MODELLING HUMAN PERFORMANCE IN SEMI-AUTOMATED SYSTEMS

AJ Bunting & AJ Belyavin

DERA Centre for Human Sciences, Farnborough, UK

ABSTRACT

The analysis of the human component of complex systems is an important element of the design process at all stages. This paper outlines the application of task network modelling to the identification of critical subtasks in the interaction between man and machine. By applying the Integrated Performance Modelling Environment (IPME) tool developed by Micro Analysis and Design Inc. under contract to the UK Defence Evaluation and Research Agency (DERA) it is possible to consider the effects of both environmental stressors and workload in conjunction with subsystem performance.

Under different operational conditions aspects of crew performance will be affected differentially. As a consequence, the aspects of system operation which lie on the critical path may change.

The application of IPME to the analysis of a simple case study is described. By considering the variation of task performance with operational conditions, critical paths are identified and overall system performance quantified. The automation of specific system elements is investigated and it is shown that overall performance can be optimised whilst minimising the cost of modification.

INTRODUCTION

The analysis of the human component of complex systems is an important element of the design process.

The case study examined in this paper concerns the benefits of automation of elements of a ground-based military air defence unit. Operation of this unit is time critical, with the probability of a successful intercept highly dependent on the time taken to respond to an incoming threat. The process must be optimised to maximise system effectiveness.

In principle, the simplest method of assessing the system is to set up a man-in-the-loop simulation. However, this may not always be practicable, for example where a system is at an early stage of design. Moreover, this is unlikely to be a cost effective approach if it is necessary to assess performance where the operators may be suffering from performance degradation - e.g. mental fatigue. The application of man-in-the-loop simulation across the range of possible degradations is a substantial undertaking, and it is unlikely to be cost effective to explore all the possibilities.

The focus of this paper is the optimisation of system performance by constructive simulation, whilst giving appropriate consideration to the expected range of operator and operational conditions.

METHODOLOGY

Background

Modelling human performance in systems has been an area of active research for at least twenty years. A popular approach is to use task analysis as the basis for the dissection of what the operator has to do, and then to simulate the system and operator elements together using task network modelling. Examples of tools which use this approach are HARDMAN (1), IMPRINT, and MicroSaint(2), developed for the US forces. In parallel with the development of frameworks for analysing operator performance in systems, there has been some attempt to systematise understanding of cognitive and physical performance by defining taxonomies (3), (4) and other models. A good example is the model human processor (5), outlined in 1986.

The approach adopted in the present study was to define the operation of the air defence through a series of well defined tasks, some performed by the system and some performed by the operator. Simple attack aircraft tracks were then generated, and the time for missile launch was assessed. The system was simulated using the Integrated Performance

People in Control: An International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centres:
21 – 23 June 1999, Conference Publication No. 463, © IEE, 1999

Modelling Environment (IPME), developed for the UK MoD under the Corporate Research Programme, following designed simulation experiments. Areas for potential system improvement were identified and quantified.

The Integrated Performance Modelling Environment (IPME)

Version 1 of IPME has been developed during 1994-1998 and is based on the MicroSaint discrete event simulation engine (6). It supports representation of the tactical scenario, the operator characteristics and the operator and system interaction.

A complete system model in IPME consists of four interrelated sub-models: Environment, Operator, Performance Shaping Functions (PSF) and MicroSaint task network, which relate according to the influence diagram shown in Figure 1.

Environment - The Environment model consists of a series of defined variables, collated into four groups - Physical, Mission, Crew and Threat. The values for the variables can be modified and linked through equations that define how they evolve and relate as the simulation develops. It is possible for the user to add variables to the threat group, but for the other three groups the variable sets are fixed.

Operator - The Operator model consists of a set of operators each with defined characteristics. For each operator the characteristics are divided into three groups: traits, states and properties. All the characteristics are expressed as variables that can be given both specific values and can be defined as expressions that depend on other models in the simulation, e.g. the characteristics of the Environment. For example, the current operator alertness can be made to depend on time of day.

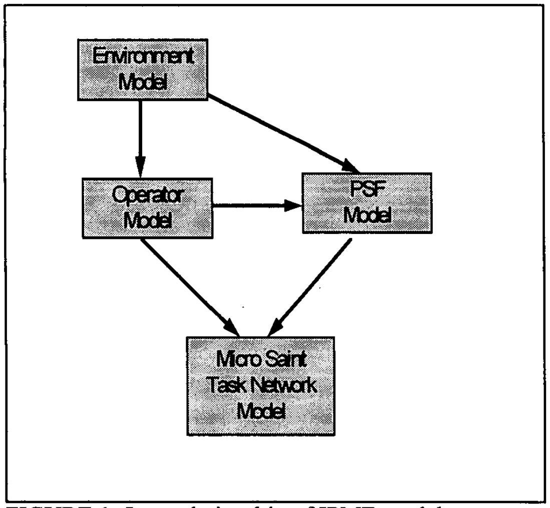

FIGURE 1- Interrelationship of IPME models

Performance shaping. The Performance Shaping Model is a system of expressions that provide modifiers to task times and errors, derived from the Operator and Environment models. Tasks are allocated to a taxonomy and each Performance Shaping Function applies only to particular elements in the taxonomy. Thus, for example, it is straightforward to degrade cognitive tasks when the operator is mentally fatigued, yet retain normal performance on purely motor tasks.

Task network. The task network is the active component of the environment, since it provides a definition of the tasks to be performed and the logic flow between the tasks. Interaction with the other models in the system is through the variables and expressions set up by the user, and these can be applied as the modeller sees fit. The simulation engine supports all the syntactical elements of a programming language, where tasks, nodes, queues and variables are the key objects in the language. Since the language is complete it is possible, in principle, to code any form of behaviour that is desired. Complex behaviour patterns are currently difficult to programme, and this is an area where some development is envisaged.

Where two or more tasks are performed concurrently by the same operator, the potential degradation to each in terms of time to perform and task accuracy is calculated. IPME has access to two algorithms: the DCIEM IP/PCT model (7) and the DERA POP algorithm (8). The degree of interference is dependent on the nature of the tasks involved and the resultant workload placed on the operator.

The IPME embodies a simple method for setting up a structured simulation experiment, varying the model parameters in a controlled manner. This feature was used to control the experiments undertaken in the present study.

The Air Defence Unit

A simplified overview of the operation of the air defence unit (ADU) under consideration is given in Figure 2. After receiving a warning alarm, three key processes must be completed before the unit can engage the target:

Check Orders - The operator must make sure that current orders permit engagement of the target.
Obtain Good Track - The operator must manually move crosshairs onto the target using a joystick.
Identify Target - The operator must visually identify the target as a threat.

These processes may be performed in parallel, subject to an upper workload limit determined by the capability of the human operator.

Each process was modelled in detail within the IPME framework. A total of 36 tasks was identified from initial alert to missile in flight, and the logic flow was defined to represent the sequence of operations to be performed during the engagement. Some tasks were to be performed by the operator, and others automatically by the system.

The process of checking orders was represented by modelling the time elapsed for the individual information gathering processes and decision making activities performed by

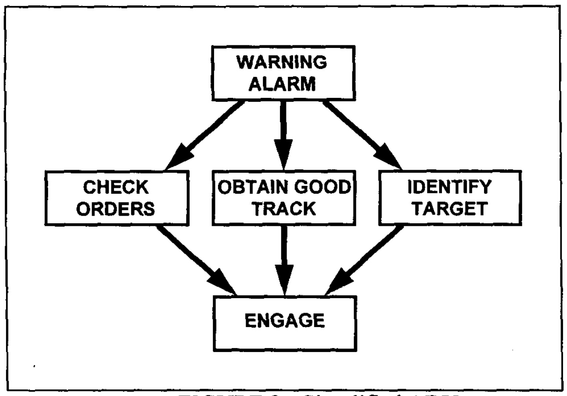

FIGURE 2 - Simplified ADU system

the operator. The process of visual identification of the attack aircraft was based on the calculations used in the BAe ORACLE model (9). Probabilities of detection and identification were calculated for 1/3 second glimpses, based on the current range of the target and the current meteorological state. The identification process was then modelled as a repeatable fixed length task taking 1/3 second which either repeats or completes successfully, depending on the probability of detecting or identifying the attack aircraft at each task execution. This mimics the process represented in the ORACLE model, but permits arbitrary target tracks during IPME model execution. The process of acquiring a good track was modelled from laboratory experimentation using a variety of control laws, and the process represented as a single task with a time distribution.

Operational Conditions

A range of operational conditions was considered by varying target type, visibility and operator alertness state, as given in Table 1. These were selected as an arbitrary subset of factors thought to have the largest impact on system effectiveness.

Target type and visibility primarily affected the target identification task through the ORACLE model. Operator alertness affected a variety of tasks through the performance shaping model. The quantitative model of the effects of time of day and time since sleep on the mental alertness scale used in the IPME has been developed at DERA CHS and its predecessor organisations, and is described in detail in a DERA internal report (10). In the simple case where an operator is entrained to the local time of day, the model is composed of two additive components: a sinusoidal component which varies with clock time; and a decaying component which varies with time since the operator last slept (see Figure 3).

Other operational variables which might have been investigated include the impact of training and experience, thermal stress and protective equipment. However, the effects of these factors are not reported here.

Target type	Fixed wing Rotary wing Late unmask rotary wing
Visibility	Good Overcast
Operator State	Alert Fatigued

TABLE 1 - Operational conditions

Experimental Design

The objective of the present study was to highlight and quantify aspects of the engagement sequence which would benefit most from additional automation.

A series of automation options was to be considered. As a full factorial replication of every mission variable was computationally impractical, the analysis was performed in two stages. Initially, the critical paths through the launch sequence were identified for each condition combination, using a limited number of baseline simulations. A particular automation option would show a similar improvement in different experimental conditions, provided the same critical path was followed. Therefore a subset of the experimental conditions could be selected which was representative of the environment as a whole. A more detailed simulation study could then be performed on this reduced environment set.

SIMULATION RESULTS

Critical path analysis

The task elements which lie on the critical path of the launch varied on a run-by-run basis due to the stochastic nature of the model (and underlying processes), and also varied with operational condition. The observed probability of each of the three main activities lying on the critical path for a range of scenarios is shown diagramatically in Figure 4.

From this analysis it was observed that improvements to overall system performance would primarily arise from additional automation of the identification process and/or the target tracking.

The time taken to engage late unmask rotary wing targets was critically dependent on the time taken to obtain a good track. The time taken to engage fixed wing targets was critically dependent on the time taken to identify the target when the operators were alert, and on the time taken to obtain a good track when the operators were fatigued. Based on this critical path analysis, a reduced number of condition combinations was selected for more detailed examination.

Selection of automation option

The relationship between launch time and probability of a successful intercept had been examined in a previous engineering study. An objective function was formulated and weighted for target type so that a single figure of merit could be derived for each automation option, based on the amount of time it saved in each experimental condition.

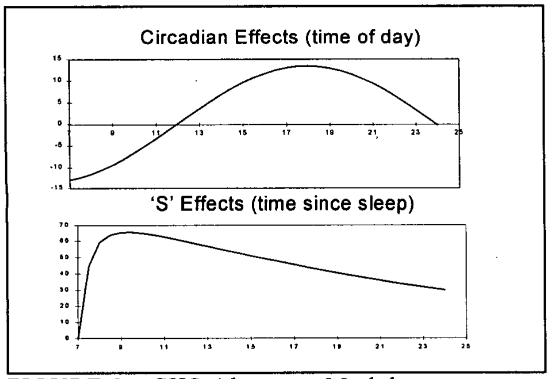

FIGURE 3 - CHS Alertness Model

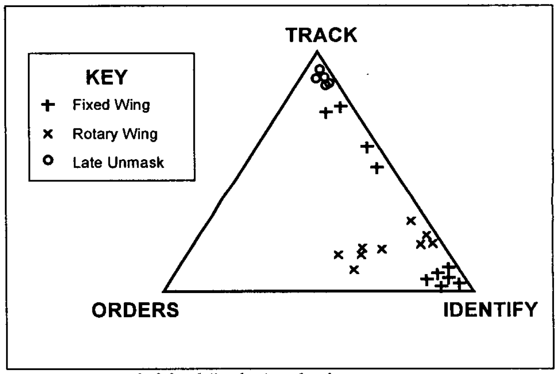

FIGURE 4 - Critical Path Analysis

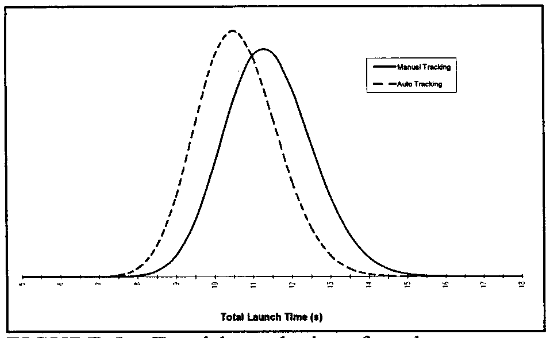

FIGURE 5 - Total launch time for alert operators

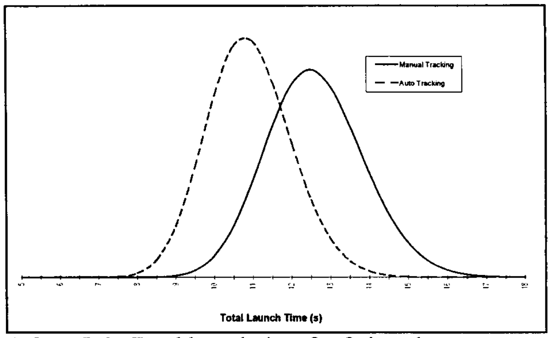

FIGURE 6 - Total launch time for fatigued operators

Each automation option was represented by modifications to the baseline network. Simulation runs were performed to establish the overall figure of merit.

Once costs of implementation were considered, it was determined that the greatest benefit would be derived from an enhanced automatic tracking device. The timeline results for late unmask targets are summarised in Figure 5 for an alert operator, and in Figure 6 for a fatigued operator.

DISCUSSION

The validity of these findings rests on the reliability which can be placed on the estimates of human performance and the performance shaping factors. The model as a whole was validated against human performance in a training simulator, but only in a narrow range of operational conditions and operator states. Few data are available for combat-realistic situations, and of course none are available for the hypothesised automated tracker.

Despite this limitation, it has proved possible to produce a quantitative framework whereby the benefits of additional automation can be assessed, whilst taking into account the environment and state of the human operators. By considering the critical paths through the task network, the number of simulations required to assess an option can be minimised.

References

1 Graine G.N, 1984, "HARDMAN, U.S. Navy's Answer to an Integrated Personnel Subsystem". Workshop on Applications of Systems Ergonomics to Weapon Systems Development, Volume 1..

2 Hood L., Laughery K.R., Dahl S., 1993, "Fundamentals of Simulation Using Micro Saint", MA&D.

3 Farina A.J. and Wheaton G.R., 1971, "Development of a taxonomy of human performance: The task characteristics approach to performance prediction." American Institutes for Research Inc AIR-726/2035-2/71-TR7.

4 Roth J.T., 1991, "A preliminary taxonomy for predicting the magnitude of stressor effects on human task performance". Applied Science Associates.

5 Card S.K., Moran T.P., & Newell A., 1986, "The Model Human Processor: An engineering model of human performance". In K.R. Boff, L. Kaufman, & J.P.Thomas (Eds.), Handbook of Perception and Human Performance: Vol. 2. Cognitive Processes and Performance. New York: Wiley.

6 David Dahn, Ron Laughery, Andy Belyavin, 1997, "The Integrated Performance Modelling Environment - A Tool for Simulating Human-System Performance". Human Factors 1997.

7 Hendy, K.C., Farrell, PSE, 1997, "Implementing a model of human information processing in a task network simulation". Report, DCIEM 97-R-71.

8 Farmer, E.W., Belyavin, A.J., Jordan, C.S., Bunting, A.J., Tattersall, A.J., Jones, D.M., 1995, "Predictive Workload Assessment: Final Report", DRA/AS/MMI/CR95100/1.

9 Cooke K.J., 1992, "The ORACLE visual performance model handbook". BAe Sowerby Research centre. Ref JS12020..

10 Montgomery J.M., Spencer M B., 1996, "A model to predict levels of alertness during irregular schedules of work and rest." DRA/CHS/A&N/CR/96/007.