to be defined.

Further, the term interfaces implies that there are distinct barriers between groups affecting the design, construction, operation of ships and ship structure. Integrating human factors in each of the phases of the industry are not yet obvious in concurrent engineering, integrated process and product development, or other forms of teamwork and cooperation, as a way of dealing with the illogical and irrational part of the organization in the industry. Therefore, some method of dealing with this illogical, irrational part of the social system has to be included and developed for any introduction of human factors into the Marine Safety Environment.

by Dr. Hal Hendrick, **Past President, Human Factors Society**
First, what Kuo proposes is very consistent with current approaches both in management and ergonomics (i.e., "Collaborative Regime"). Kuo's way of conceptualizing and presenting the concept of participation and collaboration is clear and, I believe, useful).

Second, my only difficulty with Kuo's article, is that his understanding of ergonomics appears to be about fifteen years old. For example he speaks of "Man-Machine" interface as though it is both a new and current concept. In fact, it was the perspective of human factors/ergonomics of the late 1940's through the 60's. In the 70's, given the sensitivity to sexism, the term was changed to "human-machine interface; and, in the late 70's, the term "machine" was broadened in definition to also include software and environment, as well as hardware. As we entered the 80's, human-machine interface technology was given recognition as the unique technology of human factors/ergonomics as a stand alone discipline. In the 1980's and early 1990's, with the further advances in cognitive ergonomics and the development of macroergonomics, the human factors/ergonomics discipline rapidly broadened to take on a more true systems perspective. Accordingly, in the early 1990's, the term "human-system interface" began to show up in the literature. In 1996, in its strategic plan, The Human Factors and Ergonomics Society (HFES) officially recognized "human-system interface technology" as the unique technology that defines the discipline (including approaches, methods, tools, specifications and guidelines). HFES further defines the purpose of the discipline as being to better the human condition through applying human-system interface technology to the analysis, design, test and evaluation, control and standardization of systems. It identifies this technology as involving the interface of people with such other system elements as hardware, software, environments and organizational structures and processes. [Hendrick (1986). Road map to the future. HFES Bulletin, October, 1 & 5.].

Thus, the focus is not just on task or microergonomics, but also on over-all work system design, and harmonizing the micro and macro aspects of the work system for enhancing health, safety, comfort, productivity and QWL (including the intrinsic motivation of work).

In summary, by starting out with the "man-machine interface" perspective of the human factors/ergonomics discipline, I believe the author was led to too narrow a conceptualization of ergonomics and its relation to system safety. As many of the case studies I recently have collected demonstrate, it is only when we apply all facets of human-system interface technology that we get the really significant improvements in safety (i.e., 60% or greater reductions in accidents).