SYSTEM ENGINEERING FOR FUTURE CAPABILITY
SYEC 07 LOUGHBOROUGH, FEBRUARY 12 – 13, 2007

AN ARCHITECTURE FOR ORGANISATIONAL DECISION SUPPORT

R.I. Whitfield, A.H.B. Duffy, A. Thomson, Z. Wu, S. Liu

Abstract

The Decision Support (DS) topic of the Network Enabled Capability for Through Life Systems Engineering (NECTISE) project aims to provide organisational through-life decision support for the products and services that BAE Systems deliver. The topic consists of five streams that cover resource capability management, decision management, collaboration, change prediction and integration. A proposed architecture is presented for an Integrated Decision Support Environment (IDSE) that combines the streams to provide a structured approach to addressing a number of issues that have been identified by BAE Systems business units as being relevant to DS: uncertainty and risk, shared situational awareness, types of decision making, decision tempo, triggering of decisions, and support for autonomous decision making. The proposed architecture will identify how either individuals or groups of decision makers (including autonomous agents) would be utilised on the basis of their capability within the requirements of the scenario to collaboratively solve the decision problem. Features of the scenario such as time criticality, required experience level, the need for justification, and conflict management, will be addressed within the architecture to ensure that the most appropriate decision management support (system/naturalistic/hybrid) is provided. In addition to being reliant on a number of human factors issues, the decision making process is also reliant on a number of information issues: overload, consistency, completeness, uncertainty and evolution, which will be discussed within the context of the architecture.

Keywords: Decision Management, Resource Management, Collaboration, Change Prediction, Integration

1 Introduction

The ability to make efficient and effective decisions is often seen as a quality that distinguishes people of normal and expert ability. A number of factors contribute to being able to make efficient and effective decisions, but chiefly the availability of reliable information at the point of making the decision and the experience of the decision maker may be considered as being most critical. Providing Decision Support within the process of decision-making is critical in achieving efficient and effective decisions irrespective of whether the decisions are being made within an individual or networked (collaborative) context. The provision of Decision Support within a collaborative sense raises many additional challenges; for example the decision-maker may be expected to make decisions that not only aim to satisfy the decision maker's intent, but also the intent of other decision makers irrespective of their position within or out-with the organisational hierarchy. The decision maker may be collaborating with other decision makers within a network and not be aware of whether they are human or computational agents. The NECTISE project consists of four inter-related topics: Through Life Systems Management, Architectures, Decision Support, and Control and Monitoring. The project consists of a six month definition phase to provide further definition of each of the four topics, followed by the main phase of the project that builds upon the research undertaken within the definition phase. The Decision Support topic aims to address these challenges from an organisational perspective with the aim of providing the most effective level of support to facilitate the through-life development and support of NEC systems. The main types of decision makers that have been identified that may be supported include:

- **Customer**. Supporting issues related to technology insertion points, operational deployment and support (accounting for availability of required capability by industry), setting of budgets, assessing costs of options, setting up subcontracts, negotiating terms and conditions.
- **Programme and project management**. Covering strategic issues related to the choice of products to develop/support, long term business goals, the business models to use, the choice of supply chain, the product insertion point, resource investment, through life support, etc.
- **Process management**. Covering tactical issues related to the choice of personnel, definition of collaborative teams, scheduling of projects/processes, resource investment/training, etc.
- **Resource management**. Consideration of capability, capacity, competence and commitments of resources and exploitation thereof to maximise decision making efficiency and effectiveness.
- **Engineering and scientific**. Covering real-time decision issues related to product development: which technology is best, which material is best, which system is best, etc to satisfy requirements.
- **Supply chain**. Covering strategic, tactical and real-time issues in support of (and the interaction issues with) the prime contractor.
- **Users**. Identifying issues related to requirements, goals, desires and constraints at multiple levels.

Much of the NEC (and Network Centric Warfare, NCW) literature discusses Decision Support from an operational (or battle-space) perspective, i.e. how decisions may be managed and made within a network of collaborative networked systems operating within the battle-space to achieve an expected outcome. The focus is different organisationally – the aim is to consider what technology is needed to enable organisational resources to be networked to make decisions collaboratively, increasing capability or organisational effect, for the provision of through-life NEC decision support for system development.

The organisation is increasingly becoming involved within an operational context as discussed within the Defence Industrial Strategy white paper [1]. Organisational Decision Support will increasingly be required to cover the operational phases of deployment and support with the aim of deciding what technology is needed to enable new or existing systems to be networked to either sustain or increase system capability and subsequent military effect. Whilst the underlying principles of providing Decision Support operationally (for the creation of effect) are similar to those organisationally (for NEC system development and support), the implementation of the support would differ widely.

Decision-making within NEC may be regarded as being one of the core features as defined within the UK and identified as:

> *"The linkage of sensors, decision makers and weapons systems so that information can be translated into synchronised effect at optimum tempo."*

Whilst the focus of this statement is aimed towards the creation of military effect, it can be seen that the principles of providing Network Enabled Capability focus on the gathering of information to form a (fully) shared awareness of the situation amongst collaborative entities, through the communication of information and understanding of intent (or collaborative goals) to provide decision enhancement. Since an organisation may be regarded as a number of collaborative decision-makers co-operating towards a common goal – the development, delivery, deployment and support of a system or systems – the issues of gathering information to form a shared view amongst those collaborating to achieve the goal is still relevant.

The importance of information within the MOD has been defined operationally [2] and is discussed here within operational and *organisational* contexts:

- **Sense**. The direct and indirect sensing of a situation by multiple diverse sensors (which will include people). *The direct gathering of information that influences the development or support of a system (which will involve people and autonomous agents).*
- **Understand**. The generation and maintenance of a common perception of the situation, allowing shared awareness across the battle-space. *The generation and maintenance of a collaborative understanding (between people and autonomous agents) of the information that is sensed.*
- **Develop intent**. A dynamic, distributed decision-making process at all levels of command. *A dynamic, distributed and collaborative decision support process at all hierarchical levels within and out-with an organisation.*
- **Synchronise effects**. The co-ordination of all forms of effect in the battle-space to achieve a shared objective. *The co-ordination of all organisational resource capability to achieve a shared objective or goal.*

Whilst the focus of the MoD's definition was within a military context, it is clear how the same principles may be applicable within an organisational context – the aim of the Decision Support topic.

In the NEC environment, the configuration of individual resources is particularly challenging as the problem is time dependent, and the resources that are being configured include delivered products and processes, and elements of the delivering organisation itself. Furthermore, the properties that we wish the system being developed to exhibit (military capability, lifecycle cost effectiveness, etc) are non-linear features of the system i.e. they are, to some extent, emergent. Thus, resources need to be configured to meet a number of competing optimality criteria (e.g provide maximum capability at minimum cost given fixed resource availability) taking into account current uncertainty in state, and its prediction through non-linear system models. The IDSE will provide a means to evaluate changes to the system as well as explore more radical solutions that may deliver a step change in efficiency or capability.

The Decision Support topic therefore aims to develop an Integrated Decision Support Environment (IDSE) that will provide through-life support within a networked organisation (and potentially its supply chain) for capability-based acquisition, for example. Different types of decision-making will be considered (systematic, naturalistic) and mapped to the differing requirements of the life-phases being considered. The main challenges for the provision of decision support within the NECTISE project therefore include:

- The production of a rigorous definition of organisational resources in terms of their decision making and task performance capabilities.
- The relationship with other resources, and the hierarchical status.
- Mapping decision support technologies to the differing demands of the life phases considered and capturing the design rationale.
- Predicting the impact of potential change to provide the decision maker with a more detailed description of the decision alternative space.
- Enabling multiple decision makers to collaborate within the decision making process.
- Integrating these elements into a complete decision support solution within the context of an integrated design environment - Figure 1.

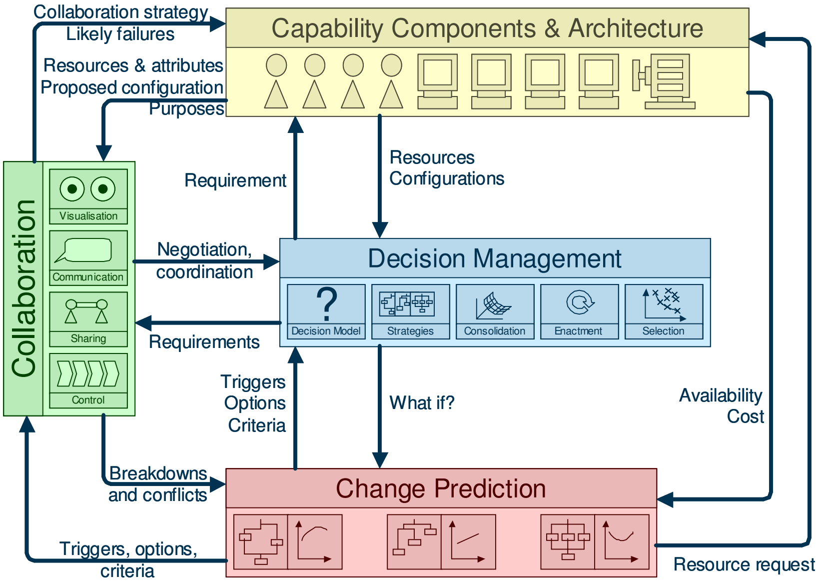

Figure 1. IDSE components and relationships.

Section 2 of this paper provides a discussion of the issues that were originally identified as being relevant to the Decision Support topic, as well as those emerging through the definition phase of the project. A high-level proposal for the IDSE is presented within Section 3, and finally the paper is concluded in Section 4.

2 Development issues

In order to understand the problems associated with developing an IDSE, a review of previous research within both decision support and decision making was undertaken. Whilst the aim of the IDSE is not to provide any automated decision-making, the philosophy of Mallach [3] is adopted where there exists a need to understand the characteristics of a decision before decision support may be provided. Mallach stated: "If you do not have a clear decision statement, you cannot develop the best system to support people making that decision." The decision statement provides the context and understanding of the need to make the decision. The IDSE provides the support for the decision to be made, but does not make the decision itself.

Ullman [4] defined a set of attributes that represent the challenges of providing what was considered an "ideal" decision support system within an engineering context:

- Support inconsistent decision-making information. Within team situations, different viewpoints occur because different people within the team represent different corporate functions or stakeholders. Team members may also evaluate alternative choices with respect to the given criteria differently especially when considering qualitative criteria.
- Support incomplete decision-making information. Most decision-making problems have an evolution of the alternatives and criteria as the problem evolves and becomes better understood. Support is therefore needed to enable new alternatives and criteria to be considered when they become available. In addition, team members may not evaluate all of the alternatives against all of the criteria.
- Support uncertain decision-making information. Decision-making always consists of some uncertainty that diminishes to some extent as the problem evolves.
- Support evolving decision-making information. Kuipers [5] stated: "Decisions are not made after gathering all of the facts, but rather constructed through an incremental

process of planning by successive refinement". The decision-makers learn about the decision problem as the choice is being made.

- Support the building of a shared vision. Sharing of information between a group of people involved within making the decision, and the outcome of the decision has been shown to have a positive impact on the quality of the decision being made.
- Calculate alternative ranking, rating and risk. Decision support systems should provide functionality to enable the alternatives to be evaluated to determine which best achieves the required outcome. In addition to this ranking and rating, risk should also be adopted to ensure that the highest ranked and rated alternative is not necessarily chosen if it has a high risk.
- Suggest direction for additional work, what to do next. One challenge for decision-makers is to consider which alternatives to eliminate and which ones to concentrate on for additional effort. Exploration of the impact of change enables additional information to be provided regarding how changes may affect the ranking, rating and risk.
- Require low cognitive load. Ullman [4] stated: "An ideal decision support system should help a team reach a better decision than they would without its use, and not require an increase in cognitive load." The aim however is not to guarantee better decisions – the decision maker is ultimately responsible for the choice – the aim is to provide support to make the decision more timely and informed.
- Support a rational strategy. Merderer [6] concluded from an investigation into rationalising strategies: "Time spent developing criteria was positively correlated to a constraint satisfaction", "The creation of several alternatives leads to a better result", and "A coherent and carefully conducted evaluation of an alternative leads to a better result." Strategies need to be adopted to fit the types of problems considered.
- Leave a traceable logic trail. The logic behind making a decision, including the alternatives considered, the criteria used, and the arguments made should be recorded for future use.
- Support a distributed team. Ullman [4] stated: "An ideal system needs to support a team of people, complete with their inconsistent, incomplete, uncertain and evolving input as they build a shared vision". In addition, this should be supported in a distributed nature.

These attributes combine to form the challenge of the IDSE. The vision is to establish how these challenges will be met.

The following list represents the main Decision Support issues that were developed through a series of workshops, developments and reviews with the research and BU team. The list is not exhaustive – its aim is to give a general understanding of the issues that the Decision Support topic proposed to address alongside those that have emerged from the definition phase of the NECTISE project. In addition to the scoping of Decision Support with respect to the original proposed issues, the topic has been scoped in terms of decision making, decision support, and network-enabled decision support issues identified as outcomes of the definition phase.

- Resource definition. Characterise the different types of organisational resource to determine properties, capability and relationships. Representation of different types of resource knowledge within ontologies to facilitate resource identification.

- Dynamic reactive problem solving. Awareness that changing situations may require response in terms of decision support. Adaptation of problem solving capability responding to changes within the environment.

- Decision assessment. Assessment of decision alternatives and contingency planning in terms of decision impact (including hierarchical), robustness, risk assessment and uncertainty.

- Rationale capture. Enable individual or team learning through the capture of rationale within the Decision Support process.
- Change prediction assessment. Determine the impacts of change made on a system to facilitate risk assessment and "what if" scenarios to be conducted. Consider how the impact of change on emergent system properties would be managed.
- Collaborative Decision Support. Consider different mechanisms for best supporting individuals and teams in decision-making (humans and autonomous resources). Understanding, sharing, communicating and co-ordinating their activities.
- Collaborative assessment. Evaluation of individual and team decision-making efficiency and effectiveness – consideration of collaborative "cost". Determination of how collaboration may be defined to reduce cost.
- Dynamic re-configurability. Consider the change in availability of capability and how this should be managed such that the IDSE automatically re-configures to perform in a near-optimal manner.

These issues when addressed within an implementation are considered to represent the "core" of the IDSE. Additional issues relating to decision making (through consideration of Mallach's [3] philosophy), decision support, and network-enabled decision support (within a networked organisation) are detailed within the following sub-sections.

2.1 Decision making issues

In order to understand what the key issues would be for providing decision support, it was firstly appropriate to consider the characterisation of decisions as well as what the constituents of the process of making a decision are. Mallach [3] defined a number of issues relevant to general decision-making and characterised a decision as being composed of: "a decision statement, a set of alternatives, and a set of decision making criteria." Mallach also stated that these elements always exist, although the decision maker at times is not aware of this.

The production of a set of alternatives is dependent upon the decision statement. The components and considerations that go towards producing the alternatives are dependent upon whether the decision statement is system (product) or process (CoA) related. In producing the alternatives, it is necessary to focus on the objectives in terms of a number of necessary and desired expected outcomes. Kepner and Tregoe [7] characterised some of the components of the objectives (and hence the alternatives) from a CoA perspective as being: people, organisations, facilities and equipment, materials, money, production output and personal aspects. Equivalent components would require consideration from a system perspective.

Choice is again a characteristic that is strongly dependent on the decision statement. Just as the alternatives are defined in terms of components that are related to the system or CoA domains, the means of measuring a choice and supporting the decision being made, i.e. the metrics, are also defined from a system or CoA perspective. In addition to having choice in terms of metrics that are specific to the decision statement, the choice may also incorporate more general "metrics of metrics" such as risk, efficiency and robustness that are used to provide an indication of the behaviour of the metrics.

Despite not being a stage within the making of a decision, the enactment of the decision alternative is part of the decision-making process, since it is necessary to consider how well the decision is performing with respect to the expected outcomes, in terms of the metrics used for making the choice.

Since the focus of the Decision Support topic will be in providing life-phase support from an organisational perspective, the following issues are relevant and will be addressed:

- Decision statement. A definition detailing the current need for making a decision, including cause of decision, information relevant to the cause, information needed to make the decision, expected outcome. Decision types will be considered to provide a template upon which support may be provided.
- Choice. Generation of solutions to the problem considering current situation and expected outcome, including efficiency, effectiveness, risk and robustness of solutions. Use appropriate approach to select most optimal solution.
- Enactment. Implement the choice.

Interestingly, Klein [8], within his "recognition primed decision model", has a different view of the decision-making process with a more "naturalistic" approach to how decisions are made. Klein's focus was more towards time-critical decisions being made within an operational sense through three stages:

- The decisions being made cognitively through realisation and matching of the situation being faced by the decision maker.
- Mental simulation and adaptation of generally a single CoA to take.
- Enactment of the CoA.

A clear distinction therefore exists between the "systematic" approach and the "naturalistic" approach on the basis of the level of support that could be provided. Klein does however realise the limitations in his model in terms of the amount of information and dimensions to the decision problem that the human mind is capable of processing.

Cummings discussed the degree to which automation (provided by intelligent decision support systems) could be introduced within the decision process, indicating where computers may be utilised in facilitating this shared understanding [9]. Cummings cites Fitts' list [10] as representing the respective strengths of humans and computers within the decision making process. Humans are regarded as being better at: perceiving patterns; improvising and using flexible procedures; recalling relevant facts; reasoning inductively; and exercising judgement, whereas computers are regarded as being better at: responding quickly to control tasks; repetitive and routine tasks; reasoning deductively; and handling many complex tasks simultaneously [10].

Despite not being included within Fitts' list, Cummings acknowledges an increasing need for the use of computational decision support to help humans navigate complex decision problems.

2.2 Decision support issues

The issues that are relevant to decision-making provided a means to develop and discuss the issues associated with providing decision support within a conventional organisational sense.

One of the issues that the Decision Support topic has considered during the definition phase of the project was in understanding how the need to make a decision is triggered. Perry and Moffatt [11] defined the need for a decision arising operationally as:

> *"…the event that the situation (in the battle-space) deviates from what is expected."*

Within complex organisational systems, change is constantly happening, but it is only when the change results in a new situation being realised that it may be observed. A new situation may arise however, which either takes a long time to be observed or which remains unobserved owing to the complex nature of the organisationally distributed elements that contribute to the situation's definition. What constitutes a new situation is dependent on the observer's perspective and level of abstraction. In order to understand the deviation within a situation, it is necessary to understand what the constituent elements of a situation are for the organisational phases where decision support would be provided (plan, deliver, readiness support, deployment, deployed support).

Knowing only that there is a deviation in the current situation from what is expected is not sufficient to trigger the decision process; it is often desirable to understand what the cause of the deviation was, either directly or through diagnosis of the effect. Providing a means to formalise the understanding of the cause of a deviation contributes to capturing part of the rationale of the decision-making process. This rationale capture may subsequently be re-used to improve future decision-making cycles. The cause may possibly have a beneficial effect on the expected outcome, whilst still causing a deviation; the decision-maker could waste an opportunity if the beneficial causes (and effects) are not considered further within the decision process.

The outcome of triggering a decision will be the selection of a CoA that corresponds to the deviation in the situation. This selection procedure will only be possible once at least one CoA has been generated. During the generation of a CoA, a number of factors need to be considered: the current situation (corresponding to the plan, delivery, readiness support, deployment, or deployed support phases for example); the final situation or expected outcome; tasks to be undertaken to get from the current situation to the expected outcome (also corresponding to the relevant life-phases); the intermediate situations (to enable further deviation to be considered); how well the generated CoA achieves the expected outcome; and whether the decision maker has the resources or capability available to make the generated CoA viable. Selection may be from a set of existing CoAs, from combining whole or partial CoAs, or from newly created CoAs. In order to make a selection, each CoA requires assessment with respect to the criteria that are appropriate for achieving the expected outcome given the life-phase consideration. In addition, decision impact, robustness and risk assessment are necessary to ensure that the correct decision is made.

Within a conventional decision support situation the following issues therefore require consideration:

- Situation management. Definition of the contributing elements used to define a situation on the basis of the life-phases where decision support would be provided. Consideration of how these contributing elements would be monitored to enable the construction and subsequent observation of the situation.
- Deviation monitoring. Providing a means to assess the deviation between the expected and current situations. Notification of deviation and subsequent triggering of the decision-making process considering the decision-maker’s perspective. Capture of causes of deviation to constitute part of decision rationale management.
- Course of Action management. Definition of the contributing elements used to define a CoA corresponding to the life-phase where the decision support is required. Generation of new CoAs where alternatives do not exist. Selection including matching of pre-defined situations and multi-criteria assessment of CoAs. Assessment of decisions against associated life-phase metrics including decision impact, robustness and risk assessment.
- Course of Action enactment. A CoA will be implemented once it has been chosen through the allocation of the associated tasks to the capability resources within the organisation. During enactment, it will also be necessary to monitor the CoA to determine whether any subsequent deviations occur and develop remedial CoAs.

These issues represent decision support factors that have a more organisational sense – i.e. the management and enactment of CoA’s that may in turn be represented by process models consisting of a number of tasks, as well as the management of decision triggering within CoA’s through the management and monitoring of different situations. The following sections put these issues within the context of a networked organisation where the decision rationale, information and decision-making are collaborative.

2.3 Network enabled decision support issues

Perry and Moffat [11] provide a useful analysis of the issues of information sharing and its effect on decision-making within a "network-centric information environment" and state:

> *"The result is a significant improvement in awareness, shared awareness, and collaboration. These improvements in turn affect the quality of the decision making process and the decision itself…"*

The key issues that Perry and Moffat address are the effects of collaboration, uncertainty and complexity. In addition to simply sharing information, collaborative decision-makers must agree on a common set of critical information elements (that constitute a situation) to achieve "shared awareness", as well as agreeing on the current values and uncertainty of the critical information elements to achieve "full-shared awareness". The shared awareness may consist of data, information, knowledge and goals, of some aspect of the system being developed or supported. Within a networked organisation, the information that is used to construct the current situation is provided in a dynamic manner by distributed collaborative resources. A number of factors may contribute to uncertainty: bias, precision, accuracy, completeness, information freshness, ambiguity, errors, and knowledge (and lack) of unknown information.

One of the objectives when generating a collaborative decision-making environment should be to minimise the information overload for each decision-maker. Where information is known to change rapidly there may be the need for the information to be "pushed" to the decision-makers so that decisions may be made at the correct point for rapid changes in situation. Alternatively, if the information is known to change less rapidly, the information can be "pulled" by the decision makers whenever they consider it necessary for making a decision. It is hypothesised that an information pull strategy may reduce the effects of information overload, through the provision of information to the decision-maker only when it is needed (or requested), however information overload will remain a consideration for minimisation irrespective of the strategy adopted.

The goals that decision-makers are collaborating on map to a specific situation within a CoA and combine to represent some progress towards the overall goals of the expected outcome. Support is required to manage the goals of individual and collaborative decision makers and their interactions (which may take a hierarchical form) with higher level (strategic and tactical) goals, to ensure that the decisions made do not adversely affect either the situation or goals of other decision makers. As well as requiring full-shared awareness to facilitate collaboration, some degree of global awareness is required to avoid the choice of conflicting CoAs.

Within an organisational context it is unlikely that a single CoA would govern the actions of all decision-makers – multiple CoAs run concurrently representing the simultaneous development/support of many systems. Given a decision maker's choice to generate a new CoA resulting from a situational deviation, part of the evaluation process for the new CoA will be the determination of capability requirements to enable the timely enactment of the CoA. From a networked viewpoint this will necessitate the consideration of the available capability's commitments to other CoAs both in terms of the impact to the generated CoA, and to the CoAs that they are currently involved in, and scheduled for the future.

Within a collaborative organisational decision-making situation, the decision support characteristics summarised below build on those within a conventional sense:

- Shared situational awareness. Definition of the contributing elements and values that constitute a shared awareness. Should include unreliability issues from the collaborative decision-makers that are contributing to the awareness (bias, precision, accuracy, completeness, freshness, ambiguity, and errors). Support is required to package this information into a presentable form from the distributed sources to the correct decision maker(s).

- Information overload. Push and pull strategies for the acquisition of contributing elements to a situation. Complexity effects of these strategies on the network as well as other factors such as redundancy and adaptability are considerations when designing the decision-making networks.
- Collaboration. Combining information to achieve shared situational awareness, and co-operation towards collaborative goals, as well as consideration of impact of decisions on the global goals of the organisation.
- Hierarchical consideration. The effects of decisions across the strategic, tactical and operational levels are organisationally managed.
- Global consideration. Consider the goals and tasks and capability commitments of other decision-makers that may be impacted by decisions being made.

2.4 Summary

This section highlights a number of issues that have been identified to be addressed by the Decision Support topic. The issues represent decision making, decision support and networked decision support within an organisational sense, however it is clear that many of these issues are equally relevant from an operational sense. It is therefore hypothesised that future research may consider how the approaches may be abstracted and applied within an operational context whilst considering factors such as time criticality for example. The focus of this research is however directed towards organisational decision support.

3 Integrated Decision Support Environment

The distinction between organisational and operational decision support is clarified for the present and future within the Defence Industrial Strategy white paper [1]. Three phases represent the creation and delivery of capability to military readiness: plan, deliver and support (to readiness), whereas an additional three phases represent the use of the capability in achieving the military effect, deploy, support (deployed) and create effect. A solid vertical line between the support (to readiness) and deployed phases within Figure A3(iv) of [1] represents the previously distinct but perhaps now vague division between the organisation and operations. Despite the focus of the Decision Support team within the NECTISE project being organisational, the aim will be to consider how support may be provided to those phases that are theoretically accessible to industry. It is however anticipated that there may be significant differences between the phases that deliver military capability and the phases that use the capability to achieve military effect (from an organisational perspective) in a similar manner as the differences between systematic and naturalistic approaches.

In addition, the CADMID and CADMIT cycles represent approaches for the acquisition of capability and provision of services. The cycles are characterised by approval points generally at each end of the assessment phase. Each of the six acquisition stages involves executing the plan agreed in the previous stage, reviewing the outcome, and planning for the remaining stages.

The provision of decision support necessitates the management of these plans in terms of the associated process models (synonymous with CoA), the tasks involved within these processes, the situations that parts of these process models correspond to, and the resources associated and allocated to the tasks and the decision points. As Klein stated, these processes may be known in advance, however they may also be developed as the understanding of the development problem evolves. Klein advocated that a modular approach to process construction may be appropriate. Such an approach would allow sub-processes representing particular situations to be connected together, providing that the antecedents for the sub-process are to some extent satisfied and the sub-process goals contribute to the initially defined goals. This approach allows goals to be defined across the CADMID cycles where they are known without the need for concrete process models to be defined – they could be defined within the early stages, defined abstractly within the middle stages, or left undefined within the later stages. The processes and plans would therefore be created dynamically – reacting to the current situation with respect to the system development. It is necessary to have some means of management of the development process in order to provide a context for a decision point in terms of the effort that has been used on the preceding tasks, and what tasks were planned for the future. The decision support issue of CoA management would therefore be addressed.

The processes created within the various development cycles will also require definition within strategic, tactical, and real-time organisational layers. Strategic goals may be defined for each of the development cycles and across cycles, and may be mapped to tactical goals, which may themselves be mapped to real-time goals. This structure would form a goal hierarchy which may be defined either abstractly or concretely, and would contribute to the definition and creation of strategic, tactical and real-time processes. Strategic, tactical and real-time processes require definition to ensure that a decision is both considered across these organisational layers, as well as being propagated. A strategic decision could for example result with changes to tactical and real-time goals and processes, whereas a real-time decision could result with changes to strategic and tactical goals and processes. This consideration of impact and propagation of change across strategic, tactical and operational layers is illustrated within Figure 2 and addresses the networked decision support issue of hierarchical consideration.

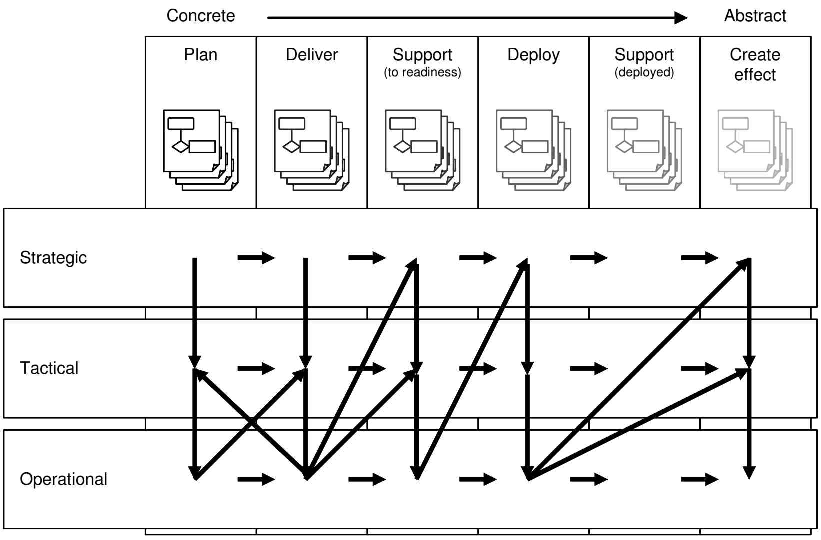

Figure 2. Development cycle, process management and hierarchical propagation.

The development cycle process may, like processes across cycles, be defined specifically for the initial tasks, and more abstractly for the following tasks. As the process is enacted, and the understanding of the development problem evolves, additional definition may be added to later tasks to make them more specific. This of course depends upon how well the processes are understood and how subject they are to change. It is expected however that relatively well established processes may be specified in advance in a static form, whereas more dynamic, variable or unpredictable processes may be created in an abstract way or in a modular fashion as suggested by Klein [8]. Processes are typically constructed with a set of interconnected tasks, which individually contribute towards the goals of the process. If a task does not contribute towards a goal, then it should be omitted from the process.

Once a development cycle process has been defined the concept of an expected situation may be associated with either individual tasks, groups of tasks, or all of the tasks within the process. The situation represents a distinct point within the progress of the process and is defined in terms of qualitative and quantitative targets that should be achieved during enactment. The situation could for example represent the expected state that the goals should have been progressed towards by the associated tasks that affect the goals. The situation may be constructed from a variety of different elements including knowledge gained, events that were expected to have occurred at that point within the process, goals to be achieved, data and information generated, or objectives met for example - Figure 3. These elements may be determined by the development cycle and hierarchical layer. In a similar way as that described by Perry and Moffat [11], the elements that contribute to the situation may be specifically defined in advance, as well as the values of these elements. If a group of resources co-operate within a single situation, participating in individual or multiple tasks, the definition of the situation by the collaborative resources would result with a shared situational awareness.

Since the tasks early within a process may be defined specifically, whilst the tasks later within a process may be defined abstractly, the associated situations may also be defined in this manner. Providing this dynamic aspect to the definition of the situations allows process compensation to be made in situations where goal values are later realised to be unachievable, as well as allowing unexpected beneficial situations to be exploited. The inclusion of situations within processes in this manner will address the issues of situation management, and contribute to addressing the issue of shared situational awareness.

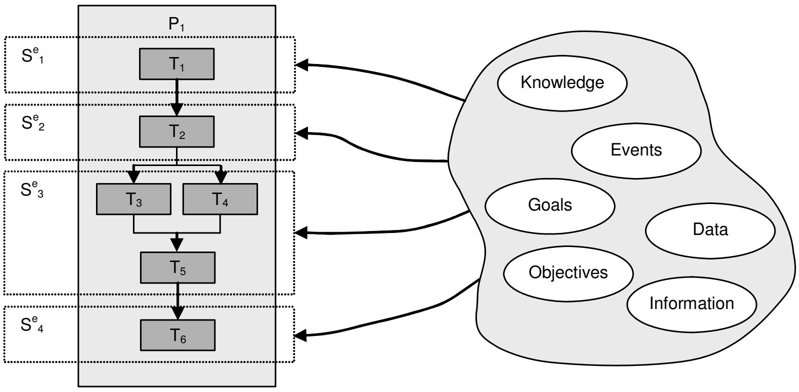

Figure 3. Mapping situations to sections within a process to contribute to shared situational awareness.

Unlike many process modelling tools, developments by the authors within the VRS virtual platform [12] allows tasks within process models to be allocated to human and computational resources for real-time process enactment. The VRS virtual platform did not however provide decision support hence additional information regarding the definition of resources is required. During process creation it is expected that a resource would be associated as an "owner" to the process, which would be responsible for ensuring that process is managed correctly. The owner may also be responsible for defining the resources that would contribute to the enactment of the tasks within the processes, as well as contributing to the decision making process. It is expected that as a minimum, the resources would be defined in terms of: their capability – what tasks and decision making they are able to undertake; their commitments – what tasks and decision making they are currently committed to undertaking (in order to minimise resource over-commitment); and their capacity – a function indicating how capable a resource is of performing multiple tasks and decision making in parallel (again in order to minimise resource over-commitment). Additional information could of course be provided to indicate the relationships between resources – i.e. line manager for example, as well as where the resource is located within the organisational hierarchy.

When a process is enacted, the tasks are allocated to the resources on the basis of either the resource allocation definitions as provided by the process owner, or automatically on the basis of the resources' capability, commitments and capacity - Figure 4. Appropriate resources may be located for the tasks to be enacted on the basis of a resource knowledge ontology containing information of the different types of organisational resources. As the tasks are enacted, the resources gather the information that is required in order for them to undertake their tasks, and transform this information into an output that contributes towards the process goals. Since the processes may be defined abstractly, the associated information may also be abstract and uncertain. The information may originate from a number of different locations within the organisation, and will therefore require compilation into a usable format that results with the appropriate cognitive load by the user of the information in order to efficiently and effectively undertake the task. The gathering of information may be achieved using either a "push" or "pull" strategy on the basis of time-criticality aspects of the tasks or the degree of availability of the information. A push strategy requires knowledge of the information that is being generated by resources (in a similar view of the "sensor" within the NEC definition) and the packaging and transmission of this information to the users of this information. A pull strategy requires an information user to be able to locate the information that is needed, when it is needed by the generators of the information. Since the information may come from multiple sources within or out-with the organisation, the information may be uncertain due to a bias imposed by one or more of the information generators. Mallach [3] defined a number of operational uncertainty factors that may be mapped to and contribute to organisational information uncertainty: precision – the degree of meticulousness that a sensor adopts in providing a quantitative or qualitative assessment of a factor contributing to a situation; accuracy – comprised of bias and precision – information may be unbiased and imprecise for example; completeness – the ratio of decision-makers contributing to providing full-shared awareness; information freshness – giving more weight to more recent reports, requiring a re-evaluation of all available valid reports at the time a decision is to be taken; ambiguity – the provision of information that does not allow clear conclusions regarding the current situation to be drawn; errors – information provided may simply be incorrect, and knowledge (and lack) of unknown information. The management of all types of uncertainty is required in order that the resource is aware of how well informed they are in terms of performing a task or making a decision.

In addition to allocating the tasks to resources, the IDSE should also provide monitoring of the capability of the resources in terms of their ability to perform tasks or make decisions. This monitoring information would therefore allow the capability utilisation to be dynamically reconfigured during enactment to ensure that the resources are being fully exploited.

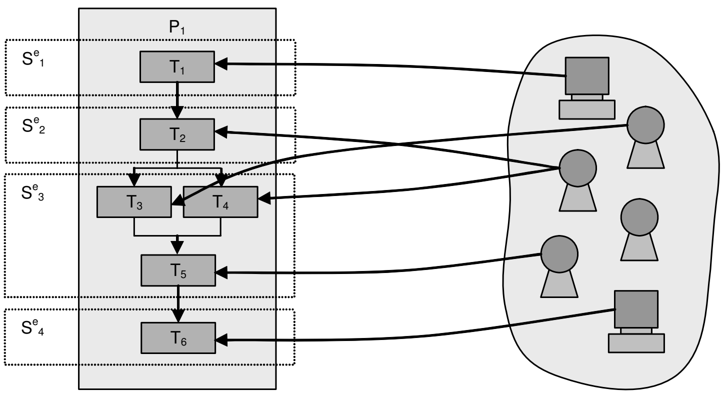

Figure 4. Process enactment through allocation of resources to tasks.

As the process is enacted, information is both created and evolved, making the tasks and situations more specific and less abstract. The issues of resource definition, dynamic re-configurability, CoA enactment, information overload, collaboration (on a task basis), and hierarchical and global considerations would be addressed by the above procedures.

During process enactment, the elements that have been defined as contributing to each situation would require monitoring and checking for deviation against the expected values as agreed by the resources achieving a fully shared awareness. Again either a push or pull strategy may be employed to gather the information that contributes to these situations. Gathering the information in this manner and consolidating it in the form of a situation may provide insight and realisation of decisions being triggered that were previously not identified due to the complexity of the organisationally distributed and disparate sources of information that contribute to the situation. The hypothesis here is that a complex organisational situation may on occasion go unnoticed until a point where their effect has significant impact on the processes and goals. The provision of such monitoring of situations could provide early warning where situational deviation is occurring. Within the current situations being enacted, once the deviation in situation exceeds values defined by the process owner, the resources collaborating within the situation would be notified of the possible need to make a decision. Such management would allow for a timely notification of complex decision triggering situations. In addition it would allow consideration of deviation within future situations that may not be in an active state, allowing pre-emptive action to be undertaken, either exploiting opportunities or planning remedial action.

A decision whether to take any action could be made by the process owner once a situation has deviated by an unacceptable degree. This decision would take the form of deciding whether to continue with the process enactment as defined, or to modify the process to either exploit or rectify the situation. Support would be provided to the decision maker in terms of providing measures of the extent of the deviation, and through the change prediction Decision Support stream, a prediction of the impact on the goal hierarchy given a choice to proceed. If the choice is made to modify the structure of the process, the modular approach described by Klein could be adopted, using either existing sub-processes or creating new sub-processes, and using change prediction to determine the impact of the change on the goals. Additional metrics of metrics such as a consideration of the robustness of the decision subject to likely future changes, and a risk analysis of the decision will provide a further layer of decision assessment and basis for ensuring that the decision is informed.

The statement of the decision situation would be created using information relating to what the antecedents of the situation are, what elements were selected to represent the situation, what the situational deviation is, and possible future CoAs to take on the basis of output from the change prediction tool.

The IDSE will track the information used in creating the decision statement, the steps considered collaboratively in refining the decision statement, the choices considered and the relevancy of the choices' antecedents, as well as the decision assessment, to capture that rationale used by the decision makers in making the decisions. The IDSE will store this rationale for possible reuse in future situations that either fully or partially match the decision situation.

Like the information used by and generated by the enactment of tasks, the information used within the decision making defining the current situation for example, may have some degree of uncertainty. The information may originate from multiple sources across the organisation. Similarly, either an information push or pull strategy would be adopted depending upon time criticality factors to make the information available to the decision maker. Support would therefore be provided to ensure that the information is compiled into a usable format that results with the appropriate cognitive load by the user of the information in order to efficiently and effectively undertake the decision making. The decision support approaches adopted may additionally be dependent upon the characteristics of the life phase, hierarchical level, uncertainty, and collaboration required.

It may additionally be appropriate for more than one resource to be involved within the decision making process - Figure 5. The resources may be selected either on the basis of a choice made by the process owner, or automatically by the IDSE through knowledge about the resources' capabilities. The decision statement would subsequently be transferred to the collaborative decision makers, who would be provided with support to ensure that the tradeoffs between individuals' goals, are considered and accounted for within the generation of the choice. Since the information used to define the decision statement may initially be uncertain or abstract, it is expected that the construction of the decision statement and solution would in some cases be an incremental process with a solution being generated after successive refinement [5]. More time-critical situations may however not have the opportunity for successive refinement and may consequently have to make decisions on the basis of uncertain information. The choice of approach will of course be dependent upon the decision-making situation.

Providing support in this manner addresses the issue of dynamic reactive problem solving, decision assessment, rationale capture and change prediction assessment; the decision making issues of decision statement and choice; the decision support issues of situation management and deviation monitoring; and the networked decision support issues of shared situational awareness, information overload, and collaboration.

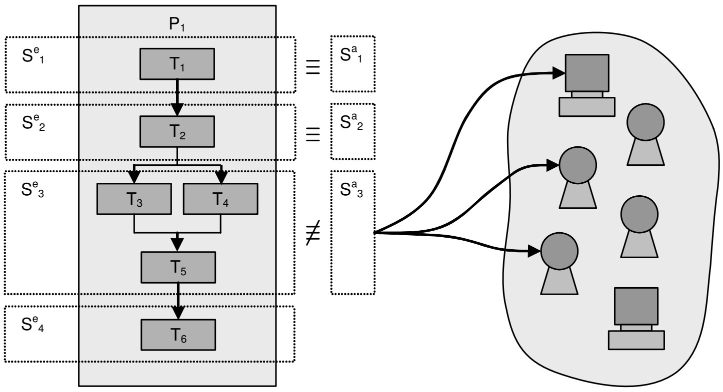

Figure 5. Situational deviation resulting with decision statement transfer to collaborative resources.

Once a choice has been made in terms of a new CoA to undertake that will either exploit or rectify the new situation, the objective is to enact the choice, implementing the CoA and executing the associated process - Figure 6.

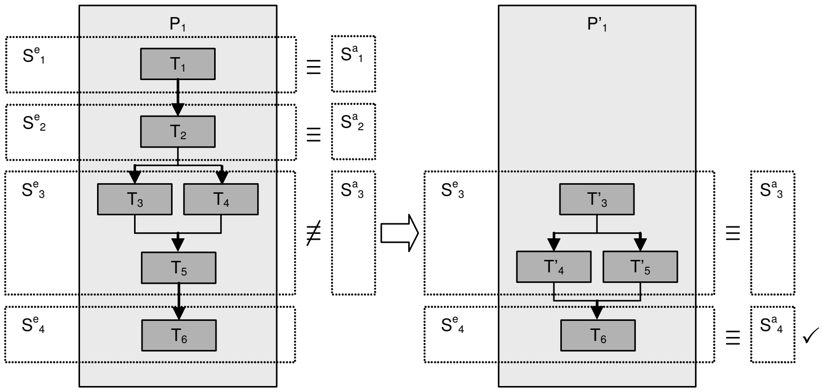

Figure 6. Successful CoA completion.

The task allocation process is repeated in a similar way as that described earlier. Providing support in this manner addresses the decision making issues of enactment. It is expected that the implementation of the IDSE would result with an organisationally distributed environment that provides support for the information used within the collaborative decision-making process. It is anticipated that some decision types within a development process will not require support, such as those that engineers make on an everyday basis, using their knowledge, expertise and intuition that they have gained from the past. The decision support that will be provided will be for complex decision situations involving the trade-off across many dimensions (goals or organisational hierarchies for example) using information that is organisationally distributed. The capability within the organisation through the use of the IDSE, would become network enabled with respect to decision support.

4 Conclusion

The investigation of decision support, and a consideration of how the associated research questions could be addressed within the development of an Integrated Decision Support Environment, has been undertaken through research within the Network Enabled Capability Through Innovative Systems Engineering (NECTISE) project. An introduction is provided to the Decision Support topic in terms of the topic relevancy for NEC from an organisational perspective. Whilst the focus of NEC as discussed within Section 1 is principally from an operational, or creation of military effect, perspective, there are a number of aspects of decision support that may be abstracted and applied organisationally (the focus of the Decision Support topic). From research by Klein [13], however, the distinction between decision-making organisationally and operationally centres on time criticality.

An overview is provided within this paper of the research questions that are relevant to the Decision Support topic. These are categorised in terms of decision making, decision support and network enabled decision support. A proposal is subsequently made for an approach for the provision of organisational decision support that attempts to address these questions which could form the basis of the technical development of the IDSE. The following points are covered by the IDSE within the text:

- **Development cycle, process management and hierarchical propagation**. Management of process models across different development phases, ensuring the propagation and consideration of decisions across strategic, tactical and real time organisational layers.
- **Mapping situations to sections within a process to contribute to shared situational awareness**. Using situation management to define the information that would represent a situation shared amongst a collaborative team, and defining how decisions may be triggered on the basis of situational deviation.
- **Process enactment through allocation of resources to tasks**. Using knowledge of the capability of the organisational resources from a task and decision making perspective, to allocate tasks and decision situations efficiently and effectively.
- **Situational deviation resulting with decision statement transfer to collaborative resources**. Monitoring the information that contributes to the definition of a situation, and using this information when it deviates to define the context for the decision statement. Allocation of the decision statement to the appropriate resources.
- **Successful CoA completion**. Managing change and decision propagation to ensure that the original objectives are achieved.

Covering these points from an organisational viewpoint highlights the same information importance as defined for NEC from an operational perspective [2]: sense, understand, develop intent, and synchronise effects.

Acknowledgements

The authors would like to acknowledge the funding received to enable this research to be undertaken from both BAE Systems and the Engineering and Physical Science Research Council (EPSRC) under grant number EP/D505461/1. The opinions expressed are those of the authors and should not be construed to represent the views of the NECTISE partnership.

References

1. *Defence Industrial Strategy*. 2005, Ministry of Defence. p. 145.

2. *Network Enabled Capability - The UK's programme to enhance military capability by better exploitation of information.* 2003 [cited; Available from: http://www.iwar.org.uk/rma/resources/uk-mod/nec.htm.

3. Mallach, E.G., *Understanding Decision Support Systems and Expert Systems*. 1994: R.D. Irwin. 695.

4. Ullman, D.G., *The ideal decision support system*, Robust Decisions, Inc.: Corvallis, USA. p. 28.

5. Kuipers, B., A.J.Moskowitz, J.P. Kassirer, *Critical decisions under uncertainty: representation and structure.* Cognitive Science, 1988. **12**: p. 177-210.

6. Merderer, C., *The evolution of information in a design team*. 1997, University of Munich.

7. Kepner, C.H., B.B. Tregoe, *The Rational Manager: A Systematic Approach to Problem Solving an Decision Making*. 1965, Princeton, New Jersey: Kepner-Tregoe Inc.

8. Klein, G., *A Recognition-Primed Decision (RPD) Model of Rapid Decision Making.*, in *Decision Making in Action: Models and Methods*, G. Klein, J. Orasanu, R. Calderwood, C.E. Zsambok, Editor. 1993, Ablex Publishing: New Jersey. p. 138-148.

9. Cummings, M.L. *Automation bias in intelligent time critical decision support systems*. in *AIAA 1st Intelligent Systems Technical Conference*. 2004. Chicago: American Institute of Aeronautics and Astronautics.

10. Chapanis, A., et al., *Human engineering for an effective air navigation and traffic control system*, P.M.Fitts, Editor. 1951, National Research Council: Washington D.C. p. 105.

11. Perry, W.L., J. Moffat, *Information Sharing Among Military Headquarters - The Effects on Decision Making*. 2004, RAND Corporation. p. 122.

12. Whitfield, R.I., et al. *An overview of the VRS virtual platform*. in *15th International Conference on Engineering Design*. 2005. Melbourne Australia: Design Society.

13. Klein, G., *Sources of Power: How People Make Decisions*. 1998, Cambridge, Massachusetts: MIT Press. 330.