Best practice for addressing human element issues in the shipping industry

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ABSTRACT

The importance of addressing human element issues has been recognised by the major stakeholders in the shipping industry. Motivations include reducing error (and consequential loss), improving occupational health and safety, improving recruitment and retention, and providing better quality of working life. The challenge has been translating aspiration into practical application. International Standards publications on ergonomics have specified the process of Human-Centred Design (HCD) in a form that is compatible with modern approaches to management (continuous improvement under ISO 9000 for example). Lloyd's Register developed these into a guide to human element best practice for ship operators. The development of this guide required tailoring the application of the standards to the needs of ship operators. Lloyd's Register is now considering the development of a best practice guide for ship design. This requires a different tailoring of the HCD process, supported by technical and management guidance. The paper analyses the latest "capstone" standards for Ergonomics and HCD in the context of ship systems and draws conclusions for design and its interface to design offices, shipyards and other stakeholders.

Keywords: Ship Design, Safety, Regulation

NOMENCLATURE

ASTM American Society for the Testing of Materials
BPG Best Practice Guide
CAD Computer Aided Design
HCD Human-Centred Design
HFI Human Factors Integration
ILO International Labour Organisation
IMO International Maritime Organisation
ISO International Organisation for Standardisation
IT Information Technology
LR Lloyd's Register
NGO Non Governmental Organisation
NI Nautical Institute
OCIMF Oil Companies International Marine Forum
PAS Publicly Available Specification
RNLI Royal National Lifeboat Institution
TMSA Tanker Management and Self Assessment

Ship *Operator* is used to mean a ship owner or management company. Individuals on ships (excluding passengers) are referred to as *seafarers*. Where standards refer to *workers* and *users*, these are taken to be seafarers in the marine context. For the purposes of this paper, *seafarers* includes portworkers.

1. INTRODUCTION

Modern commercial maritime transport is, in overall terms, highly reliable and safe. Nevertheless, the industry is still seeking to improve, and it faces increased external pressures to reduce the number of casualties. The record of safety improvement over the recent past is impressive, despite the increasing age of the world fleet.

The introduction of improved technical standards, including more demanding survey regimes and stronger regulation enforced through a rigorous Port State Control system, has had a strong positive influence on safety. However, there is a limit to how much additional improvement is possible if attention is only focused on the structural, mechanical, electrical and electronic components. Further improvements will require a focus on the way that a ship is used; in other words, considering the overall ship system. This cannot ignore the people operating it, often known as the 'human element'.

There is no accepted international definition of the term 'the human element'. In the maritime context, the US Coast Guard defines it as "human and organizational influences on marine safety and maritime system performance". It can be taken to embrace anything that influences the interaction between a human and any other human, workspace, system or machine onboard ship.

Although the phrase may be fairly recent in origin, the impact of people in the maritime safety system has been with us as long as mankind has sailed the seas. Nevertheless, the particular issues raised by human aspects of shipping that this presents are not constant. Continued vigilance and effort are required from the shipping industry to ensure that they are responded to effectively.

During the recent economic boom, the industry faced a considerable shortage of seafarers. It would appear that the difficulty of finding suitably skilled people to go to sea will continue, providing a quite separate interest in the human element.

Recognising the need for industry-wide education of the human element, the Lloyd's Register Educational Trust supports the Nautical Institute's award-winning Alert! Bulletin. Alert! has raised awareness of the breadth of the topic [NI, 2007], described the current issues facing the industry [NI, 2009], and is now addressing the competences required to address the human element by the various stakeholders [NI, 2010].

1.1 THE STATE OF REGULATION

The marine industry is self-regulating, and minimum compliance is frequently encountered. Safety can be treated as a legislative requirement rather than a self-imposed quality.

The crucial influence of the human element on safety, security and environmental protection has been recognised by the IMO, including in its 'vision, principles and goals' for the human element, as set out in Resolution A.947(23) [IMO, 2004]. This acknowledges "the need for increased focus on human-related activities in the safe operation of ships, and the need to achieve and maintain high standards of safety, security and environmental protection for the purpose of significantly reducing maritime casualties".

The ILO has combined and revised its conventions on seafarer employment and welfare into a single Maritime Labour Convention [ILO, 2006]. This sets minimum standards on issues such as seafarers' conditions of employment, accommodation, recreational facilities, food and catering, health protection, medical care, welfare and social protection. The detailed requirements of the Convention directly address issues associated with the causes of fatigue, occupational accidents, recruitment, employment opportunities, and working and living conditions for many seafarers. The long-term intent of the Convention is to improve the safety and status of the shipping industry.

Most classification societies are beginning to address ship design aspects of the human element through guidance and notations.

There is limited technical knowledge (certainly from outwith the industry) involved in the definition and development of regulation and there can be a tendency to taking whatever solution has the strongest lobbying, or is popular at the time. The human element then has to deal with the law of unintended consequences[1].

1.2 AN INTEGRATED APPROACH

In 2007 Lloyd's Register developed and released the *Human Element: Best Practice for Ship Operators* (BPG) [LR, 2007]. This document was designed to aid the transition from awareness to effective action.

The content of the BPG was derived from a number of sources, not least the articles and themed centre-spread diagrams in Alert!. The BPG was also based on an international cross-industry standard (ISO PAS 18152 – *A specification for the process assessment of human-system issues* [ISO, 2003]. It covered a wide range of operational and management practices. To facilitate ease of use and acceptance by the target audience the BPG followed the structure and methodology adopted in the Tanker Management Self-Assessment (TMSA) guide [OCIMF, 2004].

The BPG was designed to help operators improve operational safety by changing the orientation and scope of their management practices in a staged manner. The change in orientation encourages greater emphasis on identifying human element issues and then acting upon them. The change in scope helps ensure that human element issues are integrated into the way that existing practices are carried out.

These changes enable effective and thorough continuous improvement of an operator's management of the human element. The human element is a wide-ranging, systemic problem with many aspects. Causes and effects can be hard to distinguish. Addressing the human element by tackling individual symptoms or issues is unlikely to succeed, and even more unlikely to be cost-effective.

The operational safety and business effectiveness of ships are dependent on a number of elements all working together in an integrated way. This can only be achieved by assuring good design and construction as well as operation, with a complete understanding at all stages of the importance of the human element. This paper discusses how the

[1] '*Any intervention in a complex system may or may not have the intended result, but will inevitably create unanticipated and often undesirable outcomes*' [Merton, R.K., 1936].

human element can be systematically addressed in the design and construction of ships and ship systems.

2. THE APPLICATION OF ERGONOMICS TO SHIP DESIGN

This section examines the ship life cycle and how it shapes the application of ergonomics. The industry has a unique life cycle, and this presents a number of challenges to successful ergonomic design.

The management of ships is a very old skill. There is an almost unique management structure (e.g. ships are required to behave as autonomous, self-preserving entities for long periods, the safest way of handling a ship often requires seafarers to take immediate and unquestioning action in response to commands, etc.). Tradition relating to the marine context is very strong. Knowledge, responsibility and authority are defined by this tradition. New systems and ways of working have to be introduced carefully. In many cases this is not done in a sympathetic way, leading to inefficiencies or sources of error. In particular introduction of technology and reduction in manning do not take account of responsibility and human competence, capabilities and limitations (e.g. fatigue and stress) or available procedures and resources.

The seafaring culture is complex involving maritime traditions, complex personal motivations, and multilingual, multi-cultural crews. National culture has a strong influence, especially in senior operational and engineering roles. Problem solving, conformance to procedures, perception of risk and response to emergencies are all influenced by cultural issues. However, systems development and support rarely takes account of these issues. Risks are thereby built into system operation.

Beyond regulatory needs the requirements for the construction and maintenance of ships and associated equipment are defined in part in international standards but primarily in Class Rules. The marine industry is highly competitive and costs are tightly controlled. The minimum number of suitably skilled staff is employed at sea and ashore and the majority of efficiency improvements have already been made.

2.1 THROUGH-LIFE CONSIDERATIONS

A challenge to Human Factors Integration (HFI) in a number of industries is that costs and benefits are split across stakeholders. Paying more at the design stage for a benefit during the operational stage needs someone to fund through-life considerations. This applies in the maritime industry in a particular way. It is also the case that there is a significant commercial and regulatory gap between design and operation; successful ergonomics requires bridging this gap. *"The requirements for a ship rarely indicate the relative importance that the owner attaches to operating economy and first cost, although this should be an important design consideration"* [Watson, 2002]. The focus during design is on the needs of construction; product breakdown structures are based on manufacturing requirements, which do not lend themselves to operational considerations.

A ship may have several owners or operators in its life. The systems will either be a standard design or will (more or less) have been specified for a particular crew and operational concept (explicitly in the invitation to tender or implicitly through assumptions in design and modifications in use). The context of use introduced by subsequent operators may introduce hazards such as change of working language, assumptions about roles and training, assumed operating and maintenance procedures.

Some owners see ships as a tradable asset rather than as complex, mobile, sociotechnical entities, and as a consequence have no incentive to invest in through-life considerations.

Crew costs are seen as an area where economies can be made. *"A reduction of one in the number of engine room staff may reduce running costs by as much as, or more than, can be achieved by expensive improvements in engine efficiency"* [Watson, 2002]. Cost reduction is attempted by increasing working hours, reducing the use of skilled crew, recruitment from developing countries, etc. The consequent requirements on system dependability are not in general recognised.

Systems used in the marine environment tend to be "fit and forget" and may be used for the life of the ship (nowadays around 25 years but may be up to 35) or at least on a ten to 15 year refit cycle. Whilst this is not a problem for most mechanical systems, it is pushing the design lifetime for many components in electrical or electronic systems, and is many times the design life of IT systems. In operation date handling errors, obsolete data storage media, component availability and software maintenance are all potential problems. Typical problems for systems refresh include lack of design for replacement (e.g. access to cables), availability of bandwidth, access, use of non-standard interfaces, capture and use of knowledge from operation in the new specification.

Minor modifications tend to be made by the ship's engineer or by maintenance staff. Major modifications are made at scheduled re-fits. New requirements come from regulation or change-of-use and are made by service personnel. Both minor and major changes are rarely tested or assessed for overall impact, especially with regard to usability, integrity or management of the total system.

2.2 THE SHIP DEVELOPMENT PROCESS

Guidance on sensible procurement, e.g. that by INTERTANKO [INTERTANKO, 2003], is used by those who value it, but in general the industry considers that it has more guidance than it can use. Some technical guidance (e.g. [ASTM F-1166, 2007]) has reached the stage of national standards, but shipping is an international industry, requiring international standards. Good technical material tailored to the maritime industry has been available for some time (e.g. [Anderson *et al*, 1977]); the challenge is to integrate it into the working life of the key stakeholders.

Modern shipbuilding is a highly economical and efficient process. Each ship is a one-off contract. Tenders are typically fixed price excluding commissioning costs. The shipyards in turn invite equipment manufacturers and other specialist companies to provide tenders to equip the ship and where applicable offer designs for consideration based on the owner's specification. The shipyard co-ordinates the building of the ship and manages the subcontracts. The ship is surveyed during construction by the classification society and the owner, and accepted after testing and successful sea trials. Key milestones for ship classification are plan approval and initial survey. The design process is essentially a waterfall, frequently represented as a cost-optimising spiral (see Fig. 1). Ergonomics needs to find ways to influence the design within the constraints of such a process. The user-centred design approach adopted by the RNLI to optimise the safety and operational effectiveness of the Tamar class lifeboat [Chaplin and Nurser, 2007] is very different to the normal ship design process.

The strong emphasis on contract lengthens the value chain. The short design and build times (measured in months) for most ships, low profit margins, each ship being effectively a unique design, many equipment suppliers to each ship, high complexity of systems (which could create problems with system integration) and long operating life of marine systems (10 to 30 years) all contribute to a unique environment for design. There are also many strategies for ship management that affect the context of use.

Without high usability, operational safety and user acceptance of its systems the maritime mode of transport will not be able to meet the new requirements for environmental protection, performance and safety demanded by its place in an increasingly integrated transport system. However, the maritime environment presents particular special issues and potential challenges to systems engineering and ergonomics and their existing range of methods and techniques. These include: limited awareness of the context of use amongst designers, rotation of system suppliers, "outsourcing" of safety to minimum tender, rapid innovation, use of off-the-shelf solutions from other industries, preference for prescriptive standards, limited opportunity for functional testing, little opportunity for prototypes and limited opportunity for specialist staffing or training.

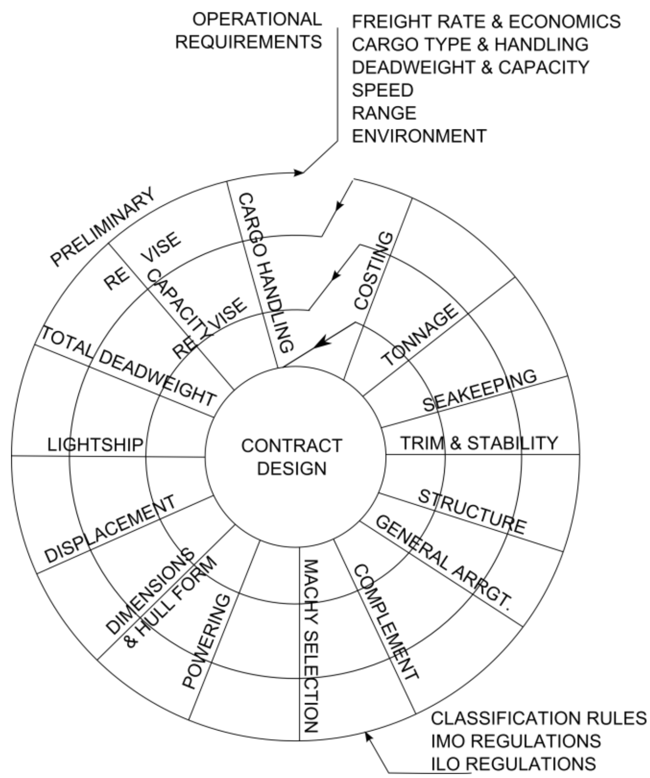

Figure 1. Design Spiral [Watson, 2002]

Working spaces and accommodation are laid out around machinery and cargo needs, or according to requirements for visibility or other aspects of ship handling. Beyond minimum legislated health and safety requirements there is little regard for physical ergonomics (motion, noise, thermal environment) or for social aspects. Requirements for safe access are not well developed for all ship and cargo operations and much more could be done to address slips trips and falls, signage etc.

Individual items of equipment tend to be off-the-shelf products, and the location and layout of working and accommodation spaces are fixed relatively early. The cost of investigation through prototyping is therefore high.

The short build time and use of standard designs further reduces opportunities for input or iteration. The tradition of seafarers ‘standing by’ during build has become a rarity, despite the greater need for user input. Input is at present made in the form of experience from the owner and the shipyard design office. The end users of the ship and its equipment (the seafarers) only see the systems late in commissioning, or when they take over an operational ship.

Some initiatives offer the possibility of new source of feedback to ship and equipment designers. Seafarer's professional bodies are getting more involved in both the development of regulation and setting of standards for the design of equipment. In Sweden cadets are being trained (and all seafarers encouraged) to make workplace ergonomics assessments (MTOSEA, 2010). Successive builds of the same ship or system design could be modified as a result of such user input, giving a form of iteration in design.

2.3 COMPUTER SYSTEMS DEVELOPMENT IN THE MARINE INDUSTRY

Safety is the primary motivation for consideration of complex system issues in the marine industry. Human error is seen as an important cause of accidents.

The merchant shipping industry is a high technology industry that considers itself to be low technology. The majority of ship systems are automated, almost completely because of the cost benefits this provides. However, the relatively low cost of automation systems and the continuing belief that the industry is low technology means that issues such as system integrity and integration are not given prominence in contract or project management. Some of the more responsible owners fulfil the role of system integrator but, in general, this role is tacitly left to the control system supplier, with little funding for the job.

Although "*Shipbuilding today is more about systems integration and management of vendors than about hanging steel*" [Fabrikant, 2008] the contract environment is still entrenched and hierarchical. Taking account of systems that cross the traditional hierarchy of design (such as control systems, new ways of working, safety systems, novel forms of propulsion, electric ships etc.) is difficult within this framework and the result is a lack of system integration, especially with regard to the human component of the system. The Oily Water Separator is an example of the consequences of not considering the systems aspects of equipment design [Van Hemmen, 2005]

In common with the aerospace industry IT was first introduced for economy (e.g. engine management, voyage planning) not safety (unlike the rail industry where signalling was the first application). Marine IT systems development culture tends therefore to be less concerned with dependability and quality and more concerned with control functionality. Infrastructure is not selected for dependability but fast development times and availability.

Several equipment manufacturers are investing in usability, based on evidence from other industries that it improves safety and prove commercially appealing (Sillitoe, 2009). In this, they are attempting to lead the market.

3. STANDARDS FOR ERGONOMICS AND HUMAN CENTRED DESIGN

This section summarises the requirements from the three capstone ergonomics standards. Section 4 discusses the users affected by them, and Section 5 discusses the application of the requirements in the maritime industry.

Since 2007 ISO has developed or revised its capstone standards for ergonomics and HCD. The (re)development of these standards is largely complete. The standards place requirements on the practice and process of ergonomics. They provide a context for the detailed recommendations and guidance in both ISO and domain specific standards that address the application of ergonomics. Both the contextualization framework and the setting of requirements are advantageous to the promotion of ergonomics in the marine industry.

3.1 ISO DIS 26800 *ERGONOMICS — GENERAL APPROACH, PRINCIPLES AND CONCEPTS* [ISO, 2009]

A substantial number of ergonomics/human factors standards dealing with different aspects and different contexts have been developed. ISO 26800 has been developed in order to bring together in one document the basic principles and concepts of ergonomics that are dealt with in these other ergonomics standards.

Although this standard is not finalised it has just finished its public comment stage, and its form and technical content are stable. It describes the general ergonomics approach and specifies basic ergonomics principles and concepts. These are applicable to the design and evaluation of tasks, jobs, products, tools, equipment, systems, organizations, services, facilities and environments in order to make them compatible with the characteristics, needs and values, abilities and limitations of people.

The purpose of the standard is improved safety, performance, effectiveness, efficiency, reliability, availability and maintainability of a product, service or system throughout its life cycle while safeguarding and enhancing the health, well-being and satisfaction of those involved or affected.

The intended users of the standard are designers, ergonomists, project managers, purchasers, managers and workers. The standard also serves as a reference standard for standards developers dealing with ergonomics aspects, for example regulators and rule-makers.

The fundamental requirements of this standard are as follows:

1. An ergonomics approach to design shall be human-centred.
2. The target population shall be identified and described.
3. Design shall take full account of the nature of the task and its implications for the human.
4. The environment in which a system, product, service or facility is intended to be used shall be identified and described.
5. Evaluation of the ergonomic design of any system, product or service shall be based on established ergonomic criteria.
6. Ergonomics shall be considered early and continuously within the design process.
7. Sufficient attention shall be given to the application of ergonomics principles in order to prevent any negative effects.
8. Ergonomics criteria shall be established for the design.
9. Conceptual and detailed designs shall take account of these ergonomics criteria.
10. The process shall take account of the human tasks and interactions.
11. Workers or users (or potential workers or users) shall be involved in the process.
12. Evaluation shall be carried out and the necessary adjustments and corrections made.
13. The design process shall have sufficient flexibility to allow for iteration of the design solution.

3.2 ISO FDIS 9241-210 *HUMAN-CENTRED DESIGN FOR INTERACTIVE SYSTEMS* [ISO, 2009]

This standard has been finalized and is in process of publication by ISO. It provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of interactive systems. It provides detail for ISO 26800 in the area of hardware and software components of interactive systems to enhance human-system interaction. Any arrangement of equipment and procedures for use can be considered to be an interactive system.

The standard is for use by those responsible for planning and managing projects that design and develop interactive systems. It addresses technical human factors and ergonomics issues to the extent necessary to allow such individuals to understand their relevance and importance in the design process as a whole. The standard also provides a framework for human factors and usability professionals involved in human-centred design.

The principles and requirements of this standard can be summarized as follows:

1. The project understands and specifies the context of use such that design is based upon an explicit understanding of users, tasks and environments.
2. The project identifies user needs and specifies the user requirements.
3. The design team includes multi-disciplinary skills and perspectives.
4. The design addresses the whole user experience.
5. Design solutions include ergonomics and user requirements.
6. Users are involved throughout the lifecycle such that the design is driven and refined by user-centred evaluation.
7. The design process is iterative.

From these principles and requirements the standard derives particular requirements on project planning and system management such that:

8. Human-centred design shall be planned and integrated into all phases of the product life cycle, i.e. conception, analysis, design, implementation, testing and maintenance.

9. Those responsible for planning the project shall consider the relative importance of ergonomics/human factors in the project by evaluating:
   a) how usability relates to the purpose and use of the product, system or service (e.g. size, number of users, relationship with other systems, safety or health issues, accessibility, specialist application, extreme environments);
   b) the levels of the various types of risk that might result from poor usability (e.g. financial, poor product differentiation, safety, required level of usability, acceptance);
   c) the nature of the development environment (e.g. size of project, time to market, range of technologies, internal or external project, type of contract).
10. The planning of human-centred design shall include:
    a) identifying appropriate methods and resources for human-centred design activities;
    b) defining procedures for integrating these activities and their outputs with other system development activities;
    c) identifying the individuals and the organization(s) responsible for the human-centred design activities and the range of skills and viewpoints they provide;
    d) developing effective procedures for establishing feedback and communication on human-centred design activities as they affect other design activities and trade-offs, and methods for documenting outputs from these activities;
    e) agreeing on appropriate milestones for human-centred activities that are integrated into the overall design and development process;
    f) agreeing on suitable timescales to allow iteration, use of feedback, and possible design changes to be incorporated into the project schedule.
11. The plan for human-centred design shall form part of the overall project plan.
12. Project planning shall allocate time and resources for the human-centred activities. This shall include time for iteration and the incorporation of user feedback, and for evaluating whether the design solution satisfies the user requirements.

3.3 ISO TS 18152 *A SPECIFICATION FOR THE PROCESS ASSESSMENT OF HUMAN-SYSTEM ISSUES* [ISO, 2010]

This document has been available as a published draft for seven years and is in process of conversion to a permanent Technical Specification. It presents a process model that implements the principles and requirements of ISO 26800 and 9241-210. This model can be used for the implementation, assessment and improvement of human-centred design processes. Table 1 outlines the processes in the model.

Process models offer:

- the potential to analyse the ability of an organisation to deliver and/or maintain a system that meets a required level of performance;
- a description of the factors that hinder this ability; and
- the means of addressing such shortcomings and mitigating risk.

These features have led to the widespread adoption of process modelling and assessment as an element in the assurance of timely and effective system delivery. Processes are defined at the level of what is done to develop and operate a system or organisation. Process reference models have been defined for particular applications and industries. International standard process models are being developed by ISO and ISO/IEC JTC1. This specification provides a bridge between standardization in the area of Ergonomics (by ISO TC159) and the life cycle standardization being carried out by ISO/IEC JTC1/SC7 Systems and software engineering.

4. USERS OF CAPSTONE STANDARDS

The standards described above represent international agreement on the scope and practice of ergonomics and HCD. They are a tool that can be used both to address a major threat to maritime safety and to improve business efficiency. They are also a resource that can be used to engender and support improvement in the marine industry with regard to the processes by which ships, systems and equipment are made more effective, efficient, safe and acceptable (in other word usable) to seafarers.

The user community for these standards is presented below. This is broken down by audience (the roles affected by the requirements), the resulting users (the roles that have to implement the process to address these requirements) and the issues for which each audience is responsible:

Executives - strategists, policymakers, executives, process owners, advisors.

Resulting users - all management and specialists implementing and assessing process in organisations, developers of standards and procedures for all aspects of systems in organisations.
Issues – quality, safety, usability, HCD, human factors, legal implications, business implications.

Management - project managers, contracts managers, process implementers.
Resulting users - project staff, project management office, assessors, developers of standards and procedures for design.
Issues – quality management, risk, usability, integration of HCD, design trade-offs.

Specialists - ergonomists and designers of products and services together with managers responsible for their development.
Resulting users - quality managers, developers of standards and procedures for ergonomics and ergonomic design processes.
Issues - ergonomic design, accessible design, HFI reference to ergonomics standards and human element content in marine rules and regulations.

Within the marine community the audience and users of these standards for ergonomics translates into the following stakeholders that have to be made aware of the implications of the requirements and recommendations of ergonomics and their responsibilities in this area:

- Senior management in operators/owners
- Senior management in yards
- Senior management in manufacturers
- Trade associations
- Project managers
- Purchasing/contracts officers
- Quality management
- Surveyors/inspectors
- Professional societies
- Teachers/colleges
- Designers
- H&S staff
- Ergonomists.

5. APPLICATION OF THE ISO STANDARDS IN SHIP DESIGN

This section presents the collated requirements of ISO 26800 and 9241-210 separated into the fundamental principles of ergonomics and HCD, required project activities and required organisational management activities. Each group of requirements is discussed in terms of how they could be applied in the marine industry to address the human element in the design of ships and ship systems. It is addressed to both ergonomists and marine decision makers.

5.1 FUNDAMENTAL PRINCIPLES

1. *Identify and describe the environment in which a system, product, service or facility is intended to be used, taking full account of the nature of the task and its implications for the human.*

The physical, social and organisational environment, and user and task characteristics comprise the context of use [ISO, 1998]. Special features of the marine context include watchkeeping, motion, hazardous environments, extremes of temperature, humidity and lighting, multinational crews, regulatory compliance, manning for tasks. Many aspects of the marine context are general across all ships and familiar to seafarers. Recent changes (unfamiliar to all but the most recently-retired ex-seafarers) include the impact of management systems, pervasive computing, short turnaround times and environmental regulations.

However, experience of the marine context of use is not widespread amongst designers and other marine project staff. Communication of the marine context is largely by anecdote. As a result there are often avoidable errors in designs and in the evaluation of designs. Tools for describing context of use are available, e.g. [Thomas and Bevan, 1996], [LR, 2008]. More could be done to communicate the marine context to designers and specialists. A generic description could be communicated widely, with novel or unique aspects for particular ship types, equipment, operations and operator procedures presented as variations. The context of use is also a useful tool for analysing human element problems with operational systems.

2. *Design for the target population and the whole user experience.*

Designing for the target population and the user experience are means of scoping a design to better suit the intended users. Designers tend to design for either an idealised individual (often themselves) or attempt to design for the entire population. The biomechanical, sensory and cognitive capabilities of seafarers and their range of variation do not fit either of these patterns. A range of target populations can be identified, e.g. most seafarers have defined qualifications and levels of fitness. Ranges of strength and size are less well defined, but have a significant impact on seafarer safety or their correct use of arrangements and equipment. For example, a study of habitual non-use of safety boots by Philipino seafarers revealed a particular foot shape that resulted in all available boots being too uncomfortable to wear.

Designing for the user experience involves considering the seafarers' likely background, skills, limitations, preferences and expectations. In addition to the usual consideration of layout, environment, regulation and user-system interfaces, considering the user experience requires a broader concept of design to address or take account of what happens during recruitment, training, job design, watch-keeping, and allocation of responsibility and functions.

3. *Drive and refine the design by user-centred evaluation and use of established ergonomic criteria.*

There is a large body of human science knowledge, much of it documented in standards and guidelines that could be applied more widely in the marine industry. IMO, flag administrations, NGOs and mutual insurers produce a range of informative material (circulars, guides, handbooks, etc.). This knowledge can be used to set design requirements and evaluation criteria. However, with the range of marine contexts of use and target populations there may be a need to assess the effect on users for the selected design solution. This is especially the case for the usability of complex systems. The project process by which this assessment is carried out is described below at Section 5.2.

4. *Include multi-disciplinary skills and perspectives in the design team.*

Human-centred design teams do not have to be large, but the team should have access to a sufficiently diverse set of skills and viewpoints to collaborate over design and implementation trade-off decisions at appropriate times. In the marine industry the skill areas and viewpoints that need to be taken into account include not only awareness of the marine operational and regulatory context but also the technical skills necessary to design for people. These include HFI, systems engineering and management. In some parts of the industry additional skills will be required, such as interior design and catering passenger ships and luxury yachts.

5.2 PROJECT PROCESS

1. *Consider human-system issues and the relative importance of ergonomics/human factors early and continuously in the project*

In the context of the interlinked lifecycles of ship and equipment design this translates into a need for preliminary human factors analysis for a new generic ship design by a yard and for a new version of equipment by a manufacturer. It also requires a consideration of specific issues related to the intended crewing and operating procedures in the preparation of a specification for a newbuilding and any acquisition of new equipment. The management of these issues is best accomplished by their inclusion in the project risks register. Feedback from closely-related designs is potentially a good source of issues.

2. *Identify user needs and specify the user requirements based on an explicit understanding of users, tasks, interactions and environments.*
3. *Establish ergonomics criteria for the design.*

User needs include needs enshrined in codes, conventions and Flag legislation, needs arising from human-system issues identified in the particular context of use (as discussed above) and seafarer's expressed needs, wants, constraints and desires related to working and living on ships. These sets of needs must be analysed to give a consistent set of user requirements (related to achievement of targets for performance, safety, maintenance, functionality, etc.) that are added to the technical and other sets of requirements for the project. As discussed above the project team may need access to particular skills to address these 'human element' requirements. At present the degree to which the context of use is analysed, or seafarer needs are elicited and considered, in shipbuilding or equipment design varies considerably, but in general is not adequate to reliably address human-system issues reliably in the design of ships and their equipment.

As mentioned above iterative evaluation against ergonomics criteria is an integral part of any ergonomics-based design process. Evaluation should take into account both short- and long-term effects. Ergonomics criteria can be related to human performance, health and safety, skills, abilities and knowledge, or acceptability. The relative importance of the criteria varies depending on the role of the seafarer with respect to what is being designed and the attributes of the target population. For example, ships designed for Japanese crews have bunks that are too short for US seafarers. Setting the criterion of having bunks long enough to accommodate 99% of US seafarers would be a suitable criterion in the acquisition of ships manned by US crews.

4. *Include ergonomics and user requirements in design solutions.*
5. *Take account of ergonomics criteria in conceptual and detailed design.*
6. *Prevent negative effects by application of ergonomics principles.*

There are a variety of ways of communicating these human element requirements to those teams and individuals responsible for design, construction and testing. The goal is to make the relevant information and advice usable by project staff. Effective means of communication can vary from providing appropriate documentation to embedding experts in ergonomics and human-centred design in the design and development team.

Whatever the team structure there should be a sustained channel of communication between those responsible for addressing the human element and other members of the project team. When design solutions are communicated, they should be accompanied by an explanation and justification of the design decisions, especially where trade-offs are necessary.

The communication should take account of the constraints imposed by the project and the project team's knowledge and understanding about ergonomics and user interface design. Training the whole team in awareness of the human element is helpful.

7. *Identify appropriate methods and resources for human-centred design activities.*
8. *Integrate these activities and their outputs with other system development activities.*
9. *Feedback and communicate on human-centred design activities as they affect other design activities and trade-offs.*

Project timescales, access to users, aspects of the marine context of use, regulatory requirements and the level of maturity of the marine industry with respect to addressing the human element all have an effect on the suitability of methods and type of resource required for marine HCD activities. At present simple methods involving relatively few seafarers are likely to be more acceptable and feasible. Access to seafarers is, and will continue to be, a challenge for individual projects. Good communication about HCD work and its implications is important, with regard to having a beneficial effect, identification of additional requirements or changes to project criteria, and promotion of the value of addressing the human element. Sufficient time needs to be allowed to carry out HCD and make any changes in response to user evaluation or other feedback. This, and an understanding of the scope and type of change that might result from HCD are the critical success factors for effective HCD.

5.3 MANAGEMENT PROCESS

1. *Include and integrate human-centred design into the overall project plan and all phases of the product life cycle.*
2. *Integrate milestones for human-centred activities into the overall design and development process.*
3. *Allocate time for iteration and the incorporation of user feedback, and for evaluating whether the design solution satisfies the user requirements*

These are the requirements for establishing organisational support for integration of HCD into a project. All organisations involved in a shipbuilding project have to take account of the implications of addressing the human element. The project milestones for HCD activities will relate to satisfaction of ergonomics criteria and user evaluation with respect to usability requirements. A critical success factor is the existence of a champion for the human element within the organisation.

4. *Identify the range of skills and viewpoints required.*
5. *Involve workers or users (or potential workers or users) in the process*
6. *Make individuals and organization(s) responsible for the human-centred design activities.*

The involvement of workers/users, i.e. seafarers, is a principle of ergonomics. User evaluation is best accomplished by serving seafarers, or those with recent seafaring experience, carrying out representative tasks in a realistic simulation of the context of use. The risks of not carrying out evaluation with users in context need to be assessed and the effect on the results of evaluations with lower fidelity should be taken into account in presenting feedback. Alternatives include advice from professional societies, evaluation by retired seafarers, cadets and those attending training courses, evaluation by ergonomics experts, simulation (e.g. using CAD mannequins).

6. CONCLUSIONS

The commercial and management processes driving ship design and construction are highly evolved. The number of stakeholders involved is considerable, with many stakeholders involved indirectly, and with little awareness of their influence on the human element.

Because of unappealing through-life considerations, the most straightforward form of intervention is regulatory. The pervasive nature of the human element means that such intervention would be cumulatively massive. In order to address the human element rapidly and effectively a human-centred approach within design is also encouraged. Guidance on human-centred design needs to be readily absorbed by those who need to apply it, and with an obvious cost-benefit advantage. Guidance also needs to be internationally based, and of obviously sound provenance.

Ergonomics now has an internationally agreed definition of practice, and has placed greater emphasis on ease of application. As a discipline it is now better placed to produce guidance that is easily used. This definition of practice provides a focus for awareness raising, experimentation and solicitation of agreement.

Feedback from users to inform design evolution is an important next step, along with highly tailored requirements and guidelines.

ACKNOWLEDGEMENTS

Sections 3.1, 3.2 and Table 1 are abstracted from the cited standards.

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Table 1 — ISO 18152 Human-system life cycle processes

Process Category	Sub-processes
Life cycle involvement This process anticipates the particular human-system issues at specific stages of the life cycle. It makes the system life cycle efficient by addressing people in the stage enabling systems for the system of interest.	• Human-system issues in conception • Human-system issues in development • Human-system issues in production and utilisation • Human-system issues in utilisation and support • Human-system issues in retirement
Integrate human factors This process ensures that human-system issues are addressed by the appropriate stakeholders. It reduces life cycle costs by ensuring that design for people is used within the organization.	• Human-system issues in business strategy • Human-system issues in quality management • Human-system issues in authorisation and control • Management of human-system issues • HF data in trade-off and risk mitigation • User involvement • Human-system integration • Develop and re-use HF data
Human-centred design This process enables user centred technical activity to be focused appropriately. It contributes to a better system by designing for people who use the system of interest in its context of use.	• Context of use • User requirements • Produce design solutions • Evaluation of use
Human resources This process provides the means to resolve issues by means of the human part of the system, rather than the equipment-centred part. It ensures the continued delivery of the correct number of competent people required to use the most suitable equipment.	• Human resources strategy • Define standard competencies and identify gaps • Design staffing solution and delivery plan • Evaluate system solutions and obtain feedback