Modelling User Contribution to Capability Within a Supervisory Control System

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ABSTRACT

Supervisory control is a common category of system employed for many surveillance applications and is a continuing subject of interest to ergonomists. During their development, following an initial statement of system requirements, capability options need to be assessed to understand the contribution of design features to system effectiveness. One technique that can be employed is capability modelling which aims to generate predictions of outcomes dependent on initiating events. A novel capability modelling technique is proposed based on an integration of ergonomics research results and professional input.

KEYWORDS

System development, capability modelling, supervisory control

Introduction

Over recent years there has been a trend to develop supervisory systems, where the person carrying out the controlling and the object being controlled become ever more separated and the controlling process more complex. Previous maritime studies have addressed some of the general aspects this topic (Tainsh, 1982). However, there is little ergonomics modelling work to address the broader systems design issues that are identified early in the development cycle when we work with our engineering colleagues to develop design options. This modelling work could include capability modelling (Lindbom, Tehler, Eriksson and Aven, 2015).

Hence, it is useful to briefly review the results from research studies to support the development of a modelling technique to support capability studies of future systems.

This work focuses on modelling at the early stages of the development process before the start of design work. It addresses system capability and system architecture and capability. The systems engineering aim is to model capability which leads on to system architecture and design. The foci of this work are users with their equipment, and the means of achieving predicted goals.

It appears common for work on capability to take account of the organisational issues and hence this approach provides a useful starting point for ergonomics.

The aim of this study is to model the user characteristics of future capability of supervisory systems prior to the architectural stage of the development process.

Initial Considerations of Development and Architecture

The starting point is an approach based on the development process as given in ISO 15288 (2013).

In ergonomics, the use of a layered functional model of user characteristics has been referred to as a User System Architecture (USA) (Tainsh, 2018). This functional description provides a framework which can be populated by human/organisational detail of the roles, tasks and the activities to be carried out.

The issues to be addressed initially are:

1. Execution of Capability:
   (a) The system capability should match the demand required to a level that meets the risk requirements.
   (b) The human contribution must match the contributions of the other parts of the system, its hardware, functionality or other features.
2. The characteristics of the control process. The progress of the controlling activities needs to be understood so that it matches the required operational timescale.
3. The team organisation. The team members who may be remote from each other and the items being controlled.

Literature Review

Lindbom et al address the issues associated with preparing a system for uncertain outcomes. They have provided a definition of capability:

> "A description of capability based on our definition includes descriptions of the initiating event, the performed task, the consequences associated with the performed task, the uncertainties concerning these consequences and the background knowledge, which form the basis for these descriptions."

Capability is associated with the consequences of the system's operation. We wish to model the human components of the capability to indicate the potential of the system to manage uncertain events. This work suggests that we employ a concept of capability with a consideration of roles, organisation and resources to link with a concept of risk. It provides a set of concepts from and engineering background which enable us to link ergonomics issues into a broader disciplinary framework. Risk is defined in terms of uncertainty of outcome and the severity of the consequences.

Large scale systems and levels of automation

Sheridan (1983) specified the characteristics of supervisory control which included operators working remotely from the object or events under their control. He characterised the control tasks as having two components initialisation and performance. He provided a detailed set of considerations of the advantages and disadvantages of various design strategies.

Supervisory Control

Sheridan and Hennessy (Workshop 1984) characterised a supervisory control system and the tasks that could be carried out by it. The importance of the user trusting that the system will carry out its allocated functions was emphasised, along with the complementing levels and where control was located.

Management of Multiple Dynamic Human Supervisory Control Tasks

Mitchell and Cummings (Workshop 2005) linked the concepts associated with levels of automation with workload and the damaging consequences of overloading. This is placed in a context of information waiting to be handled so that the time taken to switch from one object to another may result in undesired consequences.

Team Behaviour

Artman (2000) investigated team behaviour and its dependence on the allocation of tasks within the team. In particular, it is important whether team are carried out in serial or in parallel as there may be “overheads” in the amount of communication within the team as a consequence.

Ecological displays

Burns (1999) investigated ecological displays to understand the design criteria and parameters to ensure effectiveness. In the course of this work, it was possible to investigate the characteristics of the users when visual scanning. This is important as it yields evidence of how users perform the task of understanding the situation that they are attempting to control.

Initial considerations

The following topics need to be addressed and variables represented so that they can be included within the modelling process:

- The roles/tasks/events that enable the goal to be achieved. The set of roles, tasks and events that can be modelled depends on the performance data available. It appears that much of this data is held within proprietary databases.
- The acquisition, collation and integration of information are likely to be component tasks of any but the simplest of control systems and are very likely to be included within a system with multiple sensors and users.
- Time-based performance characteristics. In the MoD UK, maritime world, we have the benefit of work carried out over 40 years ago at the EMI Laboratory for the MoD. The validity of this performance data underpins the value of this technique.

- Performance of controller and the exercise of control via a control loop is likely to be an important focus of any investigation of supervisory activities, to understand how performance on decision-making may depend on system design - including the implementation and use of automated functions.

The Approach

The highest level statements within the USA will be expressed in operational and systems engineering terms. For ergonomics practitioners with systems engineering, a User Systems Architecture (USA) provides a framework (i.e., a structure with a set of design constraints) that provides a starting point for the development of the representation.

A generic layered description for a supervisory system working for surveillance purposes is given in Table 1. This applies to both individual users and a team working together.

Table 1: A description of the USA layers

Layer number	Layer Name	Brief description
1	User goal, scenario/ context and constraints	A description of a context in which the system operates
2	Business description	The business processes which satisfy the scenarios
3	A technical description	Overall technical system structures, forms and processes
4	Users' roles and team organisation	An ergonomics description of the team its organisation and individual roles.
5	Individual User's characteristics and tasks	Each participants tasks, activities and personal descriptions

The approach to capability modelling

The organisational arrangements (Figure 1) to support the control of the surveillance system are similar to those previously described in this set of investigations (Tainsh; 2018).

The approach has been:

- The first stage is to verify the description of information associated within the USA and the implied control loop as described in Figure 1. While there may be maritime traditions that have to be taken into account, the use of automation is likely to be widespread even when unnoticed by the users. The work of Sheridan is useful to help understand the characteristics of the USA.
- The control loop(s) are central portions of the modelling process, and it is critical to ensure a full understanding of this loop to enable a valid investigation which includes the assignment of performance values to the activities and tasks.
- The assignment of performance values is associated with at least two major difficulties dependent on the processes which are being controlled:
  (a) learning;
  (b) boredom and fatigue.
- The assignment of values to the performance characteristics needs to be agreed/validated in discussion with user representatives.

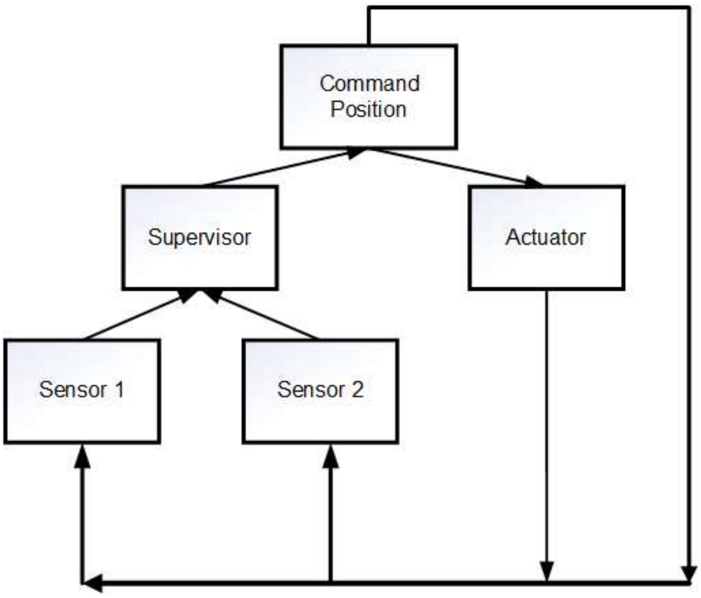

Figure 1: Control diagram for supervisory system showing roles and information flows

Design criteria for this model

Investigation of Resource Demands. For many years, there has been a concern in system design that users were likely to be overwhelmed by the rate of data coming into a control system. However, there are no techniques to help understand the extent of the problem or its mitigation. The model must be open to the investigation of a variety of demands.

Investigation of Automation and Complement. The introduction of automated functions is sometimes unnoticed for example the user of algorithmic techniques for signal processing would often never be considered as automation by ergonomists. However, there are many cases where automation impacts directly on the way that users carry out control tasks and the system effectiveness. Hence the technique must be able to investigate alternative automation techniques.

Investigation of Potential System effectiveness. For many maritime systems, the prime requirement is to be effective, and that means enabling the system and the users within it to carry out control actions as swiftly and accurately as possible. This technique is required to indicate that time-based schedule of the outcome of its controlling actions.

A Generic Model

The current model has been implemented in an Excel spreadsheet using the standard Excel functions and the information provided above. Initiating events are specified. There are limitations when using a spreadsheet in some applications but in this case the accuracy of the calculations was estimated to be in line with the accuracy and precision of the values of the performance variables.

The generic characteristics of the user components of the model are shown in Figure 2:

- Process 1 involves detection and includes initial assessment which enables the object being controlled to be moved to the next process i.e Process 2. The learning here will involve knowing that an object has been detected.
- Process 2 will involve the main controlling processes and involve understanding the classification of the object and the necessary controlling activities.
- Process 3 is included here to include the handling of objects which involve high levels of risk and need to be handled differently from those handled in Process 2.

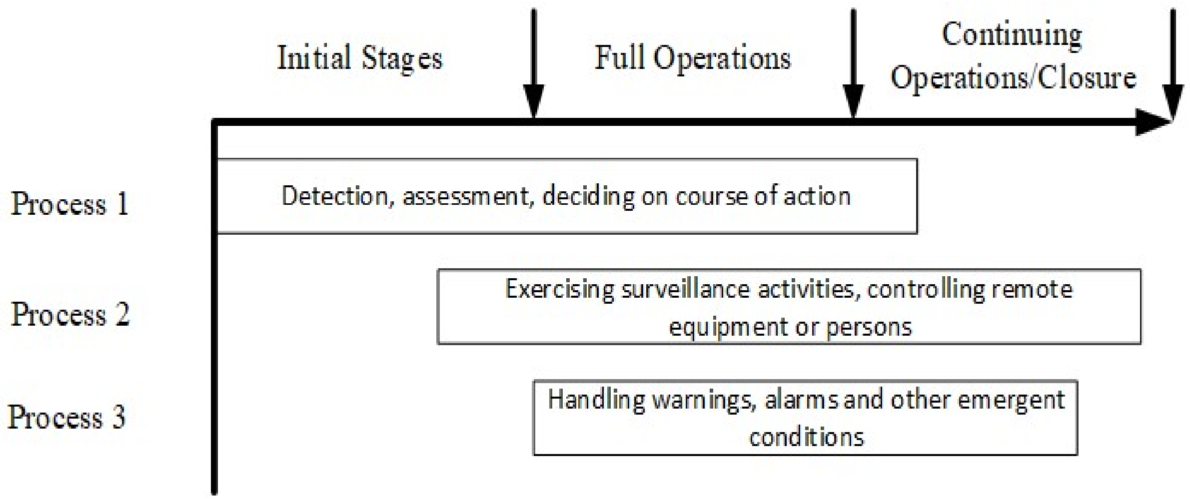

Figure 2: Timeline for Operations

Results

The table of technical information used in this study is given in Table 2.

Task models are derived for each user role, the sets of tasks and activities as specified within the USA. In each case the role, task and activities model have similar characteristics to that shown in Figure 2. Clearly these will depend on the application and requirements but in the maritime applications investigated up until now, there appears to be a common pattern.

Table 2: Technical information used in within the modelling technique

Descriptor	**Range of values**	**Reference**
Role and Task design	Goal dependent	Sheridan, T. B. (1983) and Sheridan, T. B. et al (1984)
Scan times	Within the range 15 – 120 secs	Burns, C. M. (1999), Mitchell P. J. et al (2005)
Performance times for mouse with flat screen	Detection 5 secs, Appreciation 5 secs, Selection/Deselection 5 secs	EMI Electronics (1979)
Performance Shaping Factors for learning	Within the range 0.25 to 1.0	Experience with Users
Allocation of resources at individual and team levels	Within the range 0.1 to 1.0	Experience with Users
Effectiveness and safety criteria	Scenario dependent	In agreement with Users
Team Organisation	Serial versus parallel organisation	Artman, H. (2000)
Supporting equipment functionality	Equipment dependent	In agreement with system engineering specialists
System architectural options	System dependent.	In agreement with system architectural specialists

The results for the whole control team can be aggregated as shown in Figure 3. This shows the performance of one team (successes and failures) in the event of three possible sets of initiating events: low, medium and high demands. In each case, it was seen that user performance starts at a relatively low level as the tasks develop and then both success and failure will change dependent on the characteristics of the role, task and activities. With low levels of demand the control achieved must be balance against potential failures but given time the situation appears to come under control. In the case of medium demand the situation may be brought under control but the time taken may be unacceptable.

In the case of high levels of demand the situation incurs the possibility of moving out of control with an unacceptably high level of failure.

The design aim is directed towards understanding the capability required to handle normal, extreme or other sets of circumstances that may define demand.

The use of figures such as this show performance against requirements. In particular, it can be seen that for this team as the demand associated with the initiating event(s) increases, the risk of failure increases. Hence, we can estimate the likely maximum performance for varying levels of demand and help understand the risk.

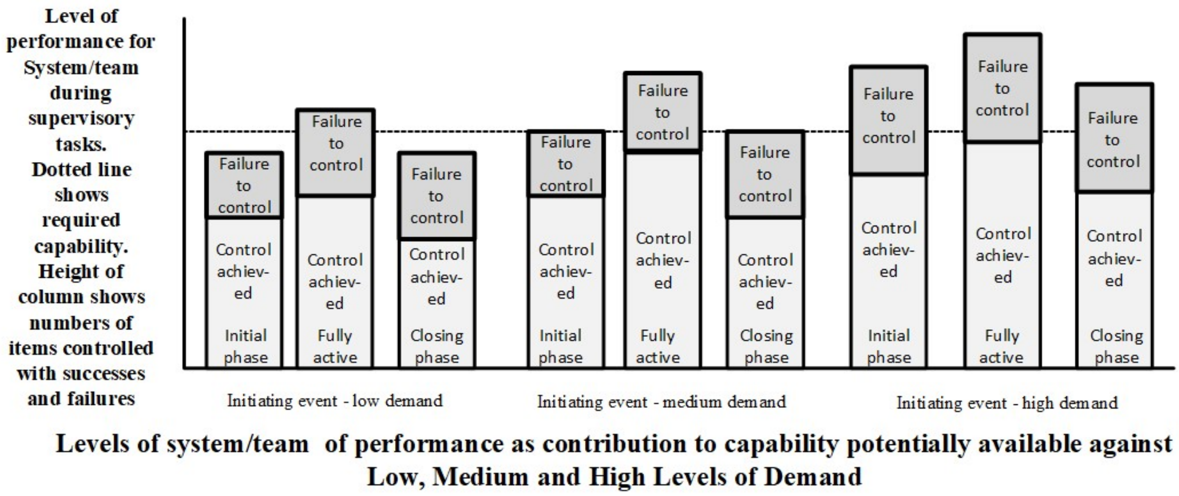

Figure 3: Capability available dependent on stage and level of demand

Conclusion

The precision and accuracy associated with the predictions given in Figure 3 may be lower than we might wish for. However this technique does offer a means of understanding better the consequences of design options when predicting capability. The model becomes available to the team - enabling debate. It has been used to show the sensitivity of design variables (e.g. allocation of function within the team) on capability.

In line with the definition of capability, it is possible to model initiating events and understand better the possible outcomes and areas of risk that may need to be addressed. Figure 3 showed that consequences of meeting three levels of demand.

This technique has been used in BAES to understand manning options for teams of up to three persons. This has enabled designs to be assessed and indications provided on bottlenecks associated with information flow. It has aided understanding of potentially important design issues while helping to understand which variables can safely be considered low risk.

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