Back to Index

Human Factors in Ship Design and Operation
27 - 29 September 2000, London

A SYSTEMS APPROACH TO INTEGRATING THE HUMAN ELEMENT INTO MARINE ENGINEERING SYSTEMS

R V Pomeroy and C M Tomlinson
Lloyd's Register of Shipping, London, UK

SUMMARY

Classification Societies have played a pivotal role in marine safety ever since Lloyd's Register (LR) was founded in 1760. The process of Classification has evolved to meet emerging challenges and will continue to meet the needs of the shipbuilding and operating community. As part of this process of development, LR's Rules are developed on a continual programme and changes are introduced to reflect advances in technology and design. The Rules now encompass some explicit consideration of the human element. As an example, the Rules for the operational notation relating to crew and passenger comfort set out appropriate standards for the environmental conditions facing people on board the vessel, both in terms of occupational health and safety and the reasonable expectations of fare paying customers.

However, certain human element issues are not so amenable to the traditional approach used in presenting the Rules, particularly in a prescriptive format. In this paper the authors indicate how technological innovations may increase the potential for accidents because of the more complex human interface they can present. These hybrid technical-human systems[1], where human performance is not external but integral, present novel problems and some ideas on how these may be treated are presented.

AUTHORS' BIOGRAPHIES

Vaughan Pomeroy is responsible for the management of LR's research and development programme, marine advisory services and the global naval business activities. He joined LR in 1980 after working in the aircraft industry and with mechanical and electrical engineering consultants, initially to work on engineering research and specialist projects.

Mr Pomeroy has held management positions within LR since 1987, successively responsible for machinery, pressure equipment and HQ engineering activities.

Christine Tomlinson joined LR in 1990, following lecturing and research work at Brunel University, where she was awarded a PhD for her research on Knowledge Based Systems. At LR Christine initially specialised in human factors and organisational aspects of software development. In 1996, she gained an MSc in Organisational Psychology, which included a dissertation on human error in teamwork.

Since 1997, Christine has been LR's human element representative at IACS and IACS' human element representative at IMO Maritime Safety Committee meetings.

1. INTRODUCTION

Over the last two decades, there has been a significant improvement in the number of ship losses (Fig. 1, based on LR data). This reduction in the loss rate is all the more remarkable when it is considered that over the same period the average age of ships has increased by a factor of 1.6, as it is generally assumed that older ships are more vulnerable.

Recent claims data shows that "human error, though declining marginally, continues to be the major challenge, accounting for 58% of major claims" (1). This figure is somewhat lower than the widely quoted figure of eighty per cent but this may be due to the inclusion of only major claims. There is widespread acceptance that the true figure may be even higher, as the analysis is usually restricted to claims or casualties that arise from operational error, including errors in carrying out maintenance but excluding errors traceable to design, manufacture or installation. It is reasonable to assume that a significant proportion of the incidents attributed to the failure of machinery, equipment or structure is the consequence of some human fallibility in terms of, for instance, a genuine mistake or a misunderstanding of the application demands. As an indicator the main causes of P&I claims, from an earlier analysis (2), is given in Fig. 2.

[1] A system is hierarchically organised, so that each level can be decomposed into subsystems which are parts in relation to the whole, but also wholes in their own right. A subsystem has two tendencies: to integrate into the whole and to assert its autonomy - sometimes viewed as emergent properties. At base, a system decomposes into interactions between parts and *not* to isolated primitives. The adoption of a systems approach to design facilitates the construction of a complex system without loss of system properties.

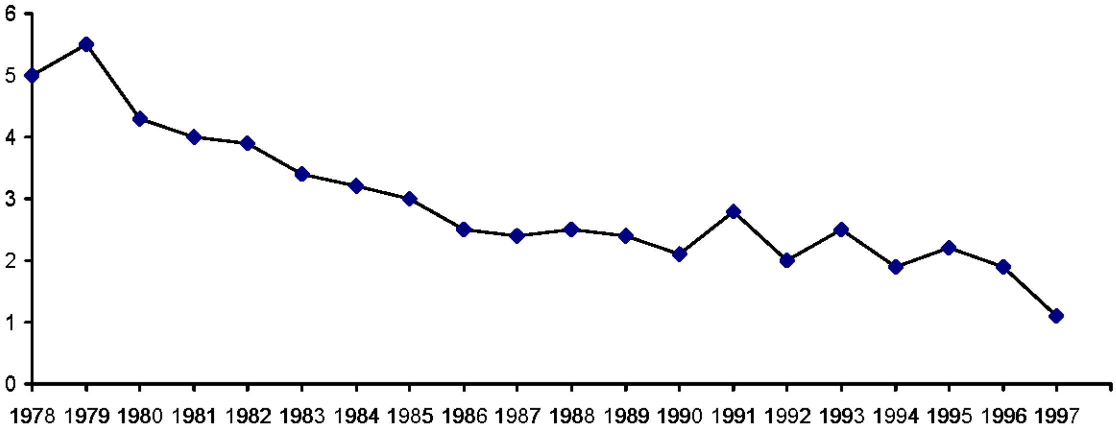

Fig. 1 Actual loss rate per 1000 ships 1978-1997

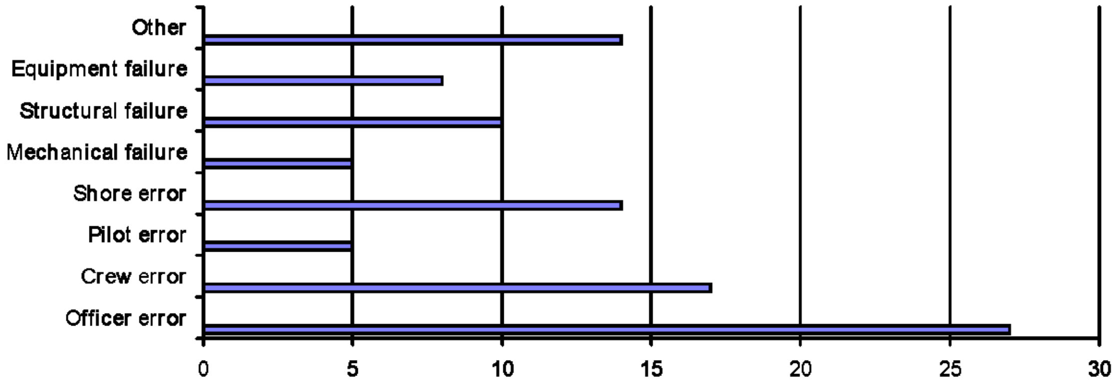

Fig. 2 Main causes (%) of P&I claims (2)

An analysis of accident records provides some comparative data, but has limited usefulness when it is based on inadequate taxonomies of human error. For the majority of incidents, there is no imperative to discover underlying causes or to ascertain whether a complex set of contributory factors operated in concert. Only detailed investigations provide the necessary insight into the various factors that precipitated a major incident. However, a number of recent incidents have caused specific comments about the influence of working patterns, fatigue, information reliance and dependence on ship systems (for instance the collision between “Norwegian Dream” and “Ever Decent” (3) and the stranding of the two short sea ships (4)).

There is growing concern that human error is the most significant factor in marine incidents. Furthermore, underwriters, both hull and machinery and P and I, indicate that human error is the most significant factor in claims. “A decade ago, the maritime world concentrated its loss-prevention efforts on technical matters, such as the water-tightness of hatchcovers. Now it has become generally accepted that such issues are only part of the story and that the root-cause of the great majority of claims is human error.” (1). There is even recognition that many of the incidents that would traditionally have been considered as a function of the ship in hardware terms actually result from human, if not user, error. The increasing complexity of systems allows greater scope for errors by designers and constructors, particularly in terms of integration and interfacing.

The UK P&I Club admit that the data cannot explain why people go on making mistakes and has launched a study to try to identify root-causes. They surmise that risk areas could include communication problems, confusion and fatigue. The authors note that the categorisation used in the analysis does not include ‘poor design’ or failures during manufacture or installation and so it is suggested that an additional, technological, risk area should be added within the analysis of human error. It is considered that advances in technology, which are technology-led rather than being designed-for-use, have a major influence on the frequency of occurrence of human error in ship operation.

2. TRENDS IN MARINE SYSTEMS DESIGN

There has been a notable trend over recent years towards increasingly complex shipboard systems. Modern vessels now rely on a high degree of automation and supervisory control that adds considerably to the complexity of the total installation. The major driver for change has been to achieve greater competitiveness through the reduction in through-life costs. The advance in automation technology and increased use of digital systems in place of traditional hard-wired or pneumatic controls provides an opportunity to reduce both the first cost, not least by reducing the cost of cable runs or fixed pipework. These systems also offer opportunities to reduce operational costs, particularly the larger components, such as fuel and crew.

The options available to the systems designer have expanded as the capability of electronic systems has increased remarkably. This explosion in potential has been quite extraordinary and is evident in terms of a very definite increase in the number of possible solutions. Furthermore, things can now be done that would have been impossible without this technology, such as build an engine that does not require a camshaft or optimise performance on a continuous basis, to enhance overall fuel efficiency, through a sophisticated power management system. The very possibility of increasing the level of functionality that can be delivered encourages the design and construction of ever more complex systems that offer to the purchaser more options when using the ship and the facility for greater customisation. Moreover, with the progressive reduction in the cost of programmable devices this increase in capability can be achieved cost effectively.

The downside of this trend is that the user is left with a system that may possess unnecessary properties, and the result may well be beyond the understanding of the average, well-trained user. The situation is made more complex by the interconnection of systems, using networking, so that the possible interactions and dependencies are no longer as obvious as with older simple systems.

2.1 TOLERANT SYSTEMS

It is a well-established practice that marine systems are designed to tolerate a single failure without presenting a major hazard. This principle is clearly limited since, in most ships, failure of any shaft line component will result in loss of propulsion. Nevertheless, the principle is established; controls and alarms provide the necessary protection. In many cases it is possible to configure systems so that failure by the user is reasonably unlikely and can be tolerated in the same way as a mechanical failure - it should not lead immediately to a hazardous condition.

Essentially the designer is providing the user with a system that can be used in a manner that will allow the user more time to react in the event of a failure and therefore improve the probability of correct action being taken. The authors contend that designers should, wherever possible, consider the system arrangement carefully and configure it so that if any component fails the behaviour of the system degrades gracefully rather than collapsing instantaneously. This generally requires the designer to look at wider definitions of systems rather than the traditional breakdown used in marine engineering.

2.2 DESIGN FOR USE

It may seem obvious that systems must be usable by sea-going staff of average competence - but this demands more than the systematic conformance of the working environment to ergonomic[2] principles. Having said that, there are plentiful examples of modern ships where the background noise, vibration and lighting levels do not provide an ideal working environment for the crew. It is possible for the basic ergonomic requirements of the installation to be addressed but for the system to become unusable under certain circumstances, notably during abnormal operations and emergencies. The design of bridges and control rooms should reflect the operating procedures, both routine and emergency, and suit the characteristics, capabilities, experience and training of the crew. As it is, errors can often be traced to a misunderstanding of the information supplied by the machine interface or to an overload of information, rather than a mistake in operation per se (3). In short, a badly designed interface encourages mistakes that no amount of training or management intervention can completely mitigate.

A typical modern bridge arrangement, aimed at providing safe operation with a reduced bridge team, demonstrates the information-intensity facing crew. Since a human operator is unlikely to understand all of the characteristics of the total hybrid system, it follows that the designer must ensure that the system hardware is usable by the average, competent operator. Moreover, when the system is procured from many suppliers of individual items of equipment the problems are compounded. Suppliers of the individual items use their own standards, particularly for user interfaces, and the total system lacks consistency. Often the user is left with manuals and instructions for the component parts and little assistance in understanding the complete installation with the various interfaces and interactions, which compounds the problems of operation.

Ideally, design should include active participation by the people who will actually operate the system (user-centred design) but different crews will inevitably operate the ship during its service lifetime. Nevertheless, user input is extremely valuable and should be sought at appropriate times. It should also influence any standards, codes of practice and rules that are referenced by the designer. This requires that those documents are prepared for systems and not for their component parts.

[2] *"Ergonomics produces and integrates knowledge from the human sciences to match jobs, systems, products and environments to the physical and mental abilities and limitations of people. In doing so, it seeks to improve health, safety, well-being and performance."* Definition of Ergonomics prepared by ISO/TC159/SC1/WG1 'Principles of the design of work systems' Vienna, Austria (Oct. 1997).

It is, of course, much more straightforward to write a standard for a single discrete item, defining dimensions, characteristics, materials and interfaces. Systems thinking brings in the need for an approach that permits the designer to select the best solution whilst ensuring that the key requirements are satisfied. The more open approach to definition of requirements can make it easier to incorporate the human element aspects since it inevitably means taking a non-prescriptive goal-setting approach.

2.3 CHANGES IN OPERATOR WORKLOAD AND TASK CONTENT

Improvements in the reliability of equipment and extended intervals between routine overhaul have resulted in a significant change in the demand for ships' staff. The decrease in maintenance and repair work is consistent with the reduction in crew numbers but it also significantly reduces the exposure of sea-going engineers to the learning experience that is associated with these tasks. In effect, the lack of opportunity to learn from "precursor" events may reduce effectiveness when dealing with a hazard. The environment that provided the experience for dealing competently with all manner of abnormal situations has been changed by the advances in technology that have increased reliability and reduced maintenance. Familiarity with items of equipment has been reduced by the reduction in routine intervention.

At the same time, the operator is faced with an increased dependence on marine electronics, generally with no specialist electronics engineer available on board. Where repair is necessary the owner has to resort to servicing by specialists, usually from the original supplier or his agents. The electronic systems for automatic control, even of complicated operational patterns some of which would simply not be possible to achieve using traditional manual controls, and the safety monitoring systems that provide shut downs and alarms are all inherently highly reliable. Despite the warnings of the potential for software errors leading to major disasters, there is very little evidence of these being considered in a rational manner. Software errors result in systematic, rather than random, failures. Examples of failures resulting from these errors include software problems with electronic charts and failure of the Panama Canal VTS. (The scale of application of software based systems and the scope of their application became very evident during the Millennium Bug programmes, since ship operators became aware of how many programmable devices were actually present on a modern ship).

Given the reliability of machinery and the presumption that the alarm and control systems are, essentially, fault-free, it is not unreasonable that the human operator is comfortable relying on the systems. To some degree, the roles of the automation and safety systems and the human operator have been reversed. The operation is now controlled automatically with human supervision rather than the control and alarm system assisting the human operator to identify malfunctions at an early stage. The reliance on the system, with the human relegated to monitoring the progress of the ship can encourage a suspension of the traditional seafaring skills of the crew. Dulling of the response to visual signals, such as observing weather changes from the bridge, or to smells and sounds in an engine room because the user is focused on monitoring information presented to him, represents a danger to safety that is often overlooked.

Certainly the improved functionality of all manner of support systems, including navigation, communication, control of main and auxiliary machinery and general monitoring and alarm, has been essential in the reduction of crew numbers. It appears from some recent incidents that this reduction in numbers of available people has more complex consequences with more examples of fatigue. Some maintenance tasks, such as repairing machinery after failure, simply cannot be handled by the number of people available, thereby presenting an additional potential hazard to the ship. In designing the total ship system it is therefore imperative that the corresponding workloads are considered, including the availability of people to deal with reasonably foreseeable incidents. The ISM Code requires that mitigation measures be put in place for all identified hazards.

As the level of complexity increases so the human element becomes more deeply embedded amongst the physical elements. As machinery and equipment are left to operate unattended, the monitoring systems detect warning signals and prod the control systems to take immediate action. The crew member that gets involved in a major problem enters a situation part through. Without time to 'gear up' for the situation, it is all too easy to misjudge the situation in the confusion and to initiate actions that exacerbate the situation.

3. IMPROVEMENT STRATEGIES

Over the last decade or so, some of these problems have been addressed at LR, within a broad programme of research and development. Three strands of the research will be outlined in this section.

3.1 ENHANCING THE SHIPBOARD WORKING ENVIRONMENT

LR has participated in a current International Maritime Organisation (IMO) initiative aiming to reduce human error caused by seafarer fatigue, with IMO producing a booklet on shipboard fatigue. This US-led effort will culminate in a document consisting of a number of self-contained modules, tailored to different audiences. LR has prepared the module 'Shipboard Fatigue and the Naval Architect/Ship Designer', which identifies the classification society Rules and International Standards that can be applied to improve the ambient environmental conditions onboard ship. It focuses on those aspects of seafarers' fatigue subject to influence by good or bad design such as:

- accommodation, e.g. location, soundproofing measures;
- habitation and recreational areas;
- user interface considerations e.g. on the bridge and in the engine control room;
- working conditions e.g. noise, vibration, ventilation, lighting, temperature, and air quality.

In drafting this module, LR was able to draw from its research and development programme, including the work that resulted in the development of LR's Rules for the operational notation for passenger and crew accommodation comfort, which were published in the current form in 1999. LR's extensive contribution to the development of International Standards for shipboard noise and vibration, design of working spaces, equipment and bridge layout and engine control room design formed an important source of reference.

In addition to this traditional ergonomic work LR has pursued an interest in improving the usability of marine equipment with embedded software, by the application of sound software ergonomic principles, such as those in ISO 9241 Parts 1, 2, 11, and 14. For example, LR participated in the development and testing of prototype computer-based Emergency Management Systems (EMS) and, at the request of the Chair of the Human Elements and Radio committees, demonstrated one of these prototypes at IMO meetings in 1995 while revisions to SOLAS were being considered. The presence of a working example from LR at these meetings may well have played a part in the acceptance of a provision for such systems. The main finding was that an EMS must be designed to suit the particular ship and the training and approach of the Master and other crew who will use the system. EMS must be tested during development to ensure that they are actually usable in emergencies.

3.2 REFINING THE DESIGN AND DEVELOPMENT PROCESS

During the course of these research activities, it became self-evident that it was not feasible to achieve the necessary improvements in shipboard systems by focusing on traditional end-product improvement alone. The traditional approach to ensuring the suitability of a piece of equipment is to undertake a structured product assessment during the final stages of development. This is considered to be appropriate for traditional items of shipboard equipment or for simple systems where good usability can be achieved by topical modification. In these cases topical modification, such as improved labelling or the application of colour, can help to improve a design to ensure a better fit with predicted human functioning.

However, it is entirely unsuitable for complex systems, especially those that are centred on the application of advanced technology. Traditional type approval and certification examines a product for compliance against an agreed standard or set of Rules. This usually involves some form of demonstration through a test programme. For more complex systems, an evaluation based on prescribed performance or feature attributes will be less valid. In addition, such standards or rules rarely contain ergonomic assessment criteria, which means that checks for potential vulnerability to human errors are not routinely undertaken.

The complexity of the system means that it is not viable to test it exhaustively, so it is not possible to be sure that all faults have been found and removed at the conclusion of the evaluation procedure. It is likely to be too late to correct many faults that are found, but even when they can be rectified, the corrections usually involve topical fixes or expensive rework.

LR has played a major role within the EU-funded ATOMOS research programme that is concerned with the development of advanced technology systems for future ships. The programme has resulted in:

- the publication of revised Rules for periodic one-man bridge operation, when authorised by the National Administration;
- the development of an assessment procedure for complex systems that incorporates consideration of human factors (5);
- a draft international standard ISO 17984 General principles for the development and use of PES in marine applications.

Interestingly, because of the flexibility of human action and the complexity of software behaviour (two critical components of the new human-machine interface) it was not feasible to develop Rules in the traditional way. It was found that as prescriptive Rules could not reasonably be expected to cover all eventualities it was necessary to take an innovative approach - a set of high-level principles for both product and life cycle assessment. Each principle is supplemented with:

- assessment criteria indicating what is to be demonstrated to confirm that the underlying principles have been satisfied ;
- guidance on good practice;
- further information including reference to appropriate standards, for those who require some assistance.

In short, the results from this research demonstrate that the development of principle-based Rules for the human-machine interface will be necessary. It has been established that this approach is achievable. This novel approach to process assessment is currently being trialled in a new EU-funded initiative, ATOMOS IV, but knowledge gleaned from this research has already been utilised by LR in other areas. For example, LR has been responsible for the production of guidelines for assessing the application of ergonomics to the development process of shipboard complex systems, containing programmable electronic systems. The guidelines specify the documentary evidence that should be sought during the development process. Evidence is required that those activities that produce good ergonomic design have been undertaken at appropriate times. This evidence is supplementary to (and does not replace) the traditional evidence sought of good working practices for system development.

Process assessment has been extended into an assessment procedure for determining the maturity of an organisation in terms of its approach to considering human factors within its own processes. This is the logical outcome of a move away from traditional type approval activities to the assessment of individual projects and processes, through to the assessment of the organisation itself. LR has undertaken a number of projects as MoD Corporate Research under TG5 RO2 in conjunction with DERA Centre for Human Sciences.

LR continues to make a contribution to the development of related international standards including those considering human-centred design processes for interactive systems (ISO 13407), ergonomics of human-system interaction and life cycle process descriptions (ISO/TC 159/SC 4) and system lifecycle processes (ISO 15288). It is expected that these standards will progressively find more widespread application, as industry becomes more familiar with the associated benefits.

3.3 CULTIVATING A SAFETY CULTURE

The International Maritime Organisation has launched several initiatives designed to bring about an improvement in safety culture in the marine industry. LR and other classification societies, independently and through IACS, play a major role in maritime safety. The following paragraphs reflect some of the recent experience of LR from participation in these new initiatives.

3.3(a) International Safety Management Code (ISM)

The development and implementation of the ISM Code has provided an opportunity for LR to become more closely involved with human factors. By 1 July 2002 all relevant ships, regardless of their date of construction, will be covered by the ISM Code. The ISM Code specifically requires that the safety management objectives of the company should, inter alia:

- provide for safe practices in ship operation and a safe working environment;
- establish safeguards against all identified risks;
- continually improve safety management skills of personnel ashore and aboard ships.

It has become clear that safety relies on more than compliance with certain prescriptive requirements, which are predominantly aimed at component level, and members of the crew holding the necessary certificates. Well-founded management processes that are proactive and regard the matter synergistically are most likely to achieve the level of safety that is demanded. These management processes must be supported by relevant rules, regulations and standards that take into account the application demands, including the interactions within systems and with operators.

The introduction of the ISM Code has gone some way in developing a safety culture, and so will help to alleviate the contribution of human error and management shortcomings on casualties. However, it is clear that it is not far enough. Implementation of a good safety policy and procedures is a superficial indication that an organisation is committed to safety, as it is all too easy to pay lip-service to safety. The challenge now facing the marine industry is to ensure that the need for safety has been internalised in ship's staff, so that any recorded evidence is a true reflection of what is really done.

3.3(b) Formal Safety Assessment (FSA)

LR recognises the important role that the development of FSA at IMO will play in the development of the safety culture of the maritime industry. IMO accepted the principle that Formal Safety Assessment (FSA) should be used as a systematic and rational process for assessing risks and evaluating the benefits of mitigation options, adopting the interim guidelines in 1997 (6). The concept of FSA provides an elegant route to the application of well-established risk analysis methods, already widely used in other industries, within shipping activities, whereas the proposition of moving rapidly towards a safety case regime would be extremely difficult.

The FSA methodology requires the inclusion of human actions both in terms of being the source of hazards and in providing mitigating controls. LR worked closely with the Marine Safety Agency (now the Maritime and Coastguard Agency), under a research contract, during the development of the first three steps of the FSA process that is described in the interim guidelines (7). The discussion during this formative phase was extremely challenging as people with considerable experience of the application of risk assessment methods in other industries developed a format that was suitable for adoption in the regulation-making framework of IMO.

In addition, LR has contributed to the FSA development with the production of guidelines on how to integrate human reliability assessment (HRA) into IMO's draft FSA guidelines. These HRA guidelines were accepted at MSC72, and work is underway to fully integrate this contribution by MSC74. In addition, LR is producing the human reliability assessment material for inclusion in the IACS training course for FSA, which will be presented at MSC74.

4. FUTURE DIRECTION AND EFFECT ON CLASSIFICATION

The preceding section has described some of the research undertaken by LR to determine ways of integrating the human element into marine engineering systems. The interconnectedness of the operational safety culture, working environment, and a design and development process suited to the production of *usable* advanced technologies, is a theme that underscores all of the research. Quite simply, it is now the case, that all three aspects have to be considered, at the appropriate time, during the design, development and operation of advanced technologies. Excellence in some aspects is not good enough.

The interconnectedness of these three elements, plus their complexity and unpredictability, means that their incorporation into Classification Rules will necessitate fundamental, unprecedented change to those Rules. Whilst their content is constantly updated to keep abreast of changes in technology and service experience, these technological developments require a fresh appraisal of the way that the Rules are devised. In this respect, there are two developments, mentioned earlier in the text, which look promising.

Firstly, LR acknowledges that the FSA methodology adopted by IMO to assist in the development of the international framework of rules for shipping must be equally valid when looking at the Rules for Classification. Any proposed changes to classification Rules could be tested by using a risk model of a generic ship-type. It is possible to set up a number of generic models for this purpose and to assess the benefit of the changes. This approach would give greater transparency and objectivity to the rule making process of the classification society. The structured approach embodied in FSA is entirely consistent with including various facets of human behaviour in the analysis and promotes the development of Rules that recognise the impact of the human element on system performance. The risk-based methodology ensures that the contributions of mechanical behaviour, environmental loading and human factors are assessed in a rational manner.

Secondly, the Rules will have to become more performance-based with defined outcomes, rather than set solutions presented in a prescriptive format. The work done on the ATOMOS projects shows one way of moving forward, as the systems approach it adopts gives a better understanding of the underlying contributors to risk and highlights the importance of user-centred design for minimising human error.

5. CONCLUSION

In summary, the increase in system complexity, even when only considering the physical elements, has outstripped the advance in standards, regulations and, indeed, specifications. It is relatively straightforward to produce statements of requirements for components and simple systems and to define tests to demonstrate compliance. When systems become very complex with large-scale integration and interconnection, the process becomes much more problematic. It is certain that the whole approach must be different, being less prescriptive whilst defining the key principles that must be satisfied and the assessment criteria for acceptance. It also becomes very apparent that the involvement of the human operator in a complex marine system becomes crucial and significantly more integral than for older, more traditional arrangements where the operator was present more as maintainer, repairer and controller. Alteration of the standards and rules used within the marine industry would have widespread effect, encouraging designers to adopt a systems approach to marine systems development integrating the human element into the system design.

In this paper the authors have set out some of the compelling reasons why marine engineering systems, and in the widest definition whole ship design, should be considered as hybrid human-technical constructions and that if safety is to be improved further this requires the active inclusion of the human element. The focus is on designing for use and a structured approach that permits inclusion of human factors in the normative text and in the assessment route has been described.

6. ACKNOWLEDGEMENT

The authors wish to thank the Committee of Lloyd's Register of Shipping for permission to publish this paper. The views expressed are those of the authors and do not necessarily represent the policy of Lloyd's Register of Shipping.

REFERENCES

1. UK P&I CLUB: 'Analysis of Major Claims, ten year trends in maritime risk', 1999.

2. UNITED KINGDOM MUTUAL STEAMSHIP ASSURANCE ASSOCIATION (BERMUDA) LTD.: 'The Human Factor - A Report on Manning', 1998.

3. BELL, D: 'Who's to Blame?', Marine Engineers Review, Institute of Marine Engineers, June 2000.

4. MAIB: Safety Digest 2/97; Part 9, Marine accident Investigation Board, 1997.

5. EARTHY, J V: 'A new approach to marine programmable systems assessment.' Scandinavian Yearbook of Maritime Technology, Scandinavian Shipping Gazette v 40 p52-61, 1999.

6. INTERNATIONAL MARITIME ORGANIZATION: 'Interim Guidelines for the Application of Formal Safety Assessment (FSA) to the IMO Rule-making Process', MSC/Circ.829 and MEPC/Circ.335, 1997.

7. BRENNAN, E G, PEACHEY, J H: ‘Recent Research into Formal Safety Assessment for Shipping’, Transactions of Lloyd’s Register Technical Association Session 1995-6, Paper No 7, Lloyd’s Register of Shipping, 1996.