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"C2 and Agility"

Title of Paper: "Integrating Operational Research and Human Sciences to analyse Network Enabled Capability"

Topic: Experimentation and Analysis

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"Integrating Operational Research and Human Sciences to analyse Network Enabled Capability"

Abstract

The UK Ministry of Defence's (MoD) vision for Network Enabled Capability (NEC) is to network a force to allow it to operate more effectively when deployed, typically achieved through enhanced C2 and force agility. In order to determine the contribution of physical, information, cognitive, organisational and social aspects of NEC to operational outcome, the MoD is sponsoring a programme to develop a constructive simulation model spanning these domains. This innovative approach integrates Human Sciences concepts such as Recognition Primed Decision Making, team maturity, cognitive and physiological aspects with an explicit representation of the deployed force organisation to derive an enhanced representation of the decision maker's situational awareness and hence ability to successfully adapt to emerging situations in the Battlespace.

Background

Introduction

This paper describes the changes in Command and Control (C2) expected as a result of NEC, and outlines the development of a simulation model to quantify the impact on operational outcome to inform MoD procurement decisions. The paper is broken down into the following sections:

- Background
- Method used to develop the modelling representation
- Exploitation of the model
- Conclusions

Definition of NEC

The increasing provision of networked connectivity in deployed military operations has the potential not only to change the way information is disseminated across the Battlespace, but also the way people operate together in order to achieve a common objective. Reducing or removing constraints on communication has the potential to allow teams to form and reform dynamically in response to changing events in the campaign, or achieve greater synchronisation of effect through a better shared understanding of each others needs.

The UK MoD describes NEC as offering "*the coherent integration of sensors, effectors and decision makers in order to achieve increased effect*" [1] and presents a strategic vision for NEC that will require new concepts to be adopted in the delivery of capability. The goal of NEC is improved military capability, enabled by improved networking - both information <u>and</u> social (i.e. human organisational interactions). As such, the NEC concept extends beyond traditional ideas of equipment performance, but encourages a more holistic approach to all aspects of sociotechnical systems.

In order to articulate the possible impacts of NEC at a high level, the MoD has developed a benefits chain [1] to illustrate the basic premise that improved connectivity should lead to improvements in information available to the decision makers, which in turn leads to a greater shared understanding of those decision makers, and hence through to operational effect by allowing the force to dynamically adapt its structure in response to unfolding events. The project team have modified the benefits chain to consider the causal linkages between the various aspects, as shown in Figure 1 below. Any attempt to quantitatively assess the impact of NEC on operational outcome should therefore take into account each of these aspects.

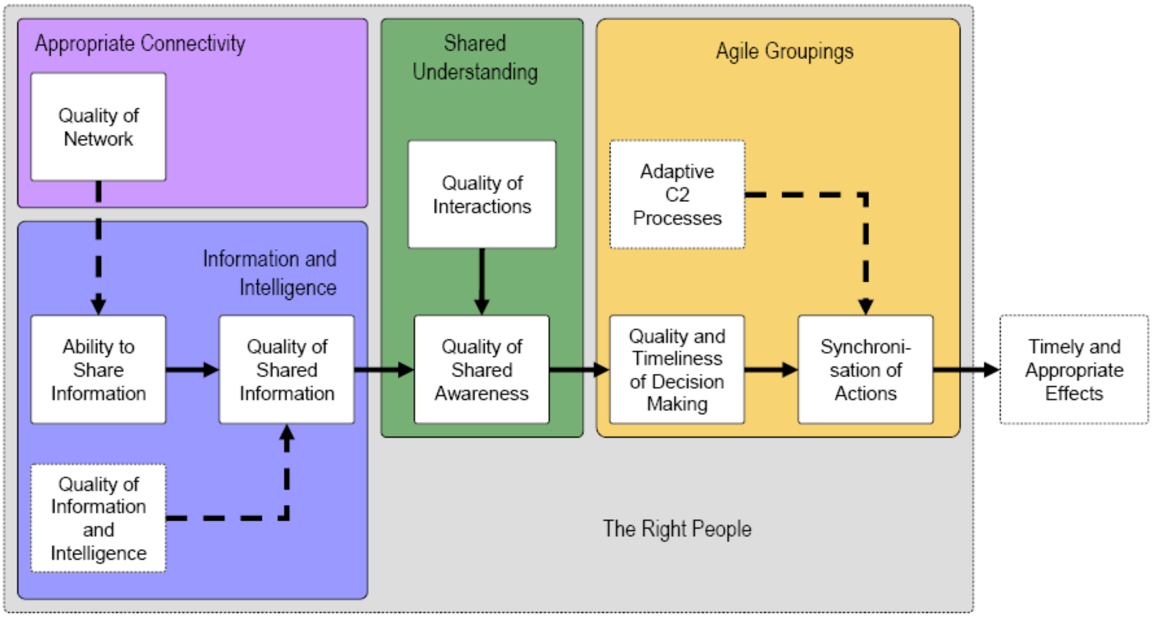

Figure 1: Modified NEC Benefits chain

Human decision making (HDM) within Command and Control (C2) is a key part of NEC and dynamic force management. It is essential, therefore, any analysis understands the factors, interactions and dependencies that will need to be discriminated between to adequately capture the contribution of NEC, and to determine how these should be represented.

Changes in Command and Control

NATO defines C2 as: “The Organisation, Process, Procedures and Systems necessary to allow timely political and military decision making and to enable military commanders to direct and control military forces” [17]. The first order representation of C2 is commonly as a cycle of fixed stages, which some view as an oversimplification of reality as the various stages used by many authors are not fixed and the borders between them can be hard to determine. A more representative treatment may be to consider many of the stages of the C2 cycle being carried out simultaneously rather than only in succession, interacting and influencing each other so that, for example, the development of assumptions regarding enemy intent can influence the type and manner in which data is gathered and interpreted.

C2 is constantly evolving and increasing in complexity. This is due to the development of increasingly sophisticated technology such as longer-range weapons, more manoeuvrable units, increasing specialisation and long range networked communications systems [4].

In the past this rising complexity has been overcome by increasing the size of command staffs with additional specialists and liaison officers. For example the Prussian Field Marshall during the Franco-Prussian war[1] in 1870 numbered only approximately 70 officers while it controlled close to a million men [5]. Since then the size of the command system has continued to increase and this trend seems to continue. This trend continued during the 20th century: a World War 1 brigade HQ (responsible for about 5000 troops) consisted of 2 staff, by World War 2 this had crept up to around 10 staff, and during Operation Telic[2] in 2003 this number had risen to over 90 [19]. Even the introduction of new information technology-based decision support systems is unlikely to decrease the staffs or the workload in the short term since the workload of the decision-makers will probably increase due to the higher operational tempo provided by such systems. The technical systems are also likely to require a higher mental ability of the staff and increase the complexity of co-ordinating the work [6].

This technological 'explosion', particularly in the increased connectivity of units brought about by improved communications systems has given rise to a considerable increase in the information available to command staffs. With the move toward full NEC, future commands are likely to be provided with still further increases in information availability and opportunities to directly control front line units. The ability of command staffs to make use of this increase in information and new technologies will be critical to the success of NEC

Command and Control methods and systems will also differ between each of the three services and between friendly/coalition and enemy forces; as they have different types of resources, capabilities, conceptual models, rules of engagement and constraints and face differing risks. The operational level of command needs to balance and utilise these differences in a sensible way.

Impact on Operational Research modelling

Much Operational Research (OR)[3] in the MoD provides objective advice to decision makers on equipment procurement. This has traditionally focussed on equipment performance issues such as range, accuracy, probability of destroying a target, etc, and the impact of this performance on operational effectiveness, through achievement of mission objectives, casualty numbers etc.

A wider MoD initiative of Through Life Capability Management (TLCM) requires that all aspects of a military capability are considered over the duration of its service life. The aspects together are known as the Defence Lines of Development (DLOD), and comprise: Training, Equipment, Personnel, Information, Doctrine, Organisation, Infrastructure and Logistics.

Given this initiative, and the likely impacts of NEC on how individuals and groups operate and train together, there is a growing need to develop OR tools and techniques to take a more holistic approach to the assessment of military capability, and in particular, to develop a better understanding of how the human (at the individual, team, organisational and social levels) interacts with equipment in theatre.

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[1] Field Marshall Helmuth Karl von Moltke

[2] UK's involvement in Iraq

[3] Known as Operational Analysis (OA) within UK MoD

Of a number of approaches underway to address these issues, one is the development of a closed form, constructive simulation model with a tight integration of equipment performance and human behavioural factors. Known as the SImple Maritime and Air model, 'SIMMAIR', the purpose is to develop a C2 centric, flexible model, able to assess the impact of NEC upon modern warfighting at the sub-campaign level, focussed on the Air and Maritime domains. In developing SIMMAIR, much work has gone into understanding how NEC may change human behaviour and how to represent this within an OR model, and is the focus of the remainder of this paper.

Method

Different types of decision making

The NATO Code of Best Practice (COBP) for C2 assessment [17] considers that:

"Analysis of C2 should consider all the relevant actors, military command levels, and functions involved and should investigate issues of integration across disparate organisations, military command levels, and functional domains over time. Consideration should also be given to … information systems, human behavioural, physiological, and cognitive factors, along with organisational and doctrinal issues"

The SIMMAIR team have attempted to bear this wide remit in mind when designing a model to address both equipment and human aspects of warfare.

In order to drive how human decision making should be represented within SIMMAIR it is necessary to understand how humans make decisions and how the conditions under which a decision is made affect the type of decision making strategy adopted. At a high level, decision making can be split into two general types; Naturalistic Decision Making (NDM) and Analytical Decision Making, sometimes referred to as Traditional Decision Making (TDM). These are not competing theories of how decision makers behave and are not necessarily contradictory as they are each applicable in different conditions.

TDM theories are based around the premise that decision makers generate a range of options and select a solution from them based on a range of criteria in an analytical and rational manner at a single definable decision point. This type of decision making assumes that the decision maker has ample time to formulate and assess the relative pros and cons of all possible courses of action in order to come to an optimal solution for the given situation. In contrast NDM theories attempt to describe how experienced decision makers make decisions under time pressure in dynamic and uncertain situations and emphasise the role that situation awareness and experience play in decision making [8]. One of the most widely researched NDM theories is Klein's Recognition Primed Decision-Making (RPDM) model [18], the essential features of which are:

- a focus on situation awareness;
- an aim to produce satisfactory rather than optimal decisions;
- for experienced decision makers the first option considered is usually workable;
- serial generation and evaluation of options;
- a check that the option will work using mental simulation;
- a focus on elaborating and improving the considered option;
- the decision-maker is at all times primed to act.

A comparison made by Orasanu and Connolly [9] of the features of completed NDM and TDM research, summarised in Table 1, highlights the conditions under which the different models of decision making were developed and assists in understanding the types of situation in which each theory might apply.

NDM	**TDM**
Ill-structured problems	Artificial, well structured problems
Uncertain dynamic environment	Static environment
Shifting, ill defined or competing goals	Clear stable goals
Action/feedback loops	One-off decisions
Time stress	Ample time
High stakes	No consequences
Multiple participants	Individual decision making
Organisational Factors	No organisational factors

Table 1: Comparison of TDM and NDM features

Thus the type of decision making occurring in a situation is likely to depend on the circumstances under which the decision is being made. It is therefore necessary to consider the potential circumstances under which each layer of command makes decisions i.e. in situations where there is ample time, low stress and a relatively complete information set a TDM model of DM would be more appropriate; whereas in a fast moving, high stress environment with poor or uncertain information an NDM model would be more applicable.

The well known Network Centric Warfare (NCW) maturity model, better known as the 'Alberts Grid' [7], and the more recently developed NATO C2 Maturity model [8] both describe the NEC 'Journey', as increased networking in the Battlespace and changes in doctrine take effect. This describes the transition from the current initial realisation of NEC with Deconflicted C2, through intermediate levels of NEC, where improvements in information sharing and changes in doctrine lead to more coordinated or collaborative command styles, through to the 'mature' NEC state, with complete C2 agility and self-synchronisation occur. Both models are summarised in Figure 2 below.

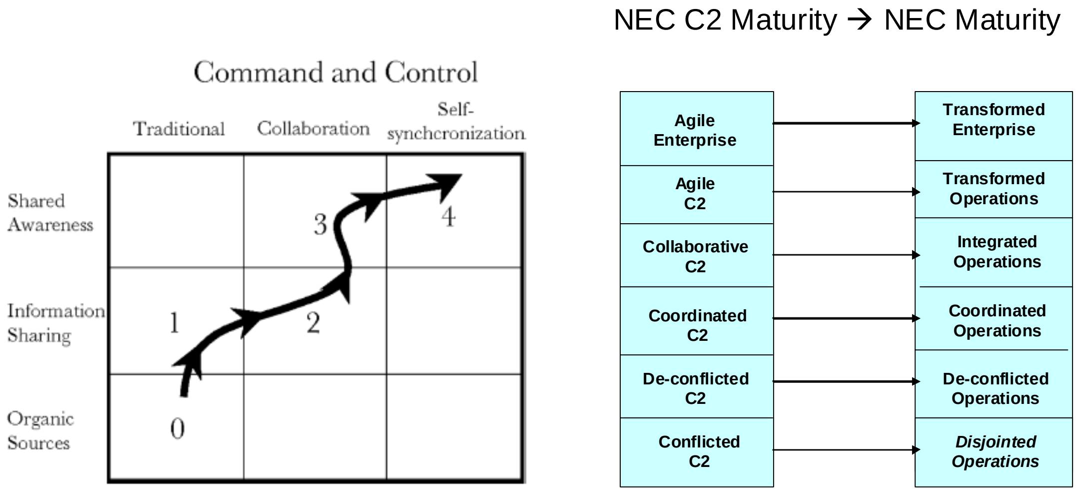

Figure 2: NCW maturity model and NATO NEC maturity model

The SIMMAIR model is required to be able to represent all states of NEC, and all possible command styles that may result from them[4]. Given the types of C2 described above, it is clear that aspects of both TDM and NDM decision making need to be represented in the model. However, it is also clear that just representing decision making is not sufficient – one must also represent the wider behaviours of the team and groups of teams that comprise the deployed force. In choosing a decision making model, one must also consider the degree to which the model can be extended to incorporate these features.

Overall, it was felt that an agent based approach offered both the greatest flexibility and the opportunity for extension to incorporate team behaviours. There are a number of decision making models that use agent based approaches, these have primarily been used at individual and unit levels. Examples of C2 agents implemented at individual or at unit levels; are STEAM (a Shell for TEAMwork [20], based on the Soar architecture [21]), and CoJACK (Cognitive JACK, [22]), or the Rapid Planner [11], which is based on Kleins recognition primed decision making [18]. The team chose the Rapid Planner to develop further, as it has a track record of use in higher level campaign OR models, and strikes an appropriate balance between psychological plausibility, complexity, and flexibility for extension.

Overall approach

In order to derive a wider representation of human behaviour, 4 distinct elements of behaviour were focussed upon. Between them, the 4 elements address all of the factors in the NEC benefits chain in Figure 1, and hence cover the breadth of behaviours to be investigated:

- Team maturity
- Decision making
- Perception of the Battlespace
- Cognitive and physiological effects

These 4 elements build upon existing research and combine together to form the Human Factors 'core' of SIMMAIR. The factors are tightly integrated with the representation of

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[4] Existing developments focus on intermediate levels of NEC which are more tractable and more likely to be realised in the medium term.

Intelligence, Surveillance, Targeting, Acquisition and Reconnaissance (ISTAR) within the model, both as a key element in NEC and the representation of Situational Awareness within the perception and decision making elements of the model.

An overview of the approach appears in Figure 3 below. In summary, a representation of team maturity derives a description of the efficiency of the decision making team, which feeds into the Cognitive and Physiological model. This model represents various aspects of human behaviour, but focuses on the physical and cognitive workload of the team, and the team's ability to cope with the workload, due to issues such as fatigue.

The decision maker's perception of the Battlespace is formed by his subscription to a number of ISTAR sources, from which he builds a local picture. The time taken to build the local picture, and error rate in doing so is affected by the picture compilation delays and errors from the cognitive and physiological model. Finally, the decision maker extracts a number of summary measures of the Battlespace, known as 'cues', upon which the final decision is made. Each of these aspects is discussed in this paper.

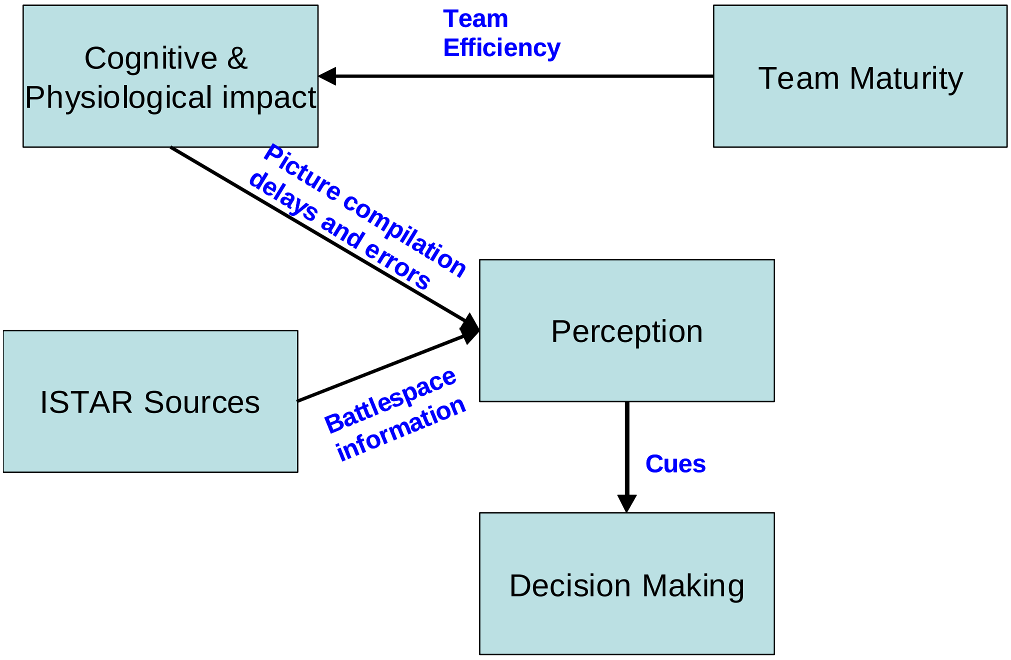


Figure 3: SIMMAIR Human Factors 'core'

Team Maturity

Team Maturity in SIMMAIR is represented using the Social-cultural Teamworking for OR models (STORM) representation [12]. Essentially, this represents a team conducting an HQ task, and in addition, contains structures to represent variability arising from human agency and individuality, teamworking, organising, and socialising. It builds upon the accepted Tuckman and Jensen model of team maturity [13], briefly summarised as:

- Forming. Individuals have not yet come to recognise themselves as a team. They are busy finding out who the other people are; their backgrounds and attitudes, and to establish ground rules.
- Storming. A conflict stage where members bargain with each other as they try to sort out what each of them individually, and as a group, want. Individuals reveal their personal goals and it is likely that interpersonal hostility is generated when differences in these goals are revealed.

- Norming. Members of the team develop ways of working to form closer relationships and camaraderie. The questions of who will do what and how it will be done are addressed.
- Performing. This stage is concerned with actually getting on with the job in hand and accomplishing objectives. The fully mature team has now been created which can get on with the work.
- Adjourning. The team disbands, either because the task has been accomplished or members have left.

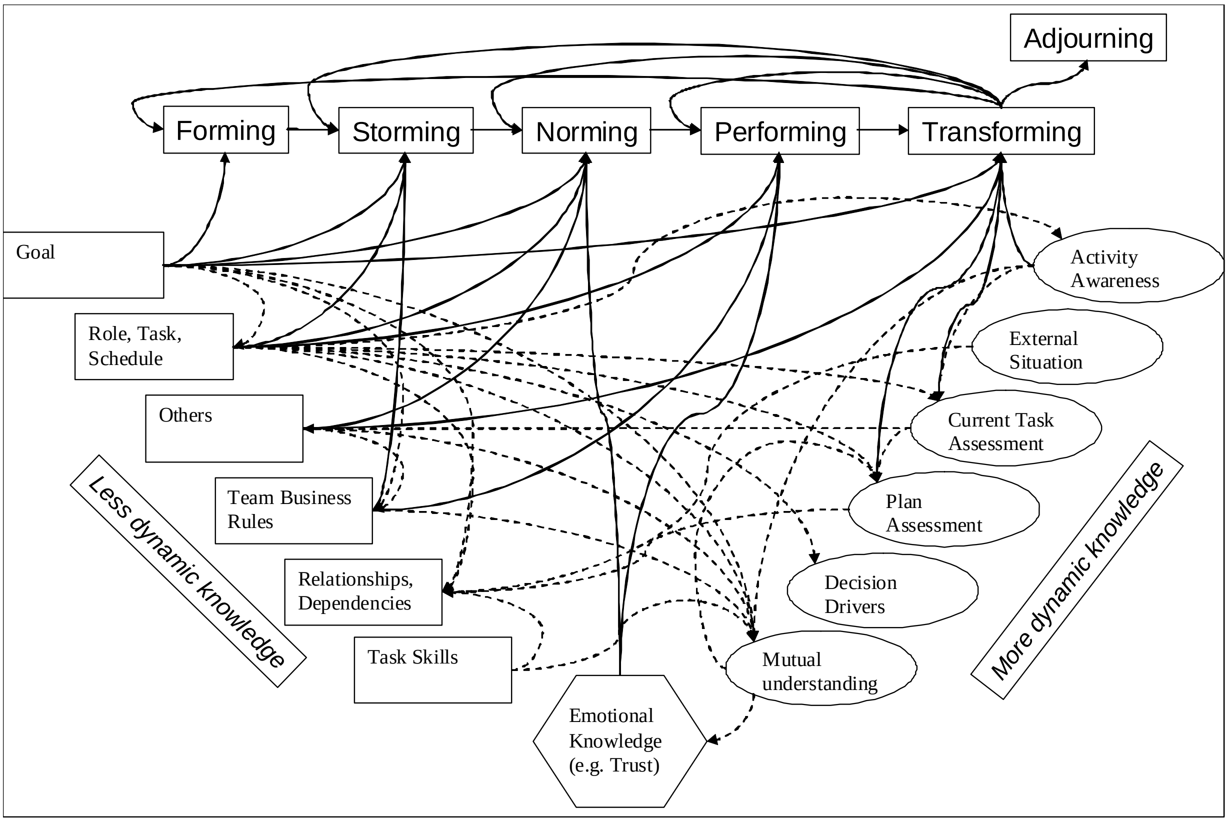
This is supplemented with a 6th maturity state, ‘Transforming’, which is a transition of the team to a lower maturity state without loss of team identity. This is important in representing various NEC constructs, such as an Agile Task-Oriented Grouping (or Agile Mission Group), where the context, task goal, or some team members change, in response to dynamic events in the Battlespace, but where the team remains fundamentally inpact.

Progression through Tuckman’s team maturity process can be described in terms of the acquisition and sharing of various kinds of knowledge. Here STORM builds upon the research work of Noble [14], who has successfully used an analysis of the knowledge held by team members to diagnose the causes of team behaviour and performance.

Noble identifies 12 ‘knowledge enablers’, or aspects of knowledge that are required for a team to perform. For application to STORM, these enablers can be considered either to be ‘more dynamic’ within the context of the decision, or relatively static for the course of the decision:

More Dynamic	**Less Dynamic**
Activity Awareness	Role, Task, Schedule
External Situation	Goal
Current task assessment	Knowledge of others
Plan Assessment	Team Business rules
Decision Drivers	Relationships
Mutual understanding	Task Skills

STORM then combines the Tuckman and Jensen with Nobles knowledge enablers, and forms a series of influence connections between them. The influence connections take the form of a series of s-shaped functions. As time progresses and the team matures, the team builds knowledge through the influence connections and hence progress through the maturity states. A diagrammatical representation of STORM appears below:



Finally, STORM relates Team Maturity to Team Efficiency, building upon work of Mathieson and Dodd [15], which has a formal treatment of this subject, but can briefly be summarised by the observation that an immature team will spend more of its time 'teamworking' (building up relationships and understanding with other team members) and less of its time 'taskworking' (conducting the job at hand) – as a team matures, this balance changes, and hence the team has a greater proportion of its time and effort to dedicate to the task required.

Physiological and Cognitive factors.

As discussed earlier, in order to fully represent the transitional and mature NEC states, SIMMAIR must capture the relevant effects the social and cognitive domains have upon human decision making.

The SIMMAIR team used an initial list of human factors as endorsed by a NATO Studies Analysis and Simulation Group (SAS 050, [16]). Whilst comprehensive, the 220 human factors listed in this document are at a far greater level of detail than appropriate for a sub-campaign level OR model. The team therefore selected the key human factors that were considered to be affected when moving to the transitional or mature NEC state. These key human factors were examined to determine their primary influence on human decision making. Some of the key factors selected were: commanders intent, social networks, motivation, level of trust, collective training and co-location of teams. Around these factors a bespoke model of cognitive and physical factors was constructed, focussing on workload, alertness and collaboration, and the ability of the team to deal with those factors. This is summarised in Figure 4 below.

The high level human factors on the left of the diagram summarise a subset of the SAS-050 factors. Firstly the likely factors affecting team workload, such as the amount of information to be processed, and the complexity of the information are combined together using a simple weighted sum. A description of the STORM team maturity state is also taken into account. A comparison of how well matched the team is to its workload (noting that an underworked team will produce errors and delays in a similar way to an overworked team) is undertaken, in order to derive a number of delays (in information passing etc), and an error rate in compiling the picture.

Secondly, a consideration of the team alertness takes into account the most significant factors, such as circadian rhythm, and environmental factors, to derive an 'average' value of alertness of the team at hand. Through series of semi-sinusoidal functions in a similar way to STORM, this impacts on picture compilation accuracy and also on team collaboration.

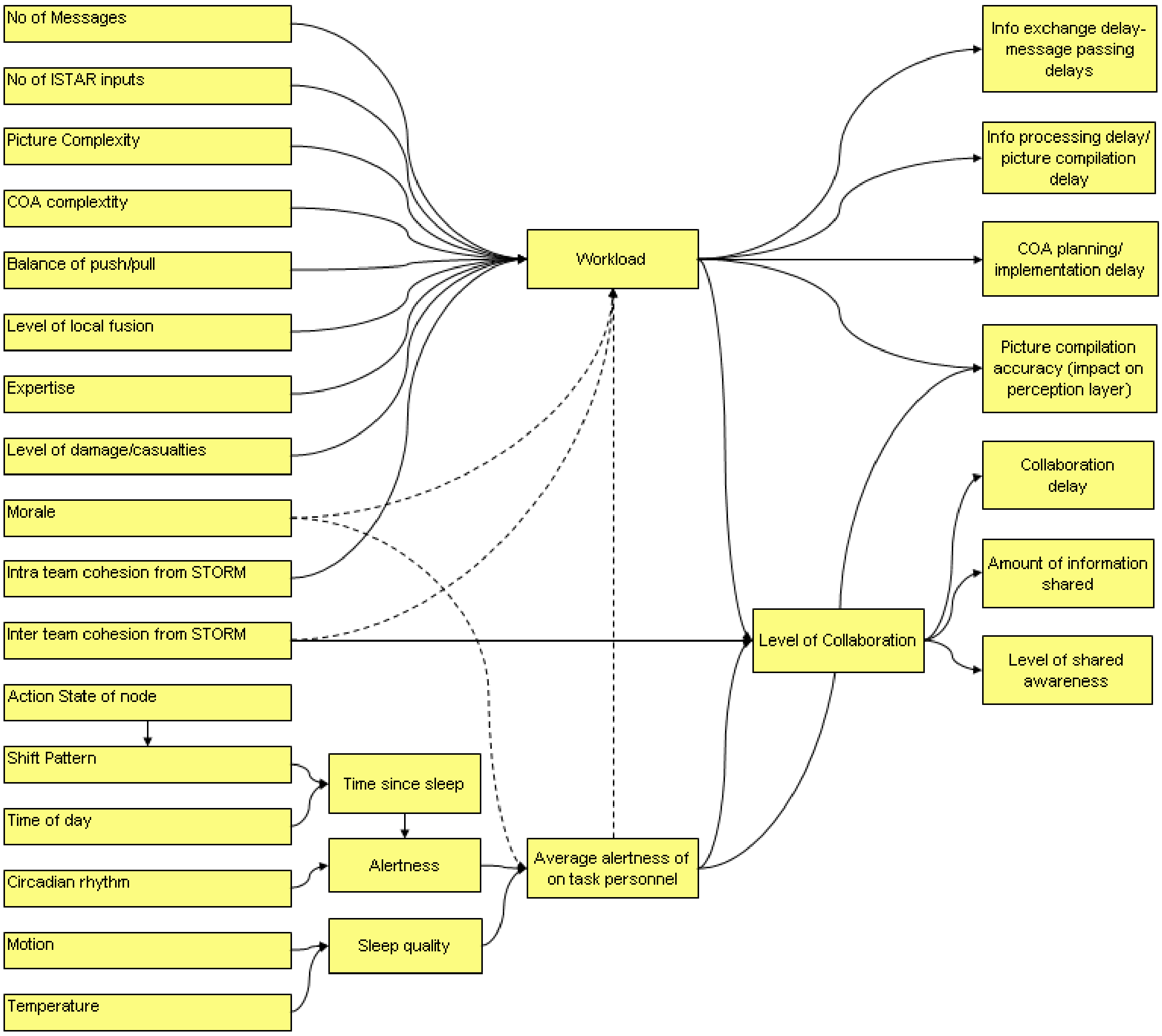


Figure 4: Model of Physiological and Cognitive factors

Perception

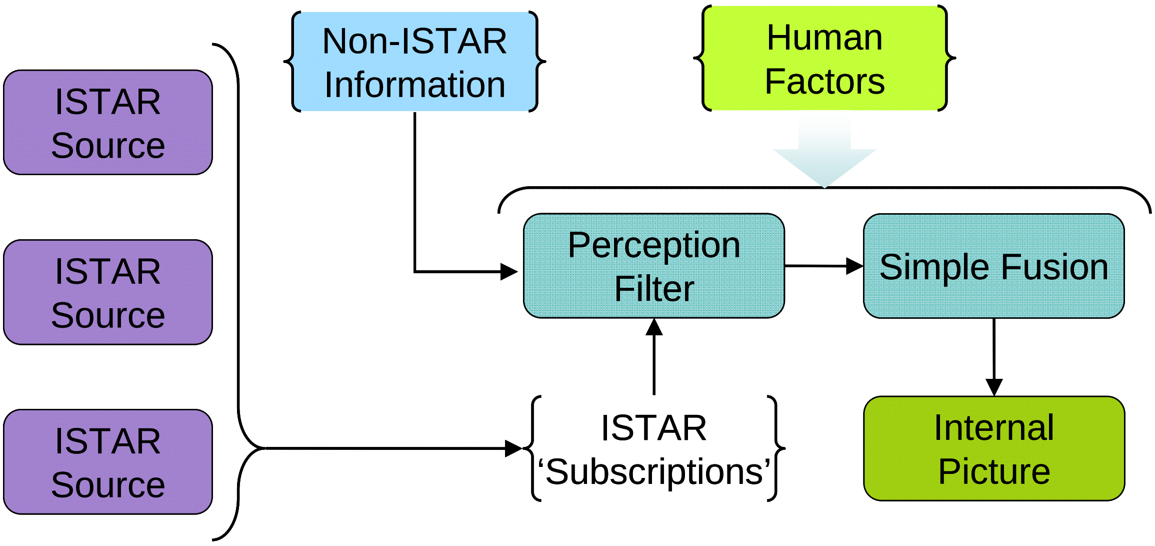
In order to represent the impact of information and shared awareness on decision making, an Information Management representation has been developed to allow an accurate representation of sensed truth, rather than ground truth, being available to a decision maker in the SIMMAIR model.

The decision maker is aware of a number of ISTAR sources available to him, and 'subscribes' to a number of them. The ISTAR sources could include any number of individual sensor feeds, local fused pictures, or a Recognised picture. By subscribing to these, the command team receives updates to the ISTAR information as they occur (delayed appropriately due to communications limitations). In addition, the decision maker subscribes to a number of 'Non-ISTAR' information sources. These would typically be reports of own force state, knowledge of commanders intent, etc.

This information is subject to a perception filter, where a number of human factors influences allow the command team to disregard some items of information or give additional weight to some items of information, depending upon the mission situation. Some examples of human factors influences that may occur include:

- Time delay and error rate in picture compilation due to fatigue and other factors arising from the cognitive and physiological modelling described above
- Perception Bias, where one's pre-conception of the situation affects how current information is interpreted (e.g if a decision maker has been briefed that the enemy is likely be in a certain area, then he is more likely to identify (possibly falsely) a contact in that area as being an enemy)
- Confirmation Bias, where a decision maker forms a view of the situation, and subsequently seeks additional information to confirm this view, but will tend to reject new evidence that contradicts it
- Trust in sources. A decision maker is more likely to accept information from agencies he trusts or has personal experience of

The resulting filtered information is then combined to form the decision makers Internal Picture, through a simple fusion process. Not to be confused with the ISTAR association and fusion processes, this 'simple fusion' represents the combination of the various information feeds within the decision makers mind in order to further determine which pieces of information to use and which to reject in his decision making. This draws upon related research into Combat Identification (CID) undertaken within MoD [23], whereby the successive changes in information available to the decision maker are fused using the Dempster-Shafer algorithm.[24], resulting in a representation of the decision makers internal picture.



Decision Making

The decision itself is made using the Rapid Planning process, as mentioned above. The Rapid Planner involves four stages that emulate the Recognition Primed Decision Making

(RPDM) approach suggested by Klein. The four stages of the rapid planner are as follows [6]:

1. Observations analysis and parameter estimation
2. Situation assessment (OK/not OK)
3. Pattern matching and preferred posture selection
4. Posture transition

Stage 1, Observation analysis and parameter estimation takes the internal picture derived above, and extracts a number of ‘cues’ from it in order to characterise the Battlespace. Traditionally, only one cue is used, namely Perceived Combat Power Ratio (PCPR), which describes the decision makers local perception of force ratios. The SIMMAIR project has derived a number of possible alternative cues, taking into account the move away from attrition based warfare towards manoeuvrist doctrine. These include:

- Recognised Threat to Self
- Threat Background or Context
- Availability of Support to Augment Capability
- Degree of Picture Uncertainty
- Threat to Mission or Campaign
- Environmental Considerations

In stage 2, Situation Assessment, the historical trend of the cue values is important, as the rapid planner then attempts to fit the trend to a number of Bayesian probability models, corresponding to whether any change in the cue state corresponds to a real change in the Battlespace or not. If the model corresponding to ‘no change’ in the external situation has the highest probability, the current situation is considered to be ‘OK’, and the model proceeds with the current course of action. If not, then stages 3 and 4 of the rapid planner are implemented.

In stage 3, the cue values are transformed into fuzzy states (e.g. ‘High’, ‘Medium’ or ‘Low’ Threat to self). The commanders experience base is then represented in terms of combinations of cue states, corresponding to courses of action. A simple example of this is shown below:

Threat	**Availability of support**	**Course of Action**
Low	*[5]	Maintain planned course
Moderate	*	Alter course to evade
High	High	Transmit turn away order
High	Very high	Fire order warning
Very High	Very high	Fire order destroy

Finally, stage 4 allows the locally chosen course of action to be tempered with the intent of the decision makers superior commander. For example, an aggressive commander may wish to override his subordinates decision to hold ground and force an attack. This is

[5] An asterisk indicates that this cue can be in any state for this course of action

specified through a simple lookup table in a similar way to the above. A course of action is then chosen and implemented within the warfighting elements of the SIMMAIR model.

Exploitation

The exploitation strand of work allowed the development of SIMMAIR to be focussed in those areas that will maximise its usefulness to current and future studies – while still at an intermediate stage of development. The exploitation work consisted of a number of shadow studies being performed in step with real studies. The term shadow study as used in this section refers to the work done by the SIMMAIR model development team to model the systems and scenarios under investigation by the real study teams within SIMMAIR. The aim of these shadow studies was to apply SIMMAIR to current work being performed by the MoD and as a consequence help guide the development of the model in those areas that are in greatest demand. The exploitation work also resulted in a number of other benefits for SIMMAIR development, including: data collection, testing and validation, and increased visibility of the model within the UK the defence community. The real studies benefited from SIMMAIR through the supplemental and unique analysis provided by the model; analysis that could not be obtained through the models originally identified for use in the studies.

Early exploitation work was undertaken to identify those areas of MoD research that would have a potential to benefit from SIMMAIR. A number of possible areas that could find significant uses were identified and included: OR studies, support to Capability Audit, informing Doctrine and Concepts Development, and support to Experimentation and War gaming.

Over all domains investigated approximately 50 studies within the MoD were identified that would significantly benefit from SIMMAIR; 12 of those studies identified SIMMAIR as being capable of providing better analysis than current models or being the only tool capable of providing the analysis required. This confirmed that the requirement for a model with SIMMAIR's capabilities was real. As it is likely that the primary use for SIMMAIR will be to support OR studies it was route that was initially pursued in the exploitation work detailed in this section.

Shadow Studies Method

The aim of the SIMMAIR shadow studies was to support the analysis being performed by a number of real studies. The main gain for SIMMAIR was the focus on which areas the model needs to be developed in from applying it to real problems. SIMMAIR was applied to some of the issues faced by the OR study teams, to provide insights into the areas that the current models they are using cannot provide. In turn, the exploitation of SIMMAIR also led to the population of the model with data and the start of detailed testing and model validation via Military Judgement Panels (MJP). The shadowing process itself consisted of the SIMMAIR team working closely with the OR study teams to determine the best way to apply SIMMAIR to the individual study problems and situations. A detailed description of the method used by each of the shadow studies is detailed below. More detail on the studies themselves and why SIMMAIR is so useful for each of them is given in a separate section.

For this first phase of the work three studies were selected for shadowing in three different domains. These domains were:

- High level/C4ISTAR
- Air
- Maritime

Studies in these domains were chosen to identify a wide range of model developments that were needed as well as to apply the model in a wide variety of functional areas (while also keeping in mind long term development of the model), for example: NEC, ISTAR, engagement, Human Factors and Maritime Logistics are just a few. Concepts of Analysis (COA) were written for each study and addressed how SIMMAIR was to be applied and to what within each of the studies. Due to the scale of some of the studies the focus was on developing functionality that would enable a useful subset of the scenarios to be shadowed in SIMMAIR providing focused analysis on the most important parts of the real studies.

The SIMMAIR shadow studies modelled segments of time of approximately 30 days length within the selected campaigns. All of the modelling in the shadow studies was based around a set of vignettes that were used as building blocks to create the 30 day time segment. A baseline vignette was generated in consultation with each of the study teams that enabled a basic representation of the system that they were interested in analysing. This baseline vignette was then increased in complexity with the addition of extra factors that represent what may occur or be encountered in “real” situations within the scenarios. This steady increase in difficulty helped guide the developments that were needed as well as provide convenient stepping stones to test the model against.

Once the order of development had been decided the vignettes were developed in more detail to allow population of the model to begin. This was done via a series of workshops and data collection exercises in collaboration with the study teams; this was necessary to capture the extra detail needed for SIMMAIR over and above that already existing to perform meaningful testing of each of the model developments. Existing models were also reviewed to see if data that already existed could be re-used in SIMMAIR. Data types collected for addition into the model included:

- Request for Information – RFIs
- ORBATs
- Relationships between the sides
- Sensor data
- Engagement data
- C2 Structures
- Decision ownership and possible courses of action
- Operating areas
- Terrain data

RFIs are vital to SIMMAIRs operation with them being a major part of the dynamic links between events in the model. An RFI would be issued by a user in order to request specific information, for example: a Commander on a Frigate may want to know if a minefield exists in a particular region before transiting through that region. The RFI would be issued to the relevant level of the command chain and if the RFI cannot be satisfied with the current information available it will be assigned to an asset to collect that information. If that asset doesn’t exist at that command level it will be passed upwards until it is satisfied or becomes redundant. The Commanders Course of Action (CoA) following the results of this RFI will be a result of the decision making logic described in earlier sections.

Constant contact was maintained with each of the real study teams during the input of the data into the model to enable timely advice on any issues encountered. Each vignette was thoroughly tested and results fed back to the study teams before progressing to the next vignette. Each of the studies had a defined number of Measures of Effectiveness

(MoE) against which the success or failure of a campaign could be judged. Typical MoE within the selected studies included:

- Speed of decision making
- Percentage of RFIs satisfied
- Time taken to satisfy RFIs
- Percentage of time for which each collector and processor is utilised
- Percentage of threats detected
- Percentage of targets against which tracking was not lost
- Number of occurrences in which own entities are mis-identified as threat units (and vice versa)
- Percentage of threats killed
- Number of collateral damage events occurring
- Number of fratricide events occurring
- Probability of own unit(s) escaping hit
- Probability of own unit(s) surviving
- Number of ships kept supplied

The vignettes were input into SIMMAIR in such a way to enable the same or similar MoE to be used but to answer the questions that the other models could not – namely the impact of HF and NEC on the campaign. More detail on what SIMMAIR achieved in each study is given in the next section.

A number of replications were run for each scenario and the final output from the model presented to military and technical review to establish if the simulation was reasonable and in keeping with the inputted scenarios. Any issues encountered, such as unexpected or unrealistic behaviour were discussed and ways of correcting the defects found. Any insights gained into the studies due to SIMMAIR's unique functionality were also identified and explored here.

Shadow Studies

Study 1 - High level/C4ISTAR

The ISTAR study investigated the campaign level effectiveness of potential ISTAR architectures and their impact and dependence on enabling Information and Communications Services. The study team constructed a number of different ISTAR architectures for each scenario under study. These included collectors, analysis nodes and the networks between them. The effectiveness of the different architectures was assessed in two ways: the ability to provide required intelligence and the impact upon the overall campaign. The relative contributions of each of the elements involved were also considered.

The study team has assessed the different ISTAR architectures proposed using a model called J2M. This model allows the examination of different architectures in terms of their ability to meet the Commander's Information Requirements (CIR). The outputs from this model fed into campaign level modelling and provided inputs to a number of lower level models. These lower level models assessed whether or not the proposed structures have sufficient capacity to cope with the communications load placed upon them. Delays in fulfilling the CIR resulted if they did not; the delays are then used as output which is fed back into the higher level models and campaign analysis to give the overall impact on the campaign due to the chosen architecture.

SIMMAIR modelled this system within one modelling environment rather than the multiple environments used by the real study team. In addition to the simplicity of using one model instead of several the SIMMAIR team incorporated its human factors elements and dynamic tasking of assets. This dynamic tasking is based upon the flow of information and intelligence and any delays related to this. These dynamic elements are not present in the original method that represents such deficiencies in the flow of information by delays in fulfilling the CIR across the different models.

The ISTAR study team had a well established and tested method in place which SIMMAIR aimed to complement; due to this fact the initial phase of the shadow study was a data collection exercise. The real study team provided the majority of the data required for the shadow study, as it already existed from previous work, leading to a only a small amount of work being done on how the systems actually operate. After collection of the data the aim of the shadow study shifted to how it should be used in SIMMAIR to represent the systems of interest. Further discussion with the real study team was required at this stage to ensure the representation created was valid. The existence of a well established method also provided us with validated output to compare against that produced by SIMMAIR.

Study 2 – Air Domain

The study shadowed in the Air Domain programme aims to provide a Land Environment air situation contribution to Command Battlespace Management (CBM), together with counter-ISTAR and air defence protection capabilities in support of land force operations. It will comprise sensing, effectors and Battlespace management and C4I. Effectors are capabilities relating to a number of defensive tasks, for example: Base protection and Battle Group force protection. The effectors could be made up of a variety of systems including Surface to Air Missiles (SAM) and air to air missiles.

The study team looked at a number of options which had different balances of the above factors to determine an optimum balance for networked enabled air defence. Issues relating to Battlespace management were covered as was the effect a network enabled defence has on protecting forces against the different threats present.

The shadow study team used the different options and functionality in SIMMAIR to investigate the effect of having a networked enabled air defence system over a system made up of non networked local air defence assets. The efficiency of the dissemination of information throughout the system (the timeliness of delivery) was also investigated as it is likely that any network enabled system will have to deal with a large amount of data. Issues related to ABM were also investigated, for example: how is the Battlespace managed when civilian/coalition air traffic is present.

The Air Domain team in comparison to the ISTAR team did not have a well established method in place nor was the concept of the system fully mature – the balance and makeup of the sensors and effectors was not known. The lack of information and data on the system led to a greater degree of interaction with the real study team to enable us to reach an agreement on what should be modelled within SIMMAIR. Not only did data need to be collected but possible ways of how the system may work and a scenario to test it had to be worked up. In effect the shadow study team had to guide the real study team to produce data and agree a way forward rather than making use of what already existed. This situation led to SIMMAIR producing results in advance of the real study highlighting the benefit of SIMMAIR as a method of achieving the study aims in its early phase.

Study 3 – Maritime Domain

The Maritime Domain study team wished to understand the ways in which various classes of tanker may be able to operate and the consequent impact upon their ability to provide fuel. The study performed by Dstl examined issues related to the capabilities of the tankers including survivability, communications and aircraft maintenance facilities. The output of the study will be used to inform the customer on the optimum mix of classes in order to achieve the desired effects.

The study will make use of a Dstl model called Fleetflow+. FleetFlow+ is a simulation model developed by the Maritime Effects Analysis Group within Dstl Naval Systems to support research to inform customers on a variety of issues. FleetFlow+ simulates the provision of Bulk Consumables (BC) by a support fleet to a deployed group, taking into account the Operational Tasking of that deployed group. The study reported on constraints due to deploying the different capability tankers in high threat high intensity operations to small scale low threat operations. It also reported on the benefits of certain features of the tankers such as a flight deck for MIOPS type operations or to act as a lily pad for other rotary wing assets.

The SIMMAIR shadow study team used the dynamic nature of the model to investigate the effect of NEC, HF and ASuW on the provision of fuel to a deployed Task Group. The use of the different tanker classes highlighted areas where the particular features of the classes play a vital role. The shadow study concentrated on a small scale section of a larger campaign where the different classes of tanker were used in a MIOPS role along with a Frigate to investigate the effectiveness of the tankers in intercepting and neutralizing a number of threats while simultaneously providing fuel to the ships it is tasked with supporting.

The maritime teams study and method was at an intermediate stage of development. The base plan was well developed but it was identified that SIMMAIR could provide extra analysis that the chosen method could not. For this shadow study this analysis was centred on the effect the extra features and assets have on the capabilities of the task group while still incorporating the effect of logistics – something the existing logistics model cannot do alone.

Conclusion

The use of SIMMAIR at such an intermediate stage of development presented a number of issues that needed to be overcome. The biggest issue was making sure the developments being undertaken in support of the shadow studies remained coherent with future developments and the overall philosophy of SIMMAIR – that of doing the hardest parts first. The studies shadowed were understandably focussed on the functionality that they were most interested in. A balance had to be reached between satisfying this need while keeping the overall development in balance. This required that only a useful subset of the campaigns within each study were focussed on. This approach meant the model could be developed in more detail in the more important areas while at the same time allowing testing to proceed at a manageable pace.

The varying stages the real studies were at when the shadow studies started also presented a number of challenges to the development of the shadow studies – though all helped guide this phase of development of the model and increase its visibility within MoD.

The studies that were sufficiently well developed led to the exploitation being focussed on data collection and future developments while the Air Domain study led to a focus on gaining an understanding of how the system may operate followed by further work to gather or create data for use in SIMMAIR as well as identifying the functionality that will be central to achieving the current study aims. The interaction with the study teams has proved invaluable and the interest raised in the model has opened up new possibilities for exploitation.

Future work will involve SIMMAIR being used in an ever increasing number of studies, both real, where the functionality exists, and shadow studies to guide development of future required functionality.

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