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A Strategy for Modelling the Human Commander

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This paper reflects the personal views of the authors and does not necessarily represent an official view of the Defence Research Agency or the UK Ministry of Defence.

1. Introduction

1.1 This paper describes some of the interim conclusions of a DRA long term strategic research task into better ways to represent C3I, especially human decision-making, in the high level battle models used for Operational Research studies. High level, in this context, refers to high levels of abstraction rather than high command levels. From previous research it has been concluded that cognitive theory is not yet mature enough to provide a whole commander model which can be practically implemented in high level battle models. Knowledge-based modelling has also failed because it is too expensive to develop and maintain and too subtle to fit easily within the battle model. A strategy is, therefore, required which will generate cheaper and simpler ways to represent the effect of human decision-makers on combat systems.

1.2 There are three reasons why Operational Analysts try to model particular aspects of a combat system or combat environment:

a) to gain a better understanding of the thing modelled. For this the model needs to be firmly grounded in reality, either theoretical or empirical, and the fidelity of the model must be commensurate with the driving parameters of the thing modelled.

b) to identify ways to improve the thing modelled. For this the model also needs to be firmly grounded in reality and must accurately represent the internal processes of the thing to be improved with sufficient fidelity to reveal the effects of such improvement.

c) to provide a context for understanding or improving some other part of the combat system. In this case the modelling of the context needs to represent those aspects which impinge on the real focus of attention sufficiently to reveal significant effects.

1.3 In modelling Command & Control and, in particular, the human commander, it is often claimed that nothing can be achieved without a theoretical or empirical model of human decision-making in general. Since theoretical models are not yet adequate and empirical models prohibitively expensive, this leads to the view that we cannot model the human commander and should go an look at something else instead.

1.4 However, this logic only applies if the commander or his command system is the primary focus of attention. If, on the other hand, one is seeking to consider the relative value of different sensor or weapon system options, then one may still need to model the commander, but only as a context. In this case the model need only capture those aspects of command and control which impinge on the effectiveness of the sensor or weapon system being studied, and need only capture these aspects to the extent that they significantly modify the primary measures of effectiveness being used.

1.5 For example, in rapid reaction ground-to-air defence the opportunities for command intervention are extremely limited. In many cases they are limited to the extent that no useful human decision-making is possible between first detection of the threat and last opportunity to open fire. In such circumstances there is no need to model the effect of human involvement except, perhaps, for the implementation of a standard doctrine and, perhaps a little time delay for the reactive implementation of pre-determined procedures.

1.6 Representation of command and control by fixed logic and time delays has often been criticised as inadequate but it is, to my mind, a perfectly valid theoretical and empirical model in some circumstances; theoretical because it assumes that commanders follow doctrine in well defined, time-constrained situations, and empirical because the delays used are based on some common understanding of human processing speeds.

1.7 There are other circumstances in which very simple representations of command and control are perfectly adequate. If the available courses of action are severely limited or one-dimensional, then it is not necessary to provide a broad, multi-dimensional model of the decision to take any particular course. For example, if a commander requires to choose, let's say, a route across a piece of terrain, but there are only two or three possible routes, then a simple probabilistic model might be perfectly adequate to describe that particular choice. Similarly, if the decision is concerned with the activation of a decoy or jammer which has only a limited time window in which it can be effective, then a random choice between inside or outside the window may be all that is needed.

1.8 Choosing the parameters of such simple probabilistic models is not trivial, but even this can be overcome with the judicious use of sensitivity analysis.

1.9 This is not a novel approach to modelling. Indeed, it is routinely used in the representations of many aspects of combat. Take the modelling of weapon lethality, for example. Operational analysts regularly use single probabilities or simple geometry dependent distributions to model the kill probabilities of weapons killing targets. In some cases these models are based on experimental evidence or detailed physical modelling of the interactions involved, but in the vast majority of cases they are crude estimates with only the most tenuous of foundations. Analysts are prepared to accept such limited models because they know about the limitations and understand how any resultant uncertainties will impact on the analysis they are conducting. Clearly, such an approach would be unacceptable if the primary focus of the study were weapon effects, but otherwise is perfectly reasonable.

1.10 Another example of the acceptance of crude models is in the representation of sensors. Most battle models used for Operational Analysis represent radars with some form of deterministic radar equation plus a statistical target model such as Swerling's Rayleigh distributions. Some models use look-up tables based on the outputs of more detailed, pulse-by-pulse models. Some even take the trouble to explicitly represent detailed propagation, clutter and multipath effects. In the main, however, sensor models used for Operational Analysis are simplistic and stylised. Rarely, if ever, do they even begin to approach the subtlety and sophistication of real modern radar waveforms and signal processing, not least because they are often representing radars which have not yet been designed at this level. Nor do these simplified models give any insight into the complex effects of modern ECM signals.

1.11 None of the aforegoing is, in any way, intended as a criticism of current modellers or modelling methods. It is only intended to show that, in most areas of combat system modelling, operational analysts are prepared to accept crude and stylised models of complex and subtle effects because they believe that they understand their limitations and can work within them to produce useful advice. There is no reason to treat that part of the combat system we call command & control any different. Human decision-making is complex and subtle, but so are warhead effects or sensor-EW interactions. Why do we apply a double standard? I can be argued that, in the case of warhead and sensors, the effects being represented are fundamentally based on physics and can, in principle, be analysed at the physical level. Human thinking, on the other hand is too complex for physical analysis and may, indeed, be meta-physical. This would be a fair argument if operational analysts always maintained strong links between their high level models and analyses of the underlying physical processes involved. The fact of the matter is that such links are rarely strong and often non-existent. As mentioned above, there are other, perfectly valid reasons for accepting the use of simplistic models in Operational Analysis and these reasons apply equally to human decision-making.

1.12 In summary, operational analysts often need to model command and control, with its attendant human decision-making, in order to provide a context for the analysis of some aspect of combat or combat equipment. In doing so they need not apply different standards to the representation of command and control than those applied to every other part of the combat system or combat environment being modelled. In many cases, crude and stylised models will be perfectly adequate to the job in hand and these do not always need to be based on some deep understanding of the underlying processes nor do they always need to be validated in fine detail to be useful for analysis.

1.13 *This is not Einstein's-Grand-Unified-Field-Theory stuff. It is more Brunel-Building-Bridges; trying to do it better than before by synthesising ideas rather than hypothesising.*

2. Modelling Human Variation

2.1 One of the key features of human decision-making (as opposed to machine decision-making) is variability. It is this variability which makes it so hard to predict and, therefore, to model the human commander. If simple models are to be used, therefore, their needs to be an understanding of the kinds of variations which arise.

2.2 It is common for those who model decision-making to use engineering corollaries; control theory, optimisation algorithms, etc. Such approaches, whilst bringing the rigour of engineering to the subject, usually produce very unnatural solutions which do not fit well with what we know of human behaviour. The work of Klein, Rasmussen, Lipshitz and others[1] looks at the human from a much more psychological viewpoint. Many different models arise from this work (none of them entirely complete enough to enable simulation building) but they have a number of common themes.

2.3 They all recognise that human decision-makers do not confine themselves to a single decision-making strategy or paradigm. Real world decisions are made in a variety of ways and one decision-maker will often change strategy depending on the circumstances. In essence, they make different types of decision at different times.

2.4 Another common feature of the naturalistic models is an element of situation assessment or situation recognition. Klein, for example, sees recognition of a situation as a key part of what makes a decision-maker "expert".

2.5 Human decision-making is not a static procedural activity. It has a dynamic nature, so dynamic that some researchers have suggested that decision-making is not a series of discrete events but rather it is an continuous evolution of thought. This means that no model based upon discrete logical steps can ever capture the essence of the human process.

2.6 As mentioned above, variability is a key aspect of human decision-making. This particular issue is dealt with more below.

2.7 Finally, human decision-makers have imagination, they often think in images rather than verbal concepts. This is important when it comes to modelling how complex situations are handled. Image-processing techniques may provide more useful models than conventional logic.

3. Multiple decision strategies

3.1 In many of the naturalistic models of decision-making one can identify different decision-making strategies. In line with Rasmussen's Skills-Rules-Knowledge paradigm, the authors propose three distinct modes of decision-making which will be useful for constructing models. These modes are:

Reaction mode - in which time or other constraints force the decision-maker to adopt an intuitive, skill-based strategy;

Doctrine mode - in which the decision-maker explicitly applies previously learned rules or heuristics to a situation that is (or appears to be) consistent with such doctrine;

Deviation mode - in which the decision-maker consciously and deliberately deviates from existing doctrine based on recognition that the situation is novel or otherwise outside the scope of that doctrine.

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[1] *Decision Making in Action: Models and Methods*, Edited by Klein et al, published by Ablex Publishing Corp., 1993

3.2 Each of these modes will require a different type of decision model if the variations on human performance are to be properly understood and captured. In each mode the strategies for decision-making and the nature of human error will be different.

3.3 In **reaction mode** decision-making is characterised by involuntary choices and a search for sufficient rather than optimal solutions. Pattern-matching strategies or those involving rapid, sub-optimal searching are likely to be used. Human error in this mode is likely to manifest itself as 'jumping to the wrong conclusions', 'ignoring contra-indications', 'tunnel vision', etc Errors will be relatively unstructured and may seem almost random. Modelling methods such as neural networks, probability models, and search theory are likely to be best suited to this mode.

3.4 In **doctrine mode** decision-making is characterised by the conscious use of well rehearsed procedures and established heuristics. Human error in this mode is likely to manifest itself as 'misinterpretation of uncertain data', 'use of inappropriate rules', etc. Errors will be reasonable and structured, possibly even predictable. This mode is likely to be best represented by logical models such as rules bases, conventional logic, and decision tables. These are the techniques which predominate existing C2 models and are likely to form the major part of any hybrid model (except perhaps for a model of higher echelons of command or of the early phases of the planning function).

3.5 In **deviation mode** the decision-maker has deliberately deviated from standard doctrine and is attempting to "think out" new solutions. Deviations can occur because:

- the situation is perceived as novel or outside the scope of existing doctrine;
- the doctrine itself is unclear and needs interpretation;
- the situation is wrongly assessed;
- doctrine is applied inappropriately.

3.6 Deviation mode will be characterised by inventiveness and optimisation. Human variation and error in this mode will be the most difficult to characterise. Multiple hypothesis reasoning is likely and the appropriate modelling methods will be such things multi-attribute value theory, optimisation algorithms, knowledge based reasoning, fuzzy logic, belief functions, etc.

3.7 All three decision modes are required for a complete decision-maker model. The work programme, therefore, will focus on identifying combinations of different decision-model types which can be made to work together. From an understanding of such 'pairing' relationships, the research will seek combinations of three or more model types which can be used to represent all three decision modes.

3.8 In order to create a hybrid model it will be necessary to adopt an overarching framework into which each sub-model can fit, and which defines the high level relationships between the different sub-models.

3.9 It is unlikely that any one combination of decision models will provide a universal solution. Therefore, the aim will be to link a wide range of models together and to implement these in a software framework which will allow the model user to select a combination appropriate to each application. In addition, the control parameters of each sub-model need to be user-accessible so that fine-tuning and refinement can take place in the context of particular applications.

3.10 One possible framework is the Rasmussen Ladder Model[2]. This is based on a form of stimulus response loop and embodies the concepts of what Rasmussen calls Skill-based, Rule-based and Knowledge-based behaviours. These align quite well with the concepts of Reaction, Doctrine and Deviation used here. Rasmussen's model is empirical, deriving from observations of expert decision-makers in the nuclear power industry.

3.11 Another possible framework is the Adaptive Decision Maker (ADM) model[3] which is based on a three-fold hierarchy of control loops called, respectively, the Execution layer, Supervisory Layer and Cognitive Layer. The ADM model is similar in structure to the Rasmussen model but, being based on control theory, it claims to be non-empirical.

3.12 In considering frameworks two architectural possibilities arise - 'frame switching' or 'nested'. In a frame-switched architecture sub-models would be used serially, i.e. 'one-at-a-time', inside their own frames of reference. Transition from one sub-model to another might be the result of the first failing to arrive at a solution. For example, one of the outputs of a pattern-matching algorithm might be 'no match found' which might lead to a higher level sub-model being invoked. This could represent the transition from reaction mode to doctrine mode.

3.13 A nested architecture is one in which the sub-models operate in parallel and simultaneously. Each sub-model processes the decision-making problem at a different level and the overall outputs are modified by all levels all the time. For example, a probabilistic model may be representing the skilled (or semi-skilled!) control of activity whilst a rule-based model is continually re-adjusting the probabilities to represent changing situation assessment.

4. A strategy for modelling the human commander

4.1 In essence, the strategy proposed is as follows.

4.2 Accept that current cognitive theory is not yet mature enough for detailed models to be built in practical programming environments.

4.3 Accept that the Operational Analysts must, nevertheless, represent human decision-making even if only as a context for analysis of the effectiveness of other combat system components.

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[2]Rasmussen J (1987); *The definition of human error and a taxonomy for technical system design*; in New Technology and Human Error, J.Rasmussen, K.Duncan and J.Leplat (eds), John Wiley and Sons.

[3]Morgan P D (1992); *The Adaptive Decision Maker Model*; EDS-SCICON reference C27993/ADM

4.4 Accept that simple, abstract models are used successfully for many other complex issues whose detailed nature is not fully understood and that there is no reason why human decision-making cannot be subject to the same treatment.

4.5 Adopt a multi-paradigm approach is essential in order to provide a model with richness and subtlety. Provide within a modelling framework a wide range of different model paradigms and as many combinations of these as can be theoretically and practically strung together.

4.6 Make use of the constraints inherent in the host battle model to ensure that the representation of human decision-making does not become so rich as to be mismatched with the simplistic world-picture of the host.