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Representing Command Decision Making in the Assessment of Future C2 Concepts

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Track 6: Modelling and Simulation

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Abstract

The Network Enabled Capability (NEC) benefits chain contains a series of linked hypotheses regarding how a more robustly networked force will enable synchronisation of action and the delivery of more timely and appropriate effects. Enhanced timeliness and quality of decision making, enabled by increased information sharing and the development of shared awareness, is cited as a key component of the benefits chain. Consequently, modelling NEC and associated concepts requires a robust representation of Human Decision Making (HDM). Without this capability there is a danger that modelling attempts may over-simplify the relationship between information and decision quality, and that any identified benefits regarding synchronisation and operational effectiveness have a rather shaky theoretical basis. This paper outlines research conducted by Dstl to develop a psychologically plausible model of HDM for implementation within Operational Analysis (OA) models. Work builds upon the existing Rapid Planner[1] decision engine, and focuses on providing an auditable theoretical grounding for continued model developments based on current understanding of cognitive psychology. This work has also recommended potential extensions to provide a more robust representation of HDM. The paper closes with a discussion of the challenges of integrating human sciences into OA models, and provides recommendations regarding how to address these challenges.

1. Introduction

1.1. The appropriate representation of Human Decision Making (HDM) remains a key challenge for the modelling and simulation of Command and Control (C2). The advent and continuing evolution of Network Enabled Capability (NEC)[2] has increased the prominence of this challenge. If we are to explore and assess the opportunities afforded to C2 by our increasing capability to pass information around the battlespace, we must understand how people within the Command structure assimilate and exploit this information in their decision making processes. Although steps forward have been made over the past decade (the recent work by Dstl on the representation of decision making in the SIMMAIR sub-campaign model being one such example[3]), HDM continues to be poorly represented in a majority of military Operational Analysis (OA) simulations, with scant attention paid to the influence of

[1] Moffat, J. (2002) *Command and Control in the Information Age: Representing its Impact*. TSO
[2] JSP 777 Network Enabled Capability
[3] Crow, H, Mistry, B. (2007) *From Storming to Performing: Combining Human Decision Making and Team Working Factors in Military OA Modelling*. (Poster) 24th International Symposium for Military Operational Research

information gathering, communication, and situation assessment on variation in decision making performance[4].

1.2. While the representation of the impact of these factors is undoubtedly challenging, it is vitally important in the assessment of C2 concepts. The UK NEC benefits chain [Figure 1], for example, contains a series of linked hypotheses regarding how a more robustly networked force will enable synchronisation of action and the delivery of more timely and appropriate military effects. Enhanced timeliness and quality of decision making, enabled by increased information sharing and the development of shared awareness, is cited as a key component of the benefits chain. Modelling NEC and associated C2 concepts thus requires a robust representation of HDM. Without this capability there is a danger that modelling attempts may over-simplify the relationship between information and decision quality, and that any identified benefits regarding synchronisation and operational effectiveness have a rather shaky theoretical basis.

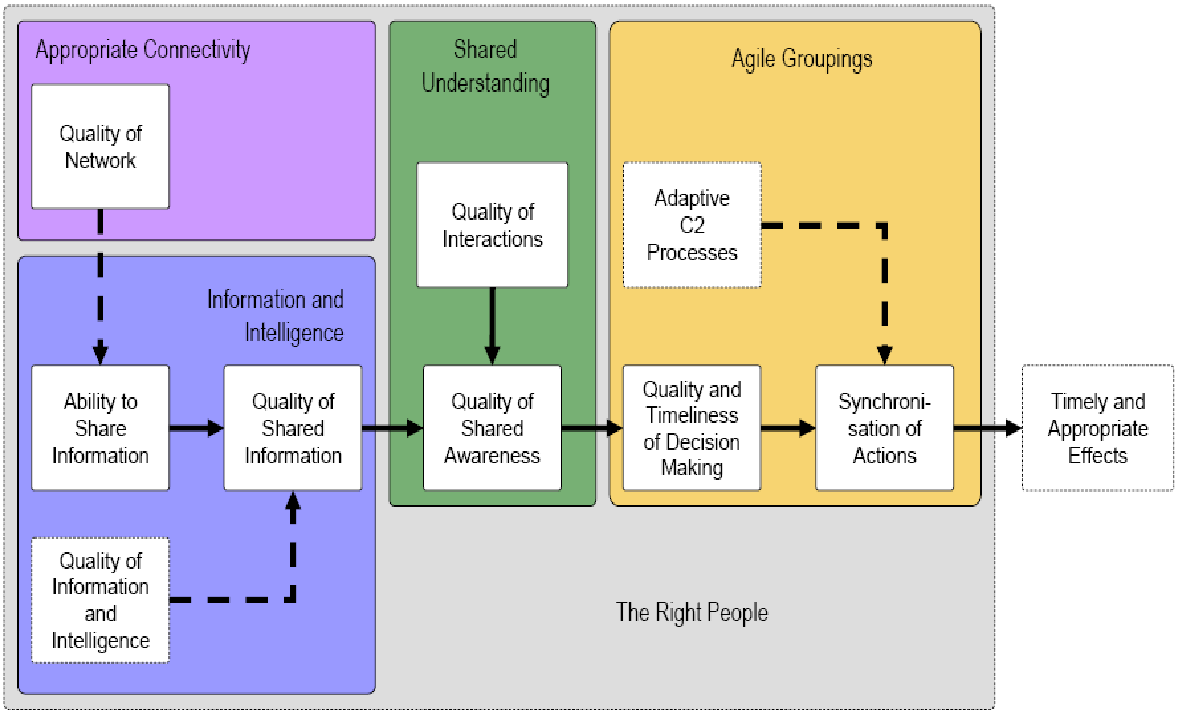

Figure 1. The NEC Benefits Chain[5]

1.3. This paper details recent work by the UK Defence Science and Technology Laboratory (Dstl) to develop a psychologically plausible model of HDM for implementation within OA models. Part of wider programme of work that aims to enhance analysis tools to support the study of NEC, this activity has

[4] Sheppard, C., Mathieson, G. (2001) *Representing Human Decision Making in OA – Final Report*. DERA/CDA/SEA/AIR/CR010051/1.0
[5] Court, G., Offord, J. (2006) *Validating the NEC Benefits Chain*. Dstl/TR17649/v1.1

focussed on reviewing the implementation of the Enhanced Rapid Planner (ERP)[6] decision engine within the Wargame Infrastructure and Simulation Environment (WISE). Using current Cognitive Psychology literature as a baseline, the psychological plausibility of the ERP was assessed and potential enhancements identified. This paper details this assessment and its findings, and closes with a more general exploration of the challenges associated with integrating human sciences into OA. Before tackling these issues however, it is important to provide an introduction to current thinking on the Human Decision Making process to situate this work and inform appropriate representation. The following section provides a summary of current thinking on HDM.

2. Human Decision Making (HDM)

2.1. Decision making, in simple terms, is the cognitive process of determining a course of action. While a myriad of definitions exist, the components of these definitions are broadly consistent. For the purposes of this paper, decision-making is defined as 'the on-going process of determining courses of action (including the option to continue as at present) with an aim of achieving tasks and goals'.[7] There are two important points to pull out of this definition. The first is that decision making should be considered as a *process* rather than the rational evaluation of courses of action at a discrete point in time. The second is that decision making is goal directed; courses of action are determined on the basis of what the decision maker, based on their experience, believes will result in a satisfactory outcome.

2.2. This definition reflects the fact that decision making research has evolved from its early analytical focus, which considered decision making as the optimisation of available courses of action, to the consideration of how human beings actually make decisions in the real world. This school of thought, which has become increasingly dominant over the past decade, is termed Naturalistic Decision Making (NDM). It builds on classical cognitive schema theory to describe how individuals make decisions in 'naturalistic' settings, which are characterised by:

- Ill-structured problems (not artificial, well structured problems);
- Uncertain, dynamic environments (not static, simulated situations);
- Shifting, ill defined, or competing goals (not clear and stable goals);
- Action / feedback loops (not one-shot decisions);
- Time stress (as opposed to ample time for decisions);
- High stakes (not situations devoid of true consequences for the decision maker);
- Multiple players (as opposed to individual decision makers);

[6] Moffat, J. (2002) *Command and Control in the Information Age: Representing its Impact*. TSO
[7] Cooper Chapman, C., Conway, G., and Sheppard, C. (2008) *Cognition, Situational Awareness and Decision Making; Literature Review*. Dstl/CR28766

- Organisational goals and norms (as opposed to decision making in a vacuum).[8]

2.3. NDM caught the attention of military analysts because these task (or situation) characteristics are features that are readily recognisable in the Command-Operating domain. From a military perspective, the most commonly cited NDM model is the Recognition-Primed Decision Making (RPDM) model proposed by Klein[9]. Klein argues that decision makers interpret a situation in which they find themselves by comparing it with similar, previously experienced situations. The RPDM model states that when experienced individuals are making decisions:

- The focus is on the way they assess the situation and judge it as familiar, not on comparing options;
- Courses of action can be quickly evaluated by mentally simulating how they will be carried out, and not by formal analysis and comparison;
- Decision makers usually look for the first workable option they can find, not the optimal option;
- Since the first option they consider is workable, they do not have to generate a large set of options to be sure they select the optimal one;
- They generate and evaluate options one at a time rather than comparing the advantages and disadvantages of alternatives;
- By mentally simulating options, they can spot weaknesses and find ways to avoid them, thereby making the option stronger;
- The emphasis is on being poised to act rather than being paralysed until all the evaluations have been completed.

2.4. A central feature of RPDM is the decision maker's expertise, as both recognising salient features of the situation and recalling possible courses of action is dependent on available memory content.[10] Representations of previously experienced situations in memory allow decision makers to recognise relevant features of the situation from environmental cues ('bottom up processing', e.g.[11]). They also help to direct the decision maker's attention towards environmental cues that are relevant to their current situation or task, helping to ensure that relevant cues are perceived ('top down processing'). A combination of these top down and bottom up influences drive attention and perception, and effectively control which stimuli are available for assimilation into the decision making process. Figure 2 provides a diagrammatic representation of how these cognitive processes interact.

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[8] Blendell, C., Pascual, R. and Molloy, J. (2000). *Decision making – Theory and Applications.* Unpublished Report.
[9] Klein, G. 'Sources of power. How people make decisions.' The MIT Press. 1998
[10] Cooper Chapman, C., Conway, G., and Sheppard, C. (2008) *Cognition, Situational Awareness and Decision Making; Literature Review*. Dstl/CR28766
[11] Wickens, C. D., & Hollands, J. G. (2000). *Engineering Psychology and Human Performance*. Upper Saddle River, New Jersey: Prentice-Hall.

2.5. This diagram is included to illustrate that a number of cognitive processes interact in determining a course of action, and decision making should not be considered in isolation of these processes. If we are to effectively represent HDM within OA models, we must take account of not only the decision making process itself, but also the attentional and perceptual processes that mediate the availability of environmental cues to the decision maker. Human beings are not passive information consumers. A number of factors such as experience and expectation affect the manner in which we select salient cues from the complex environments we negotiate. Similarly, the manner in which we interpret and understand these cues is mediated by our existing understanding of the world, and the representations within memory that constitute this understanding.

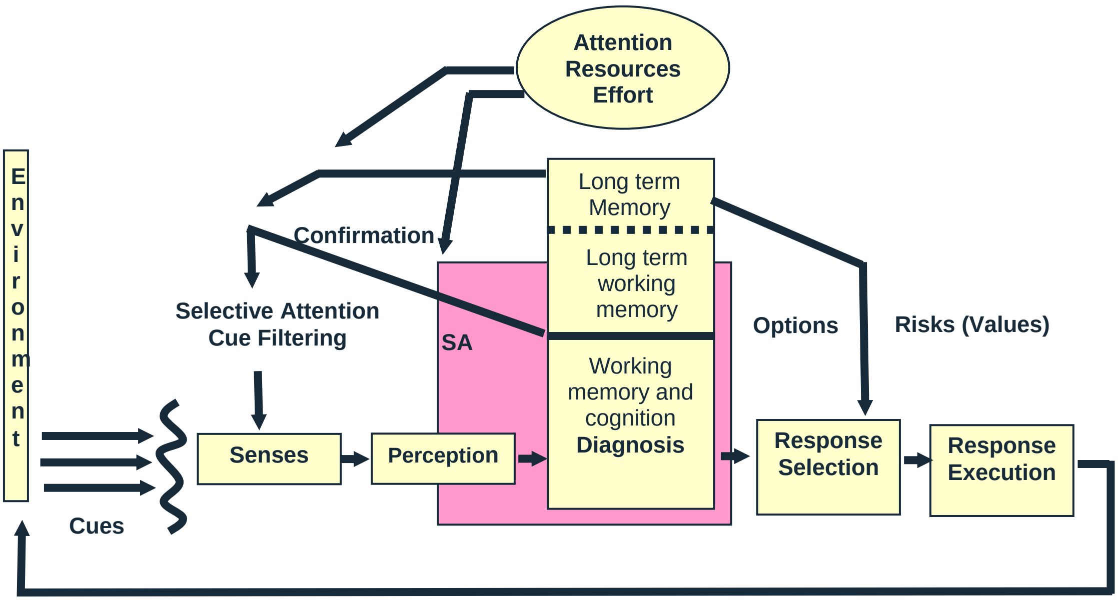

Figure 2. Human Information Processing Model (adapted from[12])

2.6. How then do we cope with this complexity within our OA modelling activities when attempting to represent Command decision making? The remainder of this paper outlines recent efforts to do just that. The Enhanced Rapid Planner (ERP) decision engine is an extension of earlier research[13] which sought to develop an algorithmic representation of RPDM. The ERP is configured to respond to data defined situational 'cues' such as perceived enemy casualties, combat power ratio etc. It then matches these cues with representations held in an 'experience base' to determine an appropriate course of action.

[12] Wickens, C. D., & Hollands, J. G. (2000). *Engineering Psychology and Human Performance*. Upper Saddle River, New Jersey: Prentice-Hall.
[13] Moffat, J. (2002). *Command and control in the information age. Representing its impact.* The Stationary Office: Norwich.

2.7. The initial development of the ERP referenced both Klein's RPDM model and Rasmussen's Decision ladder[14]. However, a number of extensions have since been implemented within the ERP, and it was determined that a review should be undertaken to ensure that these extensions have continued to display a clear theoretical audit trail. The following section provides an overview of the functionality of the ERP as implemented within the Wargame Infrastructure and Simulation Environment (WISE). The paper then goes on to examine this functionality from the perspective of the HDM principles outlined in the previous text, and provides an assessment of the psychological plausibility of the current instantiation of the model.

3. The Enhanced Rapid Planner (ERP)

3.1. The ERP has been implemented within WISE as a means of representing HDM. WISE is a Land domain model (with representation of air and maritime support to Land operations) at the system level, which can represent warfighting, peace support, or stabilisation operations. It is a stochastic, event driven model that allows decisions to be made by players, software algorithms or a combination of both. Consequently it can be used both as a Synthetic Environment (SE) and as a closed form constructive simulation. It is for the latter application that the ERP has been implemented within WISE. The aim is to provide an appropriate representation of HDM within the closed form simulation mode, which allows multiple runs to be conducted for a particular scenario to investigate the robustness of the results to perturbations.

3.2. As stated previously, the ERP is configured to respond to data defined environmental 'cues' such as perceived enemy casualties and combat power ratio, and match these 'cues' with representations held in an 'experience base' to determine an appropriate course of action. This 'experience base' is analogous to the representations contained within long term memory. Within WISE the ERP is presented with cues from individual Command nodes. These cues are in turn derived from the fusion of data presented to each individual Command node during a given scenario. On receipt of a cue from a WISE Command node, the ERP goes through four stages.

3.3. The first assesses the presented cue according to four Dynamic Linear Models (DLMs), mathematical structures used for modelling and analysing time series processes. These DLMs provide representations of four states; *no change*, a *blip* that can be ignored, a *step change* or a *change in the slope*. Using the mean and variance values for the cue each DLM then calculates the likelihood that they are the best reflection of the situation at that moment in time. In the second stage, the likelihood calculation is used to assess the current situation. If the constant DLM has the greatest likelihood, then the situation is deemed to be 'OK' with respect to the cue, meaning the observed cue value is currently

[14] Rasmussen, J. (1993) 'Deciding and Doing: Decision Making in Natural Contexts', in Klein, G.A, Orasanu, J., Calderwood, R. and Zsambok, C.E. (eds) *Decision Making in Action: Models and Methods*, Ablex Publishing: Norwood, NJ

showing a steady level. However if one of the other DLMs has the greatest likelihood, then the situation is deemed to be 'not OK', and a change of Course of Action is contemplated. For whichever DLM has the greatest likelihood its cue mean and variance values will be used as a basis for selecting the most appropriate 'fuzzy state'.

3.4 Stage three looks to match cue fuzzy states. For each cue there will be a number of these fuzzy states representing appropriate descriptors for the cue e.g. high, medium, and low. The pattern matching process takes the estimated distribution, created using the mean and variance values of the DLM with the greatest likelihood, and calculates which fuzzy state the estimated distribution falls into. To decide which Course of Action to take a number of cues must be looked at together. Each cue will have a fuzzy state and depending on the combination of fuzzy states an appropriate Course of Action will be chosen. Stage four of the process is concerned with the selected Course of Action being returned to WISE for processing and execution. Figure 3 provides an illustration of how these stages combine to determine a Course of Action.

3.5. This rather simplistic description does of course hide a number of non-trivial technical challenges associated with defining both appropriate fuzzy state descriptors, and how individual cues states combine to generate a particular course of action. In parallel with the psychological review of the ERP, Dstl has been working with Cranfield University to address these challenges, and identify an approach to generate an initial set of cues, fuzzy states and Courses of Action to populate the ERP Experience Base. Work on this axis is ongoing, and will not be covered in any further detail at this stage. The remainder of this paper focuses on conclusions and recommendations regarding the psychological validity of the current instantiation of the ERP.

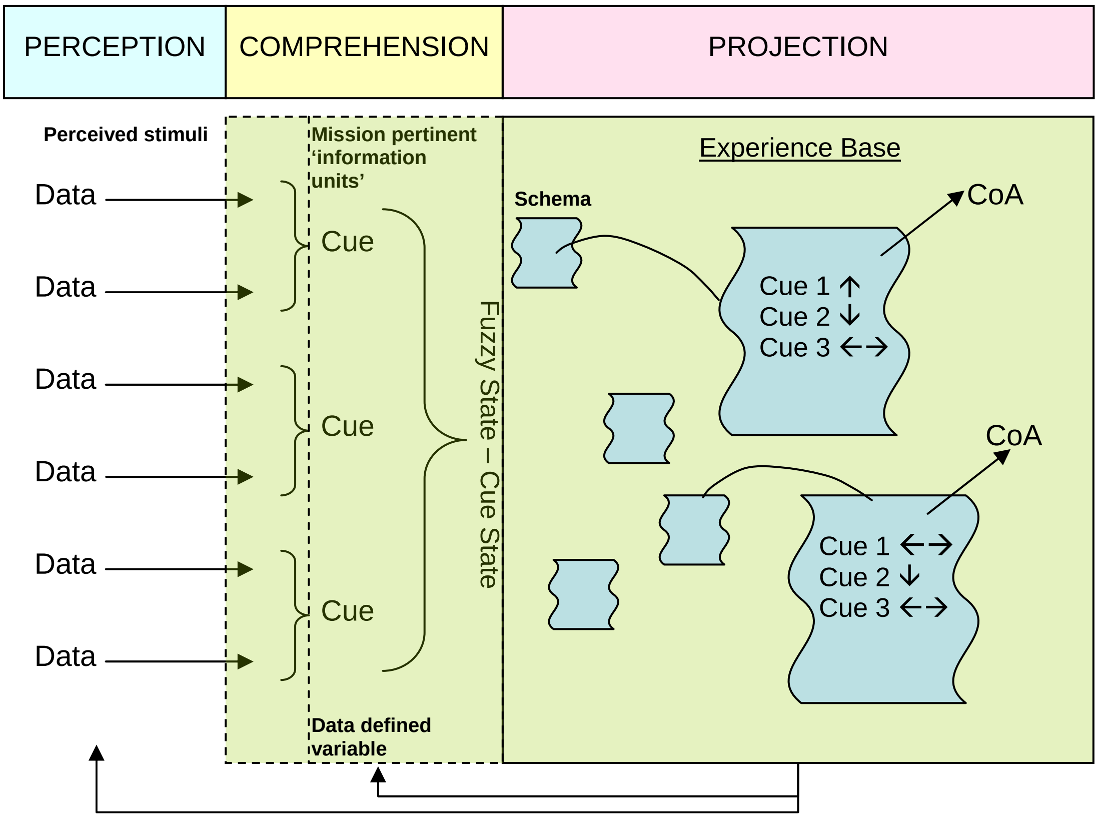

Figure 3. Diagrammatic Representation of ERP Course of Action Selection

4. Assessing the Psychological Validity of the ERP

4.1. To what extent does the current instantiation of the ERP provide a psychologically plausible representation of HDM? Before making any assessment on this axis it was necessary to resolve a terminology difference concerning the word 'cue' between the human sciences perspective at Section Two, and the OA slant provided by Section Three.

4.2. Within the psychological literature, cues generally refer to external stimuli that initiate a particular process and/or response. Within the terminology of the ERP in contrast, the term cue is used to describe a 'fused' information package of external cues pertaining to a particular mission salient construct (e.g. 'perceived enemy casualties'). While these constructs may 'cue' the operation of the ERP, they are not cues in the psychological sense of the word. Indeed, from a psychological point of view, the fact that a certain amount of processing has taken place to aggregate disparate stimuli, or data, into mission relevant information packages would suggest that perception and comprehension have occurred, and that a level of understanding has been reached. This difference in terminology does not necessarily impact on the psychological validity of the ERP's representation of HDM, but it is important to recognise this discrepancy in making any assessment. It is suggested that future model developments should strive to align the terminology they employ with psychological literature to aid communication of model functionality across OA and Human Sciences communities. Having clarified this issue, the ERP's treatment of HDM was assessed in light of the principles outlined in Section Two.

4.3. This assessment concluded that the current instantiation of the ERP provides a reasonable representation of 'bottom up' processing. More specifically, the model emulates the perception of external stimuli (or data in ERP terms), the comprehension of these stimuli in terms of their relevance to the mission (the development of model 'cues'), and the satisficing pattern matching of these cues to courses of action contained in memory via the attribution of fuzzy states. The ERP is weaker in its representation of 'top down' processing. This is principally due to the fact that within the current instantiation there is no limit to the amount of data that can be assimilated into 'cues' by the ERP, and thus no representation of selective attention processes that determine whether stimuli are perceived and made available to the decision making process.

4.4. Referring back to the Human Information Processing Model referenced at Section Two (Figure 2), the current instantiation of the ERP represents the following sub-set of human information processes:

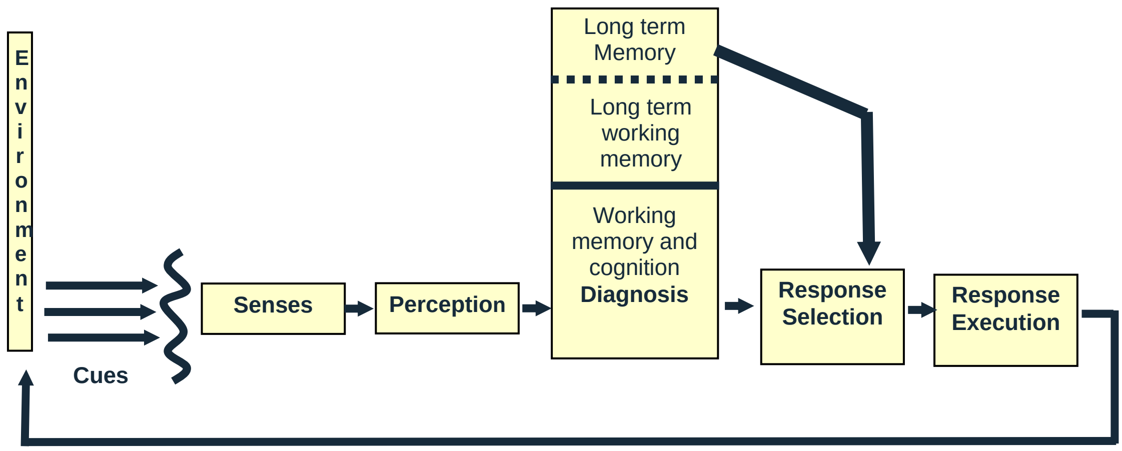

Figure 4. Current ERP HDM representation

4.5. Essentially the psychological review concluded that the ERP provides a reasonable representation of *part* of the human decision making process. It is recommended, however, that implementation of the model requires careful consideration to ensure more robust representation of top down processing and the impact of selective attention. Without the representation of these factors, modelling activities are likely to overestimate the ability of Commanders to assimilate large amounts of data, and in turn the strength of the relationship between the ability to share information and enhanced decision quality. Similarly, modelling efforts will fail to adequately represent the goal directed attention so integral to the decision making process.

4.6. Three extensions to ERP development are suggested to remedy these shortfalls. The first concerns the representation of attentional limitations. This could be achieved quite simply by limiting the amount of stimuli/data sources that can be considered within a given model time step. The finite nature of human cognitive capacity has been intensely studied by Psychologists, and as far back as the 1950s Miller[15] concluded that individuals could hold seven plus or minus two items of information (digits in the case of his research) in mind at one time. Later work by Simon[16] looked at the ability to manipulate more complex 'chunks' of information, and concluded that individuals could on average deal with around five items simultaneously. The key point to take away is that there is empirical evidence that could be exploited in constraining the amount of stimuli that can be assimilated by the Rapid Planner. It is suggested that the representation of these limitations should be pursued as a priority.

4.7. Once representation of these attentional limitations is in place, it opens the door to the representation of the top down factors that influence the direction of selective attention. Again, a more robust representation of HDM could be achieved with fairly simple interventions. Expectation and experience have been shown to be key factors in the preferential selection of stimuli. 'Priming' particular stimuli by increasing their weighting depending on likely scenario developments would be one way of providing a representation of the former. Experiential factors are a little more difficult to represent given the heterogeneity of Commanders operational and personal experience, but weighting could again be applied to provide a representation of trust in particular data sources. Implementation these extensions would enhance the ERP's ability to provide a robust representation not just of the decision making process, but also of the perceptual processes that underpin it. Doing so will in turn increase our ability to understand the impact of NEC related C2 concepts in a manner that takes full account of the people within the system.

5. Integrating Human Sciences and OA: Closing Thoughts

5.1. This paper has documented work conducted by the UK Defence Science and Technology Laboratory which has looked to integrate an appropriate representation of human sciences into an OA model. The focus here was a specific one; the evaluation of an existing model from a psychological perspective to ensure robustness of representation, identify strengths and weaknesses, and suggest any associated extensions. The construct of interest was also defined from the outset – HDM within the context of C2. In this sense the requirement for human sciences support was clear, and a multi-disciplinary team was formed to consider the ERP's representation of HDM, derive conclusions regarding its psychological validity, and provide a clear theoretical audit trail for these conclusions. This multi-disciplinary team has

[15] Miller, G.A. (1956) The magic number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81-93
[16] Simon, H.A. (1974) How big is a chunk? *Science, 183,* 482-488

worked together effectively to achieve this aim, but there are undoubtedly challenges in bridging the gaps between different disciplines.

5.2. Meeting these challenges in this case relied on a clear requirement for the translation of human sciences expertise into mathematical representation, and the willingness of practitioners on each side of the fence to remain open minded, overcome differences in terminology and compromise where necessary. It is hoped that these efforts will pay dividends as work continues, and that the development of common understanding of key concepts across the human sciences and OA personnel involved in the project will facilitate future discussion and collaboration. Additionally, a number of more generic recommendations were derived from the experience which should be applicable to the integration of human sciences expertise into OA more generally:

- **Understanding the Requirement**
  A desire to simply 'tick the human factors box' is unlikely to yield a positive result when bringing together personnel from different disciplines to work in a complex problem space such as C2. It is essential that a clear understanding of the human variables of interest is reached and agreed across the project team

- **Multi-disciplinary Team Working**
  Individuals from different disciplines should work together in an integrated manner, rather than sectioning off tasks by specialism and bringing the outputs together at the end of the task. An integrated approach should ensure that team members are aware of each other's constraints, and a holistic systems approach is adopted

- **Agreeing Common Terminology**
  Different scientific disciplines often have a tendency to be separated by a common language. Being rigorous with the use of terminology, and establishing a common understanding of key phrases is critical for effective cross domain working