Do our complex systems meet requirements? An example from naval ergonomics

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ABSTRACT

Throughout the produce or services lifecycle, the assessment of the ergonomics contribution to system development evolves to ensure that designs meet requirements. This is particularly important towards the final stages when assessment is against operational scenarios. Current assessment techniques are examined, and exemplified using experience from current work on naval systems, and User System Architectures (Tainsh, 2016). Assessment techniques for contributions to operational scenarios are proposed using risk-based metrics which include the criterion 'Risks At Operationally Acceptable Levels (RAOAL)'.

KEYWORDS

Naval ergonomics, User System Architectures, requirements, assessment.

Introduction

Stanton, Salmon and Walker (2016) consider the much-increased scope of the issues that ergonomists now address, in comparison to the physiological or psychological based work such as that from the 1960s (e.g. as described by Murrell, 1965). They point out that ergonomists may now address whole systems rather than portions or components of systems, and investigate the interaction between subsystems. However the techniques for assessment appear to be in need of development. It was concluded that the use of controlled experiments could provide limited design information. Hence, they suggested, a novel approach is required. This outcome is important not only for maritime systems (such as those where systems engineering organisations such as BAE Systems might be a stakeholder) but also to a more general set of complex systems outside the maritime application.

The work of Stanton et al., in the open journals, is a welcome development: Much of this category of methodological thinking in the past, has been only available to a limited audience within defence scientific communities e.g. UK MoD's BR93002 which reported on similar 'Future Command System' studies over 30 years ago.

For many years, the basis for assessing the ergonomics aspects of system design has been considered with few alternatives developed in a systematic way. The assessment approach was founded on the use of information obtained under conditions of controlled experiments. Typically this meant that the controlled experiments involved a single user with equipment, or small teams with workstations. The intention here is to show how this approach may be supplemented in order to help decide whether a system meets its ergonomics requirements.

The problem

This paper starts from an examination of requirements for complex systems and a possible User System Architecture (USA) description of their work. In this example, a Command System is discussed, and its work within a maritime environment. The intention is to consider how the USA may lead to improved general methods and techniques for ergonomics, and specifically, improved assessment processes for naval complex systems.

The overall aim is to propose an assessment technique that will support a decision on the fitness, as defined by a set of operational scenarios, of a complex system to meet its high level operational requirements. This includes its ergonomics contribution.

Investigation and analysis

The UK MoD uses MAP 00-010 and 00-011 to address the management and technical aspects of ergonomics within development programmes for complex maritime systems. It is described as a ‘Whole Ship’ approach.

MAP 00-010 and MAP 00-011 provide top-down ergonomics guidance for the ‘Whole Ship’. It may be used to generate ergonomics requirements for a wide range of maritime design and assessment purposes.

The content of MAP 00-010 and 00-010 can be represented in an architectural structure for requirements purposes. The document architecture is given in Tables 1 and 2. These use the conventions of layered description as described by Tainsh (2016).

Table 1 gives the upper two layers which apply to many defence developments. These include UK Law and UK defence policy.

Layer 3 gives the operational requirements which will include scenarios associated with a variety of technical requirements including those for ergonomics. The importance of health and safety is emphasised as some of the professional ergonomics activities are managed to ensure compliance with the HSE requirements.

The ‘Whole Ship’ approach starts from an initial concept for the vessel linked to a set of operational, maintenance and other scenarios that are required of it. These scenarios will be used to inform layer 4: the vessels characteristics including topics such as form, structure and spaces allocated for work purposes e.g. accommodation, messing arrangements, passage ways, bridge and operations room. The spaces/volumes will be specified in conjunction with consideration of the numbers of personnel and their jobs.

The lower layers of the USA for ships and their systems are shown in Tables 2a and 2b. Layers 5, 6 and 7 describe the work of small groups of operational and maintenance personnel. In the case of smaller craft the size of the groups may be one or two, but several hundred and more, for a larger vessel. Layer 8 contains standards information, and other design and assessment criteria.

Only after the high-level decisions have been made (e.g. defence policy, expenditure and naval operational requirements that lead to the specification of scenarios, and high level consideration of the vessel), are the more detailed technical issues addressed. These start with the overall vessel engineering characteristics and its functions with those of its systems.

Table 1: High level USA view of requirements documentation for Royal Navy ships and their systems

Layer number and name	Human factors topics to be addressed for maritime systems by UK suppliers.
Layer 1, Highest level of national and international influence	UK Law including Health and Safety at Work Act 1984.
Layer 2, Defence policy and expenditure	Ministry of Defence policy, including Defence Lines of Development.
Layer 3, Statements of requirements	User Operational Requirements (including scenarios), System Technical Requirements, MAP 00-010, MAP 00-011 which specify management approaches and technical areas with issues to be addressed.
Layer 4, Operational Layer	Whole Ship designs giving the descriptions of the, spatial arrangements, the functions to be performed within them, and some ship characteristics. It will provide high-level statements on complement and training requirements. It will include a statement on standards.

The high level ergonomics issues will include topics such as manpower, including complement recruitment, retention and training.

The lower layers of the description are provided in Tables 2a and 2b. The design viewpoints cover jobs, roles, equipment training and the spatial arrangements for compartments and related spaces. This is done in conjunction with assessment of the work of the team within, for example, the bridge, operations room, ship control or other operational spaces.

The shortcomings of the traditional approach

The MAP documents provide guidance on a wide ranging set of ergonomics design issues to support requirements formulation and design activities but they are less clear on assessment techniques for complex systems.

From a systems engineering viewpoint, the MAP documents emphasise the spaces and volumes for ship design, and locations for the positioning of equipment. They lack detailed consideration of the functions of the systems and the component equipment and personnel. They have little detail on the means to handle the interactions between the systems, subsystems and equipment system, or the means by which such interactions may be assessed.

The lack of detailed consideration of the systems engineering aspects is a consequence of the rapid development of the field of complex systems engineering. The perceived danger is one of ‘solutioneering’. Hence there is a gap in the area of assessment that needs to be filled i.e. how can the information contained within the Tables 1 and 2 be used to show that the systems of equipment, tasks and personnel which are being developed, can meet the scenario requirements?

Table 2a: Requirement documentation USA showing the Lower Layers and Viewpoints

	Miscellaneous spaces	Operational spaces		
Layer 5	Those supporting the operational role.	Those spaces and compartments are directly concerned with controlling, manoeuvring and administering the vessel in its operational role.		
Layer 6	Storerooms, workshops, briefing rooms, passageways	Bridge.	Operational/weapon control.	Ship control and machinery spaces.
Layer 7	Provision of doors, hatches, ladders etc.	Layout of equipment and users' roles.	Layout of equipment and users' roles.	Layout of equipment and users' roles.
Layer 8	Standards and other assessment information			

Table 2b: Requirements documentation USA showing the Lower Layers and viewpoints

	Manpower, complement	Crew and training	General arrangement	Accommodation spaces
Layer 5	Watch and Quarter Bill.	Target Audience Description for roles.	Internal dimensions and layout of compartments.	Spaces for recreational and domestic purposes.
Layer 6	Personnel and roles for operators and maintainers. Work organisation.	Size, shape, strength. Skills and knowledge. Training and experience.	Internal platform layout, movement and handling, internal communications, habitability and internal environment.	Bunks and personal accommodation, messes, bathrooms.
Layer 7	Personnel and roles within scenario.	Competency statements.	Organisation of major items of plant within vessel.	Provision of domestic furniture.
Layer 8	Standards and other assessment information			

The assessment of complex maritime systems

Following examination of the requirements, the architectural development may include the production of layered descriptions such as shown in Figure 1 (Tainsh, 2016). The layers where combinations of subsystems are bought together to meet scenario requirements are given in layers 2 and 3 while the lower layers of the USA description provide the details of people, tasks and equipment.

Figure 1 shows a USA with seven layers of description. The Viewpoints here have been defined by three stages within the scenario. These are:

- Awareness
- Decision-making
- Control action

It should be noted that the layers in Figure 1 are numbered differently from those in Tables 1 and 2. This is a matter of convention and there must be a mapping of one set of layers upon the other.

The question then is: how would the USA description provided in Figure 1 be used to meet the needs of future systems engineering assessments?

An example is given here using an operational scenario carried out by a Command Team as shown in Figure 1.

There are three possible ergonomics approaches to the development of assessment techniques:

- The first is to carry out a programme of controlled experiments addressing features of individual tasks and equipment. This programme could investigate all possible design applications at the level of users with individual workstations, or at most small groups. The implications of this approach for the whole of a Command Systems would mean that a very large number of experiments would be required to supplement the established knowledge available from standards or other sources. This approach is typically applied at layer 6 (Figure 1) where equipment designs may be well understood. However it would be impossible to carry out such a programme for the whole of a major complex system.

- The second is to carry out a programme of controlled experiments on combinations of workstations, and use organisational/communication/interaction/functional descriptions to better understand the interactive characteristics of a subsystem. This approach will sometimes be used at layer 5 (Figure 1) where cooperative behaviour is required within subsystem teams but detailed interaction information is not always available, particularly for new items of equipment. Hence the interactive properties may be examined on specifically built rigs or assessed by qualified personnel. It would be impossible, even where there is supporting information to investigate the total set of features within a complex system.

- The third is to use systems engineering/USA techniques to express system design requirements taken from Layers 1 and 2 in Figure 1, and develop scenario descriptions with performance characteristics. This can then provide a set of performance criteria to be used in comparisons with the implementation as described within the layered structure as shown as layers 3 and 4 of Figure 1.

The description in layers 3 and 4 will take account of the user performance information from layers 5 and 6. The performance information may be based on available performance estimates but will almost certainly be supplemented by professional judgements.

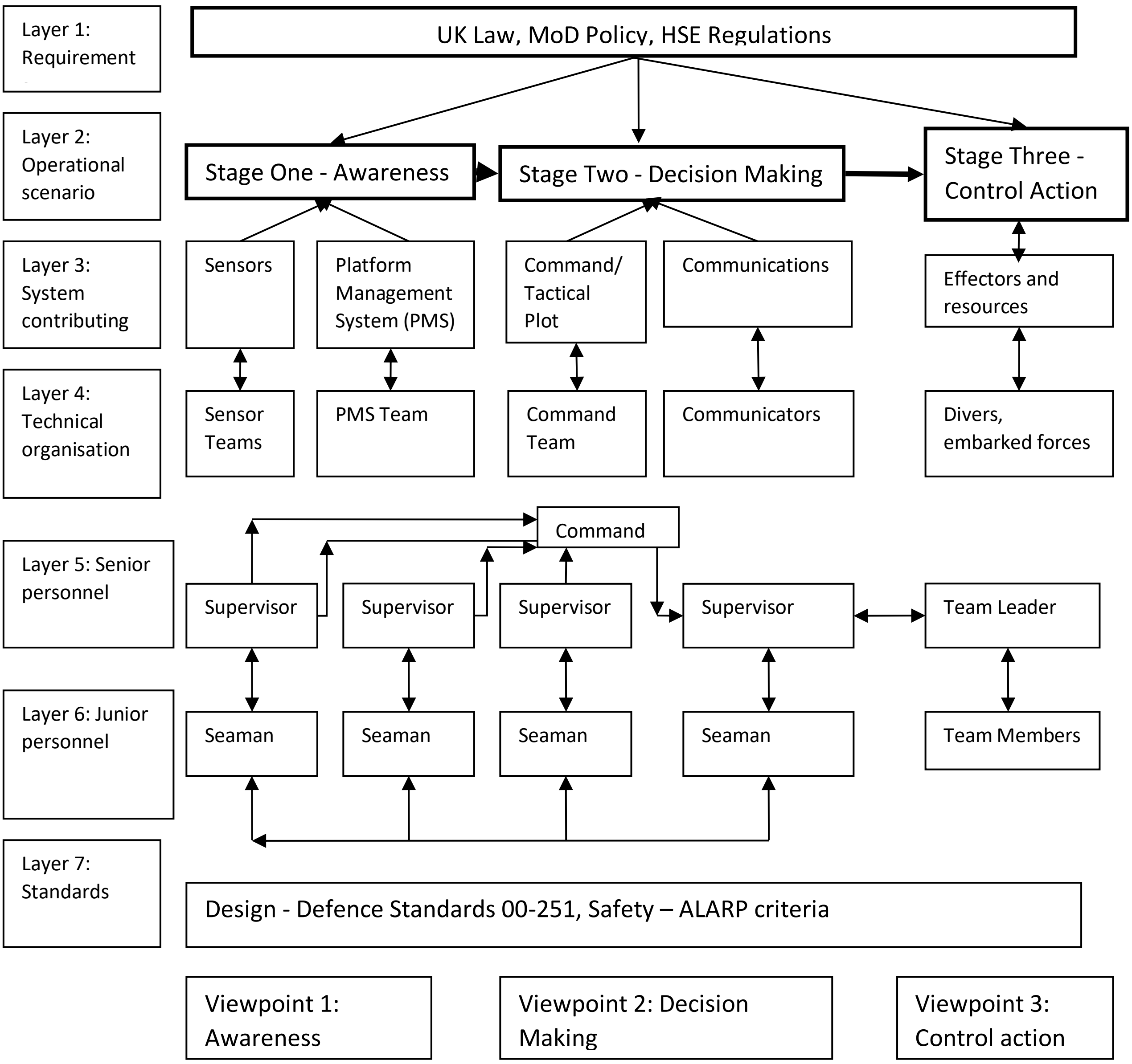

Figure 1: Generalised USA for a ship's Command System operations showing Layers and Viewpoints based on operational scenarios

User system architectures: people, task and equipment characteristics

The systems engineering assessment problem is to show that the system(s) of people, tasks and equipment that has been designed and developed can function, in the case of Figure 1 as a Command System, and fulfil the requirements placed upon it expressed in an operational, maintenance or other scenario.

Given that the requirements can be expressed in functional/performance terms and the subsystem designs can be understood in terms of performance, there is a need for a means of carrying out an assessment based on a comparison of assessed system performance against required performance with a view to inferring whether the design meets requirements.

The proposal here is that designs are assessed by professional qualified and experience Users throughout the system development lifecycle to meet the criteria: Risks At Operationally Acceptable Levels (RAOAL).

Assessment of complex system design – RAOAL

The RAOAL proposal, is to use a criterion analogous to As Low As Reasonably Practicable (ALARP) in safety work. In this case, the design aim is better requirements or to reduce risk to a degree that RAOAL criteria are achieved over the lifecycle of the system.

The RAOL assessment technique involves using a risk assessment matrix (Figure 2). Highly unlikely may be quantified as once per 25 years, unlikely as once within two years and likely every one or two months.

		Potential degree of performance loss during scenario		
		Systems experiences slight difficulties within scenario	Systems experiences minor loss of performance	Systems involves major loss of performance
Likelihood of loss occurring	Highly unlikely	Trivial	Tolerable	Moderate
	Unlikely	Tolerable	Moderate	Substantial
	Likely	Moderate	Substantial	Intolerable

Figure 2: Risk Assessment Matrix to assess achievement of RAOAL criteria

This risk matrix supports an assessment conclusion where major losses (substantial or intolerable) are to be avoided entirely. Categories including moderate and tolerable may result in a conclusion of more work necessary to investigate options, and the design work aims for the category where performance loss is trivial and unlikely.

This risk assessment process can be used to compare the performance levels for layers 3 and 4 against layers 1 and 2 in the case of accepting a system against the requirements of operational scenarios.

Each of the systems contributing to the scenarios will be assessed, using the matrix, by professionally qualified and experienced users or maintainer. The focus of their attention will be the ergonomics contribution associated with layers 3 and 4. Equally such a risk assessment process may be applied throughout all USA layers to ensure that adjacent layers support one another.

The operational problem is that small failures in performance can combine with intolerable consequences. Hence the risk gathering and risk assessment process must be conducted in a way that is commensurate with the impact of the outcome, so that mitigation can be put in place. Risks that involve the loss of the vessel, or mission failure, are clearly given the highest priority.

The detailed techniques for handling assessment and design information for systems of this complexity are still poorly understood with few reports in the open literature. The USA approach described here appears to be open to development and validation. Hence this is an area for ongoing work within BAE Systems.

Conclusions

There is, currently, a need for assessment techniques for comparing operational task performance in naval scenarios to that observed with users on sets of equipment within major maritime systems.

The use of risk matrices by suitably qualified personnel, for assessment purposes is proposed as a technique to support the lifecycle development process for complex systems. This would have benefits for both maritime and general applications as they appear open to development and validation.

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