# Generic Process Model of C4I Activities

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# Contents

# 1 Introduction

## 1.1 Purpose and Scope

The purpose of Work Package 1.1.4 is to produce a generic model or framework for understanding and analysing modern C4ISR, primarily from a human perspective. The process model described in this report was derived from a range of resources, including a review of existing models and techniques and by data from live C4ISR activities already observed within Work Packages 1.1.1 through 1.1.3. It is envisaged that further exposure to live C4I scenarios, ongoing experimental work and other progress in the field will continue to contribute to the model elaborated in this report.

## 1.2 Timeliness and Relevance of Research

The key requirement of the generic model described in this report is:

1. To simplify (by expressing commonalities between) multi-faceted command and control scenarios

This provides an intermediate step before:

2. allowing predictive modelling techniques to be developed and/or applied.

The aim of generic modelling activities is to derive tools for increasing understanding. Any increase in understanding is to be deployed in the design of systems and techniques aimed to enhance the congress of command and control.

This requirement for the management of complexity in the analysis, specification and assessment of command and control systems is particularly acute at the present time. The transformation of command and control via the Network Enabled Capability paradigm (see below) will require extensive investigations of C4ISR to assess the impacts and consequences of command technology. These investigations are likely to be wide ranging, especially as some have noted that advances in communications and networking offer the possibility of not merely *"doing existing things better, but doing better things"*, 'things' that were previously not even viable (e.g., MoD, 2005a). The inherent nature of constructing extended integrative networks of people is to 'produce' rather than 'reduce' complexity. Whilst this will, its proponents argue, enable increased flexibility, speed of reaction and effectiveness in the field, it will have the side effect of substantially enlarging the range of considerations and potential interactions an analyst must consider. In short, we stand at the beginning of what may well be the formative time in an increasingly sophisticated era of command and control research, technology and practice. The generic model developed in this report is situated within the issues and challenges that arise from this.

## 1.3 Organisation of the Document

This document is organised into three main sections as follows:

1. Review of Modelling Literature
2. Development of a Generic Process Model of Command and Control
3. Conclusions

# 2 Review of Modelling Literature

## 2.1 Purpose and Scope

In order to situate the generic process model within its wider research context an extensive review of current and 'classic' literature both within the command and control milieu and, where relevant, outside it has been conducted. A set of key concerns has guided this examination. These are:

*Model metrics:* How are aspects of command and control measured or expressed either quantitatively or qualitatively?

*Measures of modelling outcome:* How does the model define good or bad command and control system performance?

*Degrees of model reconfigurability:* Is the model tied to a particular type of activity or situation? Is it flexible enough to be reconfigured for use across a wide range of settings and contexts?

*Construct validity and reliability:* Is the theoretical basis of the model sound?

*Extent, nature and degree of dependency upon constraints and assumptions:* Are the assumptions the model is based around reasonable? Are the formal constraints within which the model falls appropriate or are they overly restrictive or too poorly specified?

Within the rubric of these key concerns exists the wider aim of extracting broad modelling trends from the prevailing literature, examples of paradigms and approaches, and to derive typologies and categories of outcome measure. The aim of the review, therefore, is not to provide an exhaustive account of every permutation of C4I related model but to illustrate the range and scope of relevant approaches and paradigms.

## 2.2 Specification

### 2.2.1 Defining Command and Control

The basic term "command and control" is defined by Builder, Bankes and Nordin (1999) as follows:

*"Command and control: The exercise of authority and direction by a properly designated [individual] over assigned [resources] in the accomplishment of a [common goal]. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a [designated individual] in planning, directing, coordinating, and controlling [resources] in the accomplishment of the [common goal]." (p. 11).*

The product of combining command (authority) with control (the means to assert this authority) is the notion of, "*unity of effort in the accomplishment of a* [common goal]" (Jones, 1993, p. 2). Despite the militaristic undertones, the notion of command and control is itself generic. It is not tied to a specific domain. As a generic activity command and control is variously defined depending on context and perspective.

### 2.2.2 Generic Properties of Command and Control

Given the definitions above the (relatively) invariant properties of command and control scenarios can be distilled down to a simplistic descriptive level as a scenario possessing the following four features, namely;

a common overall goal (this may, however, be comprised of different but interacting sub-goals), corollary: systems of command and control are goal-oriented systems;

- individuals and teams acting individually or in unison;
- teams and sometimes individuals are often dispersed geographically,
- numerous systems, procedures and technologies are in place to support their endeavour (Walker et al., in press).

Beyond the descriptive level, command and control by definition is a collection of functional parts that together form a functioning whole. Command and control is a mixture of people and technology, typically dispersed geographically. It is a purposeful intelligently adaptive endeavour representing progress towards a defined outcome. Intelligent adaptiveness requires responses to externally generated input events within a finite and specified period (Young, 1982). In possessing these attributes command and control can be further characterised with reference to, and understood from the following modelling perspectives, as:

- An (open) system of interacting parts,
- A socio technical system of human and non-human agents and artefacts,
- A distributed system,
- A real time system, and
- an intelligent system.

### 2.2.3 Network Enabled Capability

Network Enabled Capability (NEC) is a way of 'doing' command and control. It is a term used to describe what is at present a nascent paradigm within British military command and control, but also an extremely cogent modelling issue. It has been described thus: "*NEC is about the coherent integration of sensors, decision makers, weapons systems and support capabilities to achieve the desired effect*" (MoD, 2005a; this is also the canonical document defining the British vision of NEC). Diverse command, reconnaissance, weapons, support and decision making assets will be interlinked by way of a "network of networks" which will deliver and transfer data and communications in a flexible manner. In essence this is an information-based approach to command and control; aside from their obvious operational capabilities, assets also take the role of active producers and consumers of information.

Expected benefits include:

- Increased provision of timely information allowing rapid response (ideally to the point where the opposing force's own decision loop is undercut)
- Improved interoperability (across domains, services, agencies, nations etc.)
- Increased tempo of operations
- The development of more effective command and management structures (likely to be marked by a reduction in or flattening of existing hierarchies and increasing freedoms given to commanders lower in the chain of command).
- Shared situation awareness across actors (i.e. "singing from the same hymn sheet") that will in turn allow the emergence of the so-called synchronisation effect. In other words self-coordinating group actions will be enabled by improved information about what colleagues intend to do, are doing and have done, and the operational picture they are responding to.

Success in achieving these aims appears to be contingent on a set of central presuppositions about the nature of technology and human cognition: that shared information can be *actively* shared through networking; that shared information could become in the mind of operators shared knowledge (i.e., it is meaningful and supports action); shared knowledge in turn leads to shared situation awareness; that shared situation awareness enables synchronisation and that ultimately synchronisation results in operational effect.

In essence NEC represents the application to command and control of principles and technologies of the so-called information age. In particular, the effect of the Internet and related technologies within the commercial sphere to increase the responsiveness and flexibility of businesses appears to have been a primary inspiration (Kaufman, 2004).

## 2.3 Modelling Challenges

### 2.3.1 Abstracting Reality

A model is an abstraction of reality (Wainwright & Mulligan, 2004), or "*a representation that mirrors, duplicates, imitates or in some way illustrates a pattern of relationships observed in data or in nature. [….]*" (Reber, 1995, p.465). A model is also a kind of mini-theory, "*a characterisation of a process and, as such, its value and usefulness derive from the predictions one can make from it and its role in guiding and developing* *theory and research"* (Reber, 1995, p. 465). A theory is, *"a coherent set of formal expressions that provides a complete and consistent characterization of a well articulated domain of investigation with explanations for all attendant facts and empirical data"* (Reber, 1995, p. 793). Characterize refers to the *"collective qualities or peculiarities that distinguish an individual or group"* (Allen, 1984, p.117). The purpose of a model is, therefore, to explain attendant facts, to characterise them, to represent the relationships between them, in a way that represents some form of direct analogue to the phenomena under analysis but in the most parsimonious way possible or that is appropriate.

### 2.3.2 Simplifying Complexity

A model aims to simplify complexity. Complexity is related to the amount of information needed to describe the phenomena under analysis. The closer that the phenomena under analysis approaches complete randomness, the more data is needed until it *"cannot be described in shorter terms than by representing the [phenomenon] itself"* (Bar Yam, 1997). However, *"Something is complex if it contains a great deal of information that has a high utility, while something that contains a lot of useless or meaningless information is simply complicated"* (Grand, 2000, p. 140 cited in Bar Yam, 1997).

The primary purpose of the current generic model of C4I is to reduce complexity and particularly when partnered with additional modelling techniques, to offer outcome metrics that can detect and describe non-random emergent properties. Emergent properties exist where the *"characteristics of the whole are developed (emerge) from the interactions of their components in a non-apparent way"* (Bar Yam, 1997). Previous analyses of live C4I scenarios using the EAST methodology have detected the presence of emergent properties related to task, social and knowledge networks and in so doing demonstrate that information contained within these scenarios may indeed be complex, but is far from random. The optimal model of command and control can be defined as one that is sensitive enough to detect cogent emergent properties, whilst containing merely 'sufficient' complexity to explain (and predict) these *"widely observed properties and behaviours in terms of more fundamental, or deeper, concepts"* (Wainwright & Mulligan, 2004; Builder, Bankes & Nordin, 1999). These apparently simple requirements are heavily tempered by the fact that, *"the world being modelled has an inviolable nature; it cannot be exhaustively described. We can model the world but we can always go back to find new perspectives for describing what we are modelling, usually involving new perspectives on what constitutes information (data), new languages for modelling, and new perspectives on the purpose for constructing models."* (Clancey, 1993, p.41).

### 2.3.3 The Role of Constraint

A crucial aspect of any modelling enterprise is the quality of the constraints and assumptions within the model. For a model to have scientific viability it must feature some variety of formal constraint. In simple terms, constraints are the limits on what a model can and cannot do and should (for the most part) correspond with the real world. For example, if we were modelling some aspects of human manual labour, that would naturally dictate a constraint that within the model any one individual has at maximum two arms and two legs. A model may be otherwise impressive in any other aspect but if its constraints are incorrect or inappropriate then the rest of the model is invalid. A model may even appear to give the "right" answer if treated as a "black box" model where we concern ourselves only with the input and the output, but if it requires the representation of impossibilities (e.g., three armed radio operators, speed of light reaction times and so on) to generate those results it is questionable whether the model is of genuine theoretical value: a good model "plays by the rules" so to speak. Whilst it might be obvious how many limbs to ascribe to an individual, less concrete variables are more difficult to accurately and uncontroversially constrain; things like attentional capacity, situation awareness and teamwork. Whilst these are essential constructs in the conceptualisation of command and control, they have long suffered from problems in their precise characterisation (and in some cases possibly always will given that mental qualities like attention and awareness are possibly products of reification). Furthermore, where models are themselves particularly complex or abstract by nature of their operating principles (e.g., a statistical Hidden Markov-Chain Model) there can be additional challenges in translating realistic constraints into parameters (for the author) but also assessing the constraints (for the reader); not all models are so transparent that one might easily relate, say, a set of arrows on a graph or a set of numbers in a vast matrix with an inappropriate "take" on the real world.

There are also issues with underlying theory. In virtually anything other than the physical sciences a theory such as, for example, situational awareness, is more akin to *"a general principle or a collection of interrelated general principles that is put forward as an explanation of a set of known facts and empirical findings"* (Reber, 1995, p. 793). Thus the modelling of situational awareness (and other similar emergent properties) as a discreet entity is itself sufficiently challenging, without any coupling to a social-technical environment that aims to promulgate this state across dispersed geographical locations, using various technical/communications media. These problems are very much part of the territory and have no clear solution as such, but in mitigation of them we must as a consequence use some degree of judgement in assessing the constraints present in models of command and control.

There are numerous modelling challenges underlying command and control. The difficulty contained by these challenges can perhaps be summarised by the fact that the *"real world is made from open, interacting systems, behaving chaotically"* (Hitchins, 2000), and in the case of human actors, non-linearly. Complex systems like command and control also possess various real-time properties that cannot be considered 'designed' as such, they sometimes merely 'happen' (Hitchens, 2000). Therefore the notion of a commander representing something akin to the conductor of an orchestra is in some cases entirely false (Hitchens, 2000). Also, unlike neat linear systems the possibility exists (increasingly so with NEC) for there to be no clear boundaries between certain system elements, as well as no beginning and no end, given that goals are more or less externally adaptive.

The aim of this section, having defined command and control is to highlight the complexity involved in modelling it. Of course, this complexity has not deterred scientists and practitioners and there are numerous approaches to and specific models for systems with command and control-like properties. In the sections that follow approaches to modelling command and control, as well as systems possessing similar properties (or elements of) are reviewed. This requires a survey of literature in a variety of fields and perspectives, ranging from computer and environmental science through to organisational theory and psychology. Examples of models and techniques are drawn from each field based on their relevance. This review serves as the background and context to the specific process model described in Section 2 and to the other generic modelling activities underway within the DTC HFI more generally.

## 2.4 Structural Models of Command and Control

### 2.4.1 The Dominant Perspective – The Cybernetic Paradigm

C4I is variously defined as a form of *"management infrastructure […] for any […] large or complex dynamic resource system"* (Harris & White, 1987). It is immediately apparent based on this review that the dominant modelling perspective, the so-called 'cybernetic paradigm' (Builder et al., 1999) accords the structural aspect of command and control particular prominence. Dockery and Woodcock (1993) are unequivocal in stating that, *"Since [command and control] […] concerns itself with providing structure to combat, its description should be in terms of structure"*. (p. 64).

Under this structural/cybernetic paradigm a command and control scenario is divided into linked functional parts which exchange and modify signals that can be specified according to mathematical formulae (Builder et al, 1999). Or as similarly expressed from a systems dynamics point of view, *"the mathematical modelling of an assemblage of components so as to arrive at a set of equations which represent the dynamic behaviour of the system and which can be solved to determine the response to various sorts of stimuli"* (Doebelin, 1972, p. 4). An example of these 'equations', and their relation to the dynamic behaviour and structure of command and control 'systems' are reproduced in Table 1 from Dockery and Woodcock (1993) merely as an illustration of the outcome measures that can be derived.

**Table 1 - Sample of mathematical metrics for key constructs in command and control (from Dockery & Woodcock, 1993, p. 66)**

| Mathematical Tool | Modelling Requirement |
|---|---|
| Catastrophe Theory | To capture in both a time independent and time dependant manner the global non-linear responses of combat in terms of a few control variables, therefore essentially presenting the commander's command and control perspective on the battle. |
| Category Theory | To define measures of effectiveness and to embed the whole command and control modelling process in a larger context. |
| Cellular Automata | To capture the self-structuring of combat based on minimal nearest neighbour rule sets, essentially to present the small unit command and control perspective of combat. |
| Chaos Theory | To capture the observed chaotic dynamical nature of combat and to identify attractors and to present the combat evolution perspective. |
| Fuzzy/Partial/Stochastic Differential Equations | To describe attrition based combat processes. |
| Entropy Computation | To capture the effects of casualties upon the structure of the fighting. |
| Fractals | To capture deployment hierarchies. |
| Fuzzy Sets | To capture the imprecision in all phases of the military command process from data to orders. |
| Relativistic Information Theory | To capture the idea that organisations move relative to each other in a metaphorical sense of internal organisational efficiency. |
| Langrangian Formulation | To define classical, albeit heuristic, expressions such as combat momentum (tempo). |
| Petri Nets | To express the transactions that occur in a command and control system between its elements. |
| System Dynamics | To capture feedback and feed-forward aspects of command and control interacting with combat processes. |
| Games Theory | "Ways in which strategic interactions among rational players produce outcomes with respect to the preferences […] of those players, none of which might have been intended by any of them." (Ross, 2005). |

## 2.4.2 Example: Lawsons Model of Command and Control

Under Lawson's model command and control (1981) can be viewed as an information processing chain with data flows between the environment, one's own forces and the command centre. The model in Figure 2-1 epitomises this perspective. The model is rooted in the idea that there is some desired state that the command centre seeks to achieve. Data is extracted from the environment and processed. The understanding of these data is then compared with the desired state. If there is any discrepancy between the desired state and the current state, the command centre has to make decisions about how to bring about the desired state. These decisions are turned into a set of actions, which are then communicated to their own forces. The data extraction cycle then begins afresh.

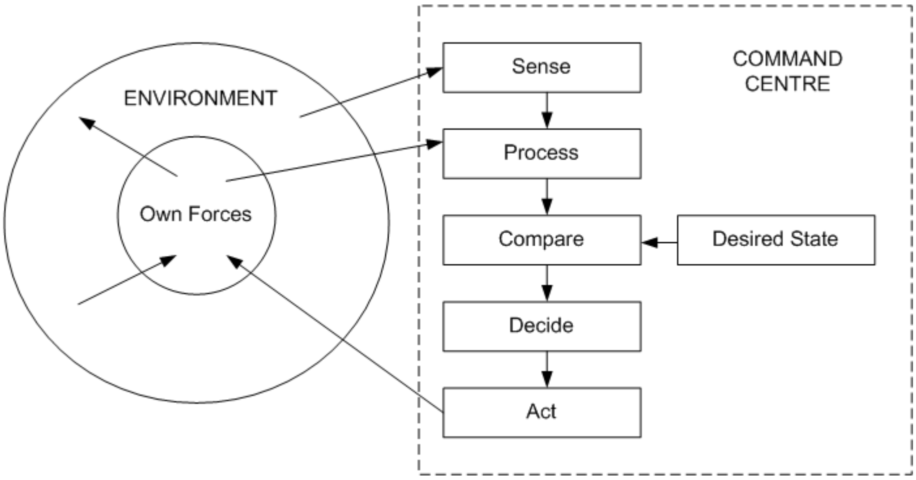


**Figure 2-1 - An adapted version of Lawson's model of the command and control process**

Lawson's model owes much to the ideas of control theory. The comparison of actual and desired states implies a feedback process and some form of regulation. Central to his model, therefore, would be the "compare" function. The feedback involves control of "own forces" to affect a change to the environment. The notional "actual" and "desired" states imply phenomena that can be described in terms of quantitative, discrete data; in other words it is not easy to see how the model would cope if the actual state was highly uncertain. Nor is it easy to see what would happen if the changes to the environment led to consequences which lay outside the limits defined by the discrete state. The model does indicate the central issue that command can be thought of as working towards some specified effect or intent but suffers, however, from its apparent reliance on a deterministic sequence of activities in response to discrete events.

### 2.4.3 Example: The Headquarters Effectiveness Assessment Tool (HEAT)

Another example derived from the 'cybernetic approach' is the Headquarters Effectiveness Assessment Tool (HEAT). HEAT's raison detre is to provide an objective measure of headquarters effectiveness based on the premise that effective headquarters approach command and control activities in quantitatively different ways than ineffective headquarters (Choisser & Shaw, 1993). The HEAT method, like Lawson's model above, is based on (mathematical) normative systems and optimal control theories, whereby the *"objective of the [commander] is to determine control activities that will induce the evolution of the system towards an acceptable goal"* (Choisser & Shaw, 1993; p. 48). The command and control system, in common with Lawsons model, is viewed as a variation on a deterministic closed loop system, expressed in very simple terms in Figure 2-2 below. The idea expressed in the HEAT methodology/theory is that rational command and control systems will possess some of the anticipatory and self-optimizing properties of a normative system. In a practical sense HEAT is used within war-game simulations and various mathematically derived outcome measures are derived from the underlying control (and decision making) model.

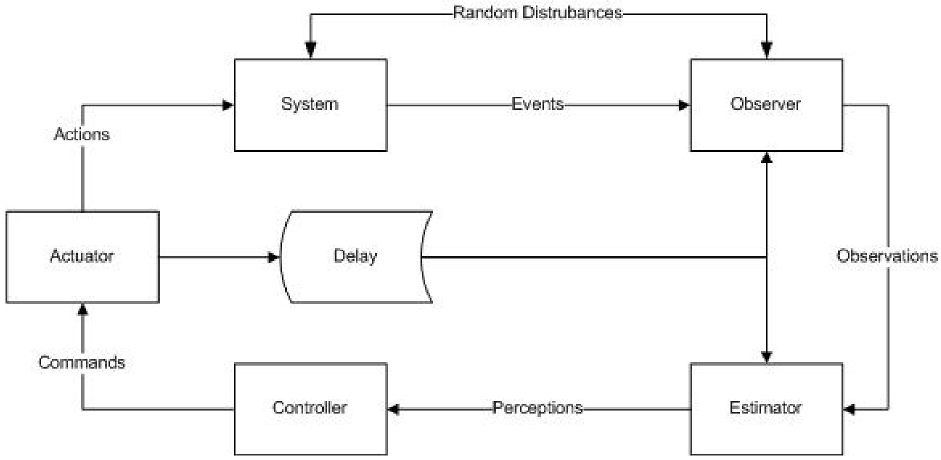


**Figure 2-2 - Example of closed loop feedback control system (from Choisser & Shaw, 1993)**

## 2.4.4 The Issues in Structural Modelling

The models that arise from this dominant perspective all tend to approximate in varying degrees towards control theory models and as Builder et al. (1999) put it, could just as easily apply to a thermostat as it could to a C4I system. Although practitioners of the cybernetic paradigm would argue that much of the complexity lies 'behind' such simple systems (within the mathematical metrics expressed in Table 1 above for example), the fact, at bottom, still remains. Overall, the specific outcome metrics from these models are relatively hard to divine, but examples include 'catastrophe manifolds', 'butterfly landscapes' (a form of 5 dimensional graph), 'control coefficients', 'time dependant behaviour', etc. These mathematical metrics provide measures related to overarching 'mission based' constructs such as survivability and effectiveness. Changes in these overarching constructs are based on changes to (and the mathematical interplay of) independent variables such as force strength, fire power, decision aids, etc, (Dockery & Woodcock, 1993).

The attractiveness, yet inherent danger associated with this modelling perspective is perhaps hinted at by Doebelin (1972), who states, *"From our intuitive ideas about the cause-and-effect nature of the physical world, it is clear that if we precisely define a model of a physical system and subject it to specific known inputs, the outputs are completely determined"* (p.4). The problem is that the robust relationship between cause and effect does not necessarily hold true for systems involving human cognition as it might do for systems involving merely physical entities with known properties and known input-output characteristics (Rasmussen, Pejtersen & Goodstein, 1994). Simply put, cybernetic models *"inadequately represent the complex and idiosyncratic activities of humans in [command and control]"* (Builder et al., 1999). *"When the [structure] is put to work, the human elements change their characteristics; they adapt to the functional characteristics of the working system, and they modify system characteristics to serve their particular needs and preferences"* (Rasmussen et al., 1994). *"It is the un-specifiable messiness of the neural system – becoming organised in new ways at the time* *of the interaction itself – which gives human behaviour its robust, always adaptive character"* (Clancey, 1993, p.41). In modelling terms two strategies within the cybernetic paradigm can be implied as routes taken to attempt to overcome this inconvenience. Firstly, the human is simply subsumed into a complete physical system, where any non-linearity's are catered for using (ever more) complex mathematical techniques (e.g. Dockery & Woodcock, 1993). Secondly, the complex role of the human may be recognised, but is still ultimately reduced and overlain on to an underlying control theoretic model (i.e. Choisser & Shaw, 1993; Edmonds & Moss, 2005; Levine, 2005).

### 2.4.5 Summary of Cybernetic Paradigm

In summary, the issue of model constraints appears to be felt particularly acutely and while cybernetic models might provide a robust basis for understanding control, they appear to be restricted in their ability to model command.

## 2.5 Network Models

### 2.5.1 Introduction

If taken as a form of doctrine the structural/cybernetic perspective yields several serious limitations for modelling the multi-faceted nature of command and control. If, however, the notion of structure is assumed to be a component of (as opposed to a complete characterisation of a system), then structural aspects of command and control can be modelled in several alternate and useful ways.

From the perspective of Organisational Theory an organisation can be defined as *"a collection of interacting and interdependent individuals who work toward common goals […]"* (Duncan, 1981). Here the focus is directed onto 'individuals', and their links and interrelations. The straightforward organisational chart is a simple example of this and *"shows the relationship between specific jobs or roles within [an] organisation"* (p. 2) (Arnold, Cooper & Robertson, 1995). Put more explicitly, an organisational chart represents the links between roles, where the hierarchical organisation of roles is reflective of command (and the cybernetic paradigm), and the links that exist between roles reflective of control (and the communications between individuals).

### 2.5.2 Example: Hitchen's N-Squared Chart

This notion of roles and links is related to a simplistic descriptive model of military command and control presented by Hitchens (2000) in Figure 2-3.

| | | | |
|---|---|---|---|
| **COMMANDER** | **Tasking** | **Decisions** | |
| **Enemy Intentions** | **INTELLIGENCE** | **Enemy Intentions** | **Needs** |
| **Operations Plans** | **Operations Plans** | **OPERATIONS** | **Needs/Priorities** |
| | **Constraints** | **Constraints** | **LOGISTICS** |

**Figure 2-3 - The N-Squared (N2) chart from Hitchens (2000): A simplistic generic model of command and control**

In Hitchens' N-squared (N2) chart, information intersects pairs of roles (shown in capitals on the diagonal). The example given is militaristic, where the content of information flow downwards from the commander is represented in the upper quadrant and information flowing upwards to the commander in the lower quadrant. The commander, therefore, interchanges 'decision' information to the operations role. Similarly, the logistics role interchanges information on 'constraints' to the operations role. And so on. In basic terms this simplistic model expresses the links between roles and the broad topic of information that the links are facilitating.

### 2.5.3 Example: Hierarchical Task Analysis (HTA)

Hierarchical Task Analysis (HTA) can also be viewed, perhaps unconventionally as a form of network model. Task analysis is the activity of collecting, analysing and interpreting data on system performance (Annett & Stanton, 2000; Diaper & Stanton, 2004). It is one of the central underpinning analysis methods within the DTC HFI's EAST method alluded to earlier.  According to Stanton (2004), task techniques can be broadly divided into five basic types: hierarchical lists (e.g., HTA and GOMS), narrative descriptions (e.g., the Crit and Cognitive Archaeology), flow diagrams (e.g., TAFEI and Trigger Analysis), hierarchical diagrams (e.g., HTA and CCT), and tables (e.g., Task-Centred Walkthough, ICS-CTA, HTA, SGT, and TAFEI). Some methods have multiple representations, such as HTA, which can be viewed as a hierarchical text list, a hierarchical diagram  or in tabular format.

HTA is often referred to as a means to 'model' an interaction. The emergent properties are related to functional groupings of tasks within a hierarchy (which is not readily apparent in most cases), and the reductions in complexity that arise from structuring tasks in this way. HTA permits multiple modelling perspectives; at the bottom layer the entire task is represented in full, whereas higher levels within the hierarchy represent progressively more parsimonious descriptions. Either may be more or less appropriate to the type of analysis required. HTA is a more rigorous means of describing a system in terms of goals and sub-goals (as opposed to roles and sub-ordinates) and departs from an organisational chart in terms of its more rigorous and highly defined internal logic used to create a nested hierarchy, and also in the provision of rules and feedback that define the deterministic (cause and effect) enactment of tasks contingent upon specific external conditions being met.

### 2.5.4 Example: Social and Propositional Networks

Various other deterministic approaches, such as pyramid laws and tree structure models can be used as ways to offer predictive network based modelling. Examples of metrics include two defined by Hitchens (2000) based on pyramid laws, namely; diminishing lateral communication (*"it is harder to get agreement with someone who is more distant laterally in the hierarchy"*, p. 6), and vertical data compression (*"as you go up the [hierarchy] data gets compressed at something like the span of control [width of the pyramid] at each level"*, p. 6), as shown in Figure 2-4.

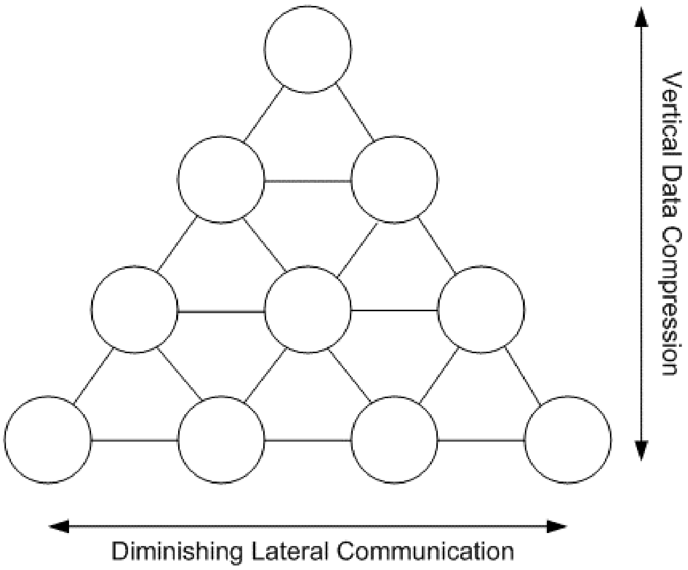


**Figure 2-4 - Pyramid structure metrics**

Similar numerical metrics can be derived using social network analysis (Driskell & Mullen, 2005)). Social networks and organisations (according to their various definitions) are virtually isomorphic, as are various numerical metrics derived from deterministic network approaches. For example, the metrics derived from social network analysis map onto those derived from pyramid laws; diminishing lateral communication is related to the property of 'degree' (the number of other positions in the network in direct contact with a given position), whereas vertical data compression is related to the property of betweeness (the frequency with which a position falls between pairs of other positions in the network). In a similar way to pyramid laws, early research on social networks illustrated how basic structural properties of a network can influence the outcome measure of efficacy of communications within the structure (Figure 2-5). For example, the 'cross' prototype is advantageous for information integration but can also lead to information overload for the central node.

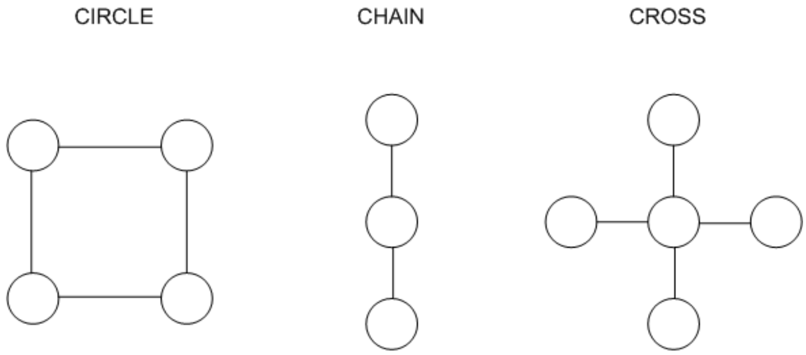


**Figure 2-5 - Prototypical social networks**

A further relevant expression of a network model is a Propositional Network. Propositional Networks are similar to semantic networks in that they contain nodes (with words) and links between nodes. It is argued that the application of basic propositions and operators enables dictionary-like definitions of concepts to be derived (Ogden, 1987). Stanton et al (2006) take this basic notion and extend it to offer a novel way of modelling knowledge in any scenario. Knowledge relates strongly to the concept of situational awareness. Situational awareness is about ‘knowing what is going on’ (Endsley, 1995) and enables decisions to be made in real time, and for the ‘commander’ in a command and control scenario to be “tightly coupled to the dynamics of [their] environment” (Moray, 2004, pg. 4). This is a large part of how decision superiority is achieved. A systems view of SA (and indeed an individual view as well) can be understood as activated knowledge (Bell & Lyon, 2000) and, therefore, propositional networks offer a novel and effective means of modelling this ‘systems level’ view of SA.

A major advantage of propositional networks is that they do not differentiate between different types of node (e.g. knowledge related to objects, people or ideas) so that from a modelling perspective they are not constrained by existing structures of people and objects, rather to the required knowledge elements associated with a scenario. It is possible to model the temporal aspects of SA by animating the propositional network in terms of active and non-active knowledge objects. To do this the scenario is divided into task phases allowing active and non-active knowledge objects to be specified and represented.

In summary, propositional networks enable SA (at the systems as well as individual level) to be modelled in command and control scenarios and for the emergent property of knowledge activation, structure and (systemic) SA to be measured. Figure 2-6 below illustrates a propositional network and Table 2 illustrates the metrics applied to the network to reveal the emergent property of SA as it relates to 'key aspects of knowledge'.

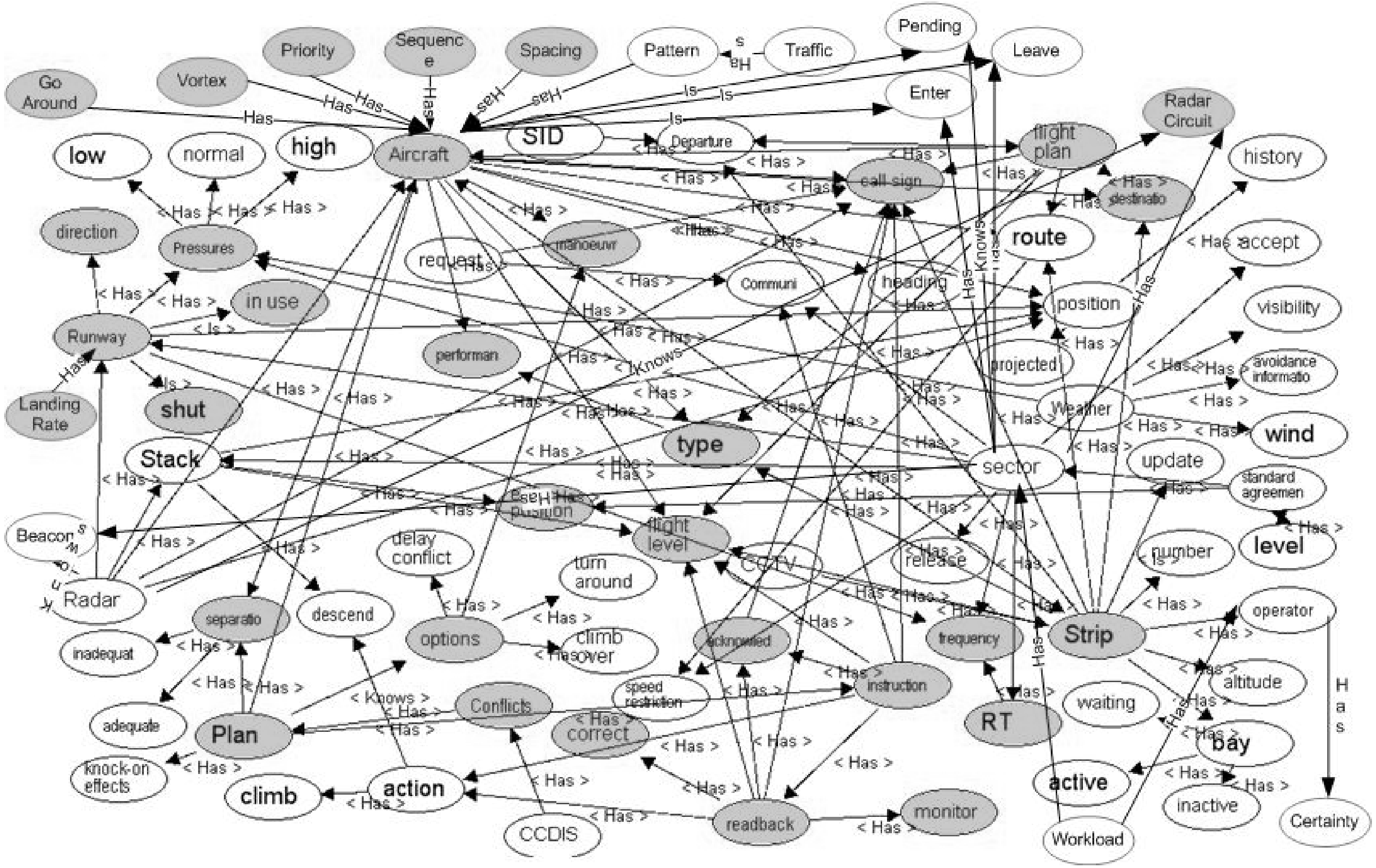


**Figure 2-6 – Propositional network from air traffic control work domain**

**Table 2 – Propositional network metrics to detect emergent property of SA in relation to key knowledge objects**

| | SCENARIO | | | | |
|---|---|---|---|---|---|
| Knowledge Object | Shift Hand-Over | Departure | Over-Flight | Holding | Approach |
| Pressures | ■ | ■ | | | ■ |
| Runway | ■ | | | | |
| Radar | ■ | ■ | ■ | ■ | |
| Stack | ■ | | | ■ | |
| Aircraft | ■ | ■ | ■ | ■ | ■ |
| Flight Level | ■ | ■ | ■ | ■ | ■ |
| Strip | ■ | | ■ | | ■ |
| Position | ■ | | ■ | | |
| Read-back | | ■ | | ■ | |
| Instruction | | ■ | | | ■ |
| Acknowledge | | ■ | | | |
| Call Sign | | ■ | ■ | ■ | ■ |
| Flight Plan | | ■ | ■ | ■ | ■ |
| Plan | | | ■ | | ■ |
| Options | | | ■ | | |
| Sector | | ■ | ■ | | |
| TOTAL KO (16) | 8 | 10 | 10 | 7 | 8 |

### 2.5.5 Summary of Network Approaches

Network models cannot be said to be widely applied in command and control settings. The various approaches do, however, appear to be highly appropriate for modelling a range of emergent properties such as task structure, social organisation and situational awareness. This approach is currently the basis for the DTC HFI's EAST methodology. While showing promise for modelling various emergent properties of specific C4I scenarios the challenge still exists in terms of bringing together these disparate networks and properties into a predictive model. This appears to be feasible. By linking various networks it is possible to subject individual networks to specified changes and to model the propagation of these changes across other linked networks. For example, modifying the social network may predict changes in terms of task structure and knowledge. This falls within the purview of current and future work being undertaken within the DTC HFI.

## 2.6 Agents Model

### 2.6.1 Introduction

An emerging theme within the literature, which might be taken as suggestive of the direction that the dominant cybernetic paradigm is taking, embodies Morgan's (1986) metaphor of organisations as a brain; resilient and flexible, capable of rational and intelligent change (Arnold et al., 1995). The language used to manifest this shift in structural modelling is related to the language (literally) and metaphors associated with computing and agent models (covered briefly in this section), and those associated with cognitive architectures.

### 2.6.2 Example: Work Environment Analysis (WEA)

*"Declarative approaches to modelling are noted for a direct and concise way of stating facts and constraints and are therefore suitable for specification of environmental elements"* (Shah & Pritchett, 2005, p. 70). Declarative approaches are supported by contemporary computer languages such as XML (extensible mark-up language), and, as an example, have been used in the context of a method called Work Environment Analysis (WEA; Shah & Pritchett). The core of the approach is that pertinent aspects of a command and control environment are computationally modelled as reconfigurable nodes, in which these nodes are linked to other nodes according to specified relations. Manipulations made using XML in the specification of context/process nodes/links enable changes to the Work Environment to be modelled and for the effect of these on system assessment criteria such as safety, stability and efficiency to be made. This approach relates to the HEAT method above, where in essence the use of a computer language and metaphors enables greater sophistication in simulation, constraint specification and a more complex (albeit flexible) underlying control model.

### 2.6.3 Agent Based Modelling

Joslyn (1999) writes that programming theory (as understood in the realm of computer science) has progressed *"from procedural through functional to object orientated models (such as XML), now culminating in […] agent-based approache[s]"* (p. 2). This progression is analogous at some level to the modelling approaches in C4I. For example, the cybernetic approach might be considered as being at a procedural level, Lawson's model and similar are at a functional level, WEA (above) is object orientated, whereas this section is concerned with agent based approaches.

Agent-based models have two essential components; a representation of a set of active entities (actors) and a representation of an environment. Agents programmed with a range of behaviours on the basis of some form of rule or state system then interact with other agents and their environment to produce behaviour. One can then use this 'test bed' to examine the effects either of changes to the environment or changes to the rules which agents operate under (which might, for example, simulate a new technology or SOP). The qualities of the environment and the agent behaviour rules then constitute the key constraints within agent-based models.

The key advantage in using agent models is that as a product of the interaction between agents, emergent behaviour is produced. Emergence is a philosophically sophisticated notion that first became popular around the end of the 19th century. It was defined by John Stuart Mill in A System of Logic (1843):

"*All organised bodies are composed of parts, similar to those composing inorganic nature, and which have even themselves existed in an inorganic state; but the phenomena* *of life, which result from the juxtaposition of those parts in a certain manner, bear no analogy to any of the effects which would be produced by the action of the component substances considered as mere physical agents. To whatever degree we might imagine our knowledge of the properties of the several ingredients of a living body to be extended and perfected, it is certain that no mere summing up of the separate actions of those elements will ever amount to the action of the living body itself.*".

It is important to note the irreducible nature of emergent properties, by definition one can observe them but not trace them back to any one element of the system that produced them. No individual part of the system has the emergent quality observable within it; emergent properties are a product of synergy. As a result of this irreducibility emergent properties will tend to be nonlinear in their response to changes within their underlying variables. If one takes the philosophical position that certain forms of behaviour are observable only as a result of complex interactions (and thus are non-linear in their response to changes in parameters, effectively putting it outside conventional analytical techniques), then agent modelling is arguably the only means by which emergent properties of systems can be explored. C4I can be considered from an agent based modelling perspective.

## 2.6.4 Semiotic Agents

The active entities (the agents themselves) in an agent based modelling paradigm can be characterized according to the following four properties (Joslyn, 1999).

- *Asynchronicity:* Agents act independently in time.
- *Interactivity*: Agents communicate and interact in something analogous to a 'social' manner, forming a collective entity through their interaction.
- *Mobility*: Agents have the capacity for 'movement', in terms not just of movement through real, virtual or simulated space, but also notions of movement of data within or between environments.
- *Distribution*: Which is the manifest property of Mobility, and
- *Non-Determinism:* In which agent systems possess some aspects that can be regarded as random (Joslyn, 1999).

The term 'semiotic agent' refers to *"the use and communication of symbols by and between agents and their environments"* (Joslyn, 1999, p. 2). *"They involve processes of perception, interpretation, decision, and action with their environments"* (Joslyn, 1999, p. 9) and are therefore analogous to some extent with a three stage model of human information processing (e.g. Newell and Simon, 1972). Perhaps because of this semiotic agents have a certain appeal when it comes to modelling the role of human agents in systems. Semiotic agents possess the following architecture (Figure 2-7).

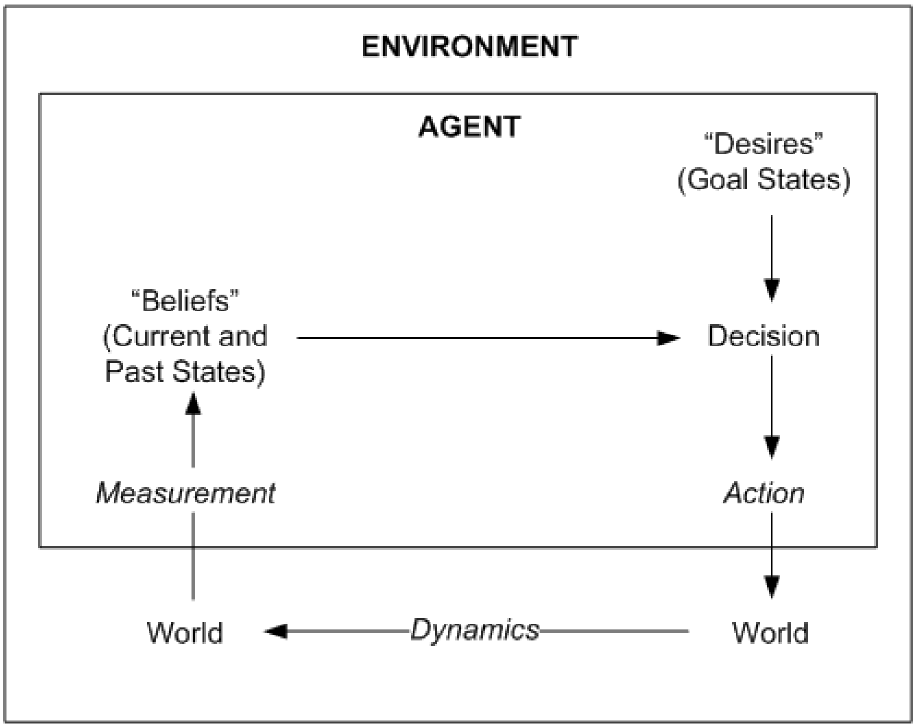


**Figure 2-7 - Architecture of a semiotic agent**

### 2.6.5 Example: BODIS

An early finding within the agent modelling community was that complex group behaviour need not be a function of complex individual behaviour; even agents following very simple rules will produce complex patterns of interaction. Probably the most famous example of this synergistic complexity effect is to be found in the model of bird flocking behaviour "Boids" (Reynolds, 1987). The aggregate motion of a flock of birds or other animals constitutes a deeply complex pattern of motion to describe in mathematical terms (as might be attempted above under a cybernetic paradigm). Reynolds (1987) found that if he modelled each individual "boid" as an entity that acted according to a simple set of rules, but otherwise independently of other "boids", a highly realistic flocking motion path was produced as an emergent property at the level of the group arising from interactions between individual entities. This occurred purely through individual boids following three rules: (i) a boid will avoid collisions by adjusting course; (ii) boids will attempt to match velocity with nearby boids and (iii) boids will attempt to stay close to other nearby boids. Fidelity to realistic behaviour was found even when objects were introduced into the environment that the "boids" had to navigate around (see Figure 2-8).

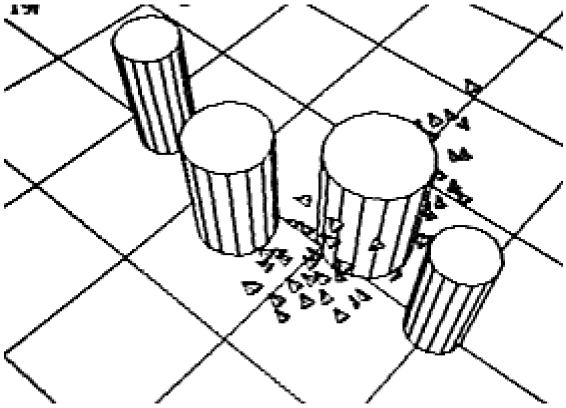

**Figure 2-8 - Simulated agents produce emergent flocking behaviour within a computer simulation.**

### 2.6.6 Summary of Agent Based Approaches

As regards modelling any complex system then, agent modelling provides the possibility of an alternate form of attack if traditional mathematical techniques (or the analyst's deployment of them) are insufficient to represent the complex, emergent and possibly non-linear behaviour of a system. One may raise the objection, however, that human behaviour is more intelligent than that of boids or indeed birds, but militating against this view is long standing evidence that significant portions of human behaviour may indeed be predicted by things like simple Pavlovian associative learning rules (Rescorla & Wagner, 1972). There may indeed by facets of a C4I system, such as procedures and rules which militate further.

Paradoxically, the agent modelling focus is still couched within the cybernetic paradigm, as the behaviour of nodes is still represented mathematically to some extent. The critical difference is that the underlying (simple) control model in this case is held within individual agent nodes, and the interactions among agents endow such models with (complex) aggregate behaviour. This at least gives the impression of much less formal determinism and can help to circumvent highly complex modelling mathematics.

## 2.7 Socio-Technical Models

### 2.7.1 People and Technology

Socio-technical systems, simply put, are a mixture of people and technology. As a modelling entity it represents an "[…] an approach to complex organisational work design that recognises the interaction between people and technology in workplaces" (Wikipedia, 2005). Command and control scenarios are a particularly complex example of these systems. Structural, deterministic approaches to modelling confer a metaphor of 'organisations as machines' (Morgan, 1986). As such, human agents tend to be modelled around the structure, rather than the other way around. An alternate metaphor, command

and control as an organism, appears to capture the essence of the socio-technical perspective rather better. Embodied within this type are the characteristics of adaptability and dynamism, which lends itself well to an environment that is more uncertain and turbulent. The challenge of course is to model such situations. An adaptation of Kotter's (1978) model of organisational dynamics presents the range of interacting, typically non-linear and overlapping facets that comprise a typical socio-technical system (Figure 2-9). This model is merely descriptive.

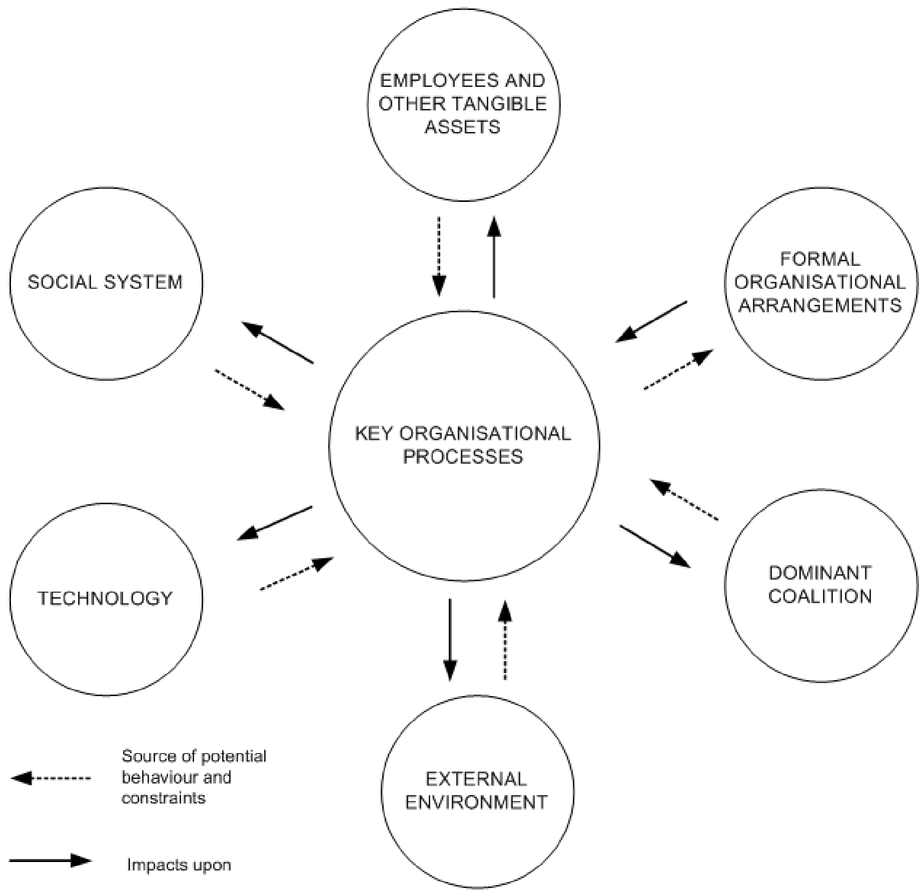


**Figure 2-9 - Kotter's model of organisational dynamics (1978)**

There are a number of different ways to visualise or otherwise represent the facets illustrated above.

## 2.7.2 Example: Process Charts

Process charts offer a systematic approach to describing activities within socio-technical systems. They simplify complexity by emphasising key features using a graphical representation that is easy to follow and understand (Kirwan & Ainsworth 1992). Process charts are descriptive in that they represent 'activity' over time, who (and/or what) is enacting any given activity and how activities are linked in order to culminate in the final goal based objective(s).

Process charts also offer some deeper predictive insights. Because activities are mapped along a timeline, outcome measures of tempo (number of activities within timeframes) can be gained. Operations loading (the type of activity versus who is performing the activity) provides some, albeit crude indication of workload. Although used in a predominantly descriptive manner there seems little reason why process charts could not be constructed before a task has taken place to form a simple type of predictive model. The construction, at a superficial level, could proceed according to a task analysis (itself a form of model), the times associated with the completion of specified tasks (a Keystroke Level Model) and any known mediating affects of communications media (expected errors etc.). Fundamentally, whilst process models of socio technical systems are adept at describing the observable outputs (and inputs) of human information processing, alternate approaches are required to model the 'unobservable' processes of human cognition; which are the main cause of modelling difficulties under more structural perspectives.

### 2.7.3 Example: A Functional Model of Command and Control

Smalley (2003; Figure 10) proposes a functional socio-technical model of command and control, comprising some seven operational and decision support functions (six in the ovals and one in the box) and ten information processing activities (appended to the input and output arrows). These include several 'unobservable processes'. The ten information processing activities are: primary situation awareness, planning, information exchange, tactical situation reports, current situation awareness, directing plan of execution, system operation, system monitoring, system status, and internal co-ordination and communications.  A representation of the relationship between the operation and decision support functions and information processing activities is shown in Figure 2-10.

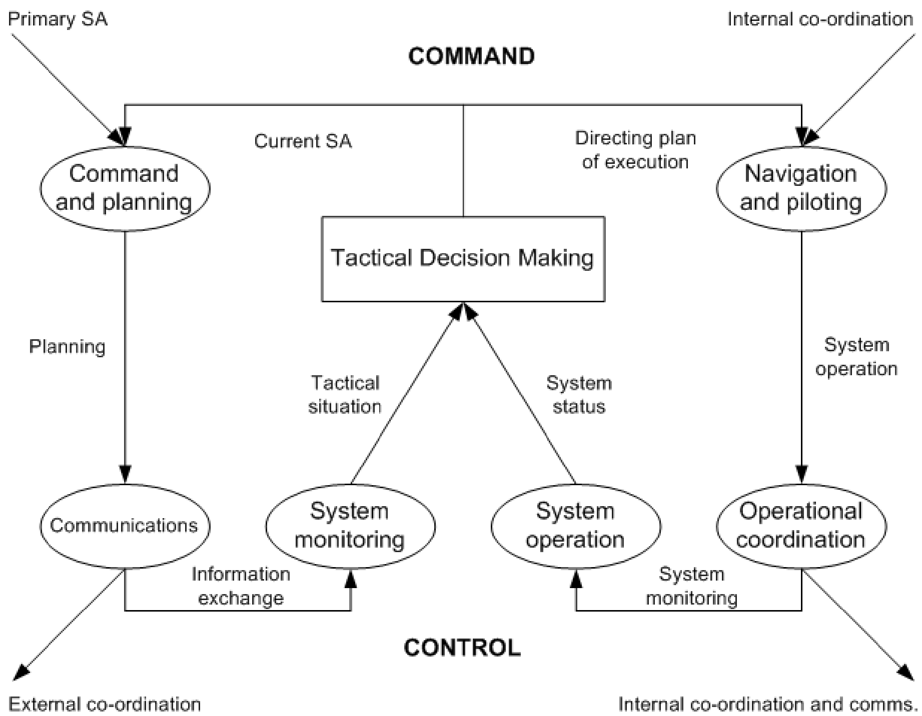


**Figure 2-10 - Smalley's functional command and control model.**

Information about the state of the world is collected through the primary situation awareness activities. The various sources of information are combined so that targets and routes can be defined in the planning activities. Information about targets, routes and intentions is exchanged with other forces. The status of the mission is communicated through the tactical situation reports. Current situation awareness activities merge information about the mission with primary situation awareness, to inform the planning process. The information from this latter set of activities will cue the start of activities that direct the plan of execution. This, in turn, informs activities associated with the direction of system operation. The system is monitored, to see if outcomes are as expected. Any changes in the system status may lead to changes in the planning and the directing of the plan. Internal and external co-ordination and communication activities keep the command and control system functioning.

Smalley's model seems to represent an integration of many command and control activities coupled together with feed-forward and feed-back loops. It has a higher level of command and control fidelity than previous model examples. The model suggests that 'command' activities (at the top pf the Figure) are separate, but connected to, the 'control' activities (at the bottom of the Figure). The activities on the right-hand side of the Figure are concerned with internal operation of the system, whereas the activities on the left-hand side of the Figure are concerned with interfacing with the external environment.

## 2.7.4 Example: Cognitive Work Analysis (CWA)

The term cognitive engineering was first coined by, amongst others Donald Norman, Erik Hollnagel and David Woods in relation to an expanding field of applied cognitive science based on the fundamental principle of human action and performance. Numerous cognitive engineering approaches fall under the umbrella of Cognitive Work Analysis (CWA; Vincente, 1999) which is to be discussed below as a paradigm. CWA attempts to offer predictive power in terms of the relationships specified in Kotters diagram above, with a focus on the goal directed behaviour of agents within the system. CWA involves five modelling phases as follows;

1. work domain analysis,
2. activity analysis,
3. strategies analysis,
4. socio-organisational analysis and
5. worker competencies analysis.

### 2.7.4.1 Work Domain Analysis

The work domain analysis involves describing the work environment using an abstraction decomposition space. The principal behind this lies in the premise that "instead of decomposing functions according to the structural elements, we have to abstract from these elements and […] identify and [..] separate the relevant functional relations"

(Rasmussen et al, 1994). In the Abstraction Decomposition Space (ADS) there are five levels of abstraction, ranging from the most abstract level of purposes (e.g. the intended effect of the whole system upon the environment) to the most concrete level of form (e.g. the physical form of actual objects in the environment; Vicente 1999). Table 3 presents a definition of the cells within the abstraction decomposition space and presents a worked example from a militaristic work domain. Moving up or down the ADS varies the level of abstraction, whereas moving left to right is the equivalent of zooming in or out on the system. When levels of abstraction are crossed with levels of system description an explanatory model of the “reasons that a technical system exists and must be controlled” is gained (Sanderson, 2003). “Connections between an element at one level to an element at the next level above indicates why the first element exists, whereas connections to an element at the next level below indicates how the element has been instantiated or engineered” (Sanderson, 2003, p. 241).

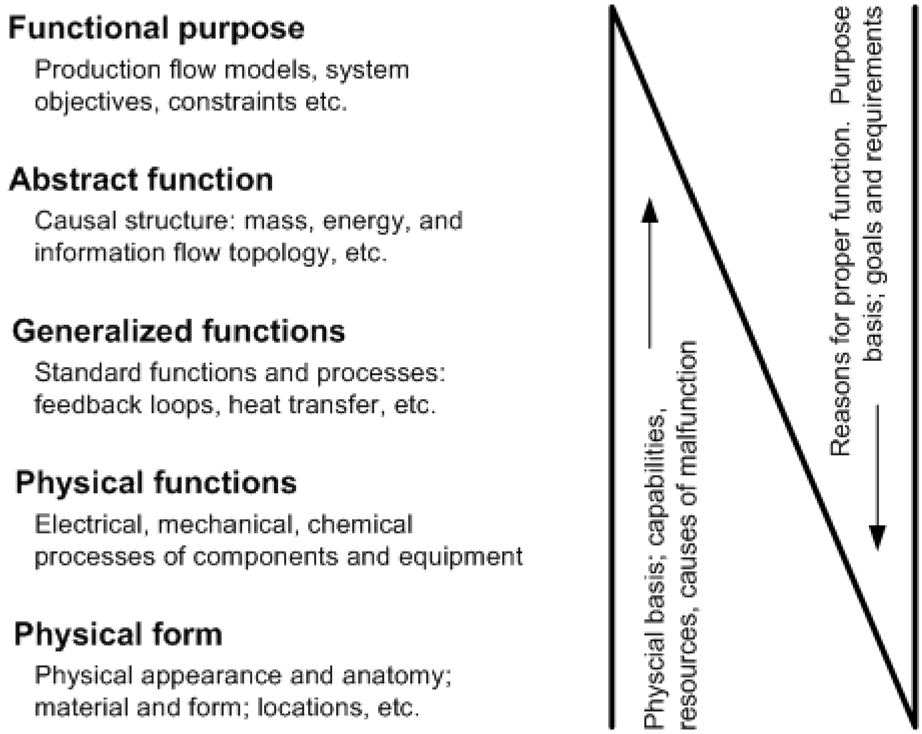


**Figure 2-11 - Definition of the abstraction decomposition space (Rasmussen, 1986)**

**Table 3 - Worked example of an abstraction decomposition space from a militaristic work domain.**

| AH/SH | Total system | Sub-system | Functional Unit | Assembly | Component |
|---|---|---|---|---|---|
| Functional purpos | Overall mission | Command level goals | Unit goals | Team goals | Agents goals |
| Abstract functior | Mission plans | Mission plans | Tactical overlays | Tactical overlays | Projected agent |
| Generalised function | Course of actior | Sub-system capability | Unit capability | Team capability | Agent capability |
| Physical functior | Mission status | Mission summarie | Unit mission summaries | Team status | Agent status |
| Physical form | Global view of B | Location of sub-system | Location of unit | Location of team | Location of agent |

## 2.7.4.2 Activity Analysis

The activity analysis component involves identifying the tasks that need to be performed in the work domain. Various task analysis techniques relate to this step of CWA and the reader is referred to the section on Hierarchical Task Analysis (HTA) described above in section 2.5 as an example. Regardless of the specific modelling technique the aim is the same; to *"[…] identify what needs to be done, independently of how or by whom, using a constraint based approach"* (Vicente, 1999, p. 183). Information processing constraints placed upon the enactment of tasks are typically modelled using Rasmussen's (1994) decision ladder, reproduced in relation to command and control tasks in Figure 2-12 below. *"The decision ladder is not a model of human decision making but instead is a template of possible information-processing steps that allow a controller [human or non-human] to take information about the current state of the system and execute appropriate actions in response"* (Sanderson, 2003, p. 243).

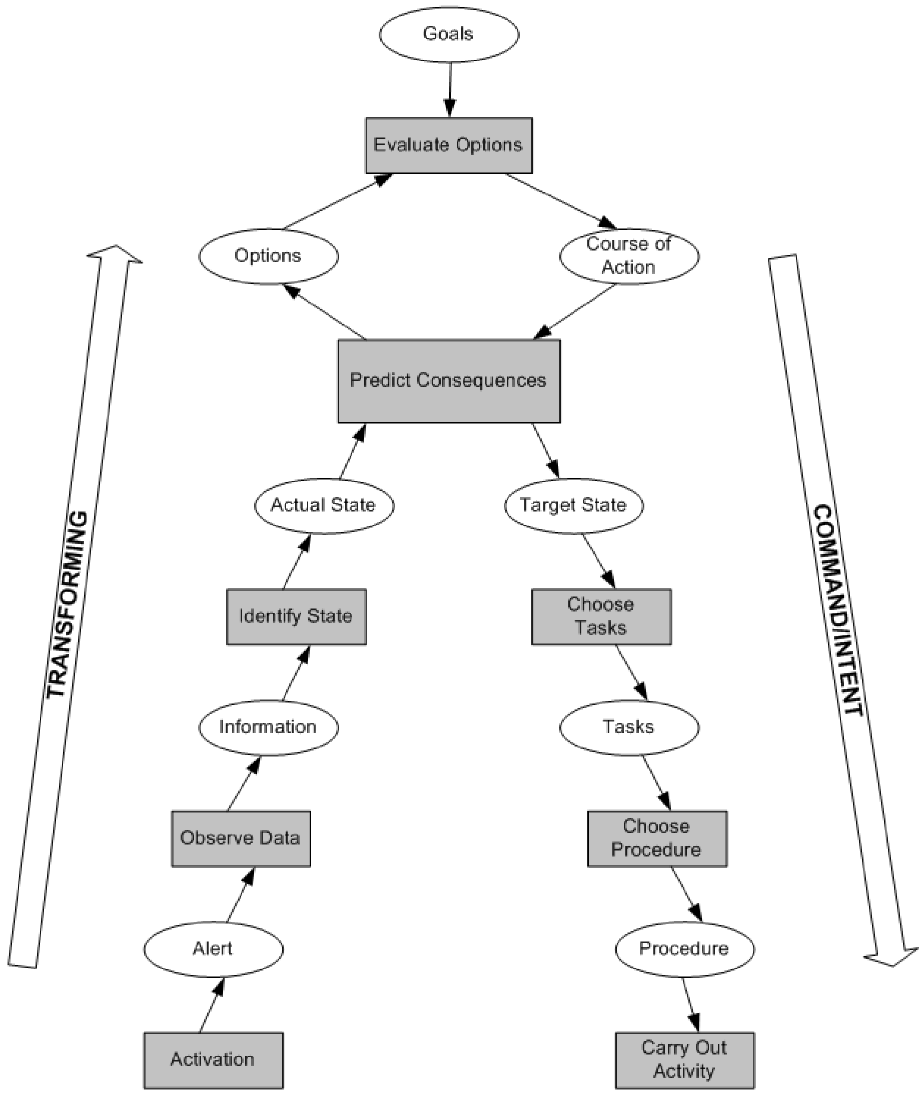


**Figure 2-12 - Rasmussen's decision-ladder applied to a command and control domain (Chin et al., 1999).**

#### 2.7.4.3 Strategies Analysis

Strategies analysis involves modelling the mental strategies that the agents involved may use during task performance in the domain under analysis. But, *"rather than descriptions of the course and content of actual mental processes [which is hard if not impossible to accurately model], descriptions of the structure of possible and effective mental processes"* are represented (Rasmussen, 1981, p. 242). This, arguably, is CWA's least defined representation. Typically, however, strategies analyses take the form of flow charts or the 'mapping' used below in the context of the DTC HFI's ongoing work in WP1 and 2 (Figure 2-13).

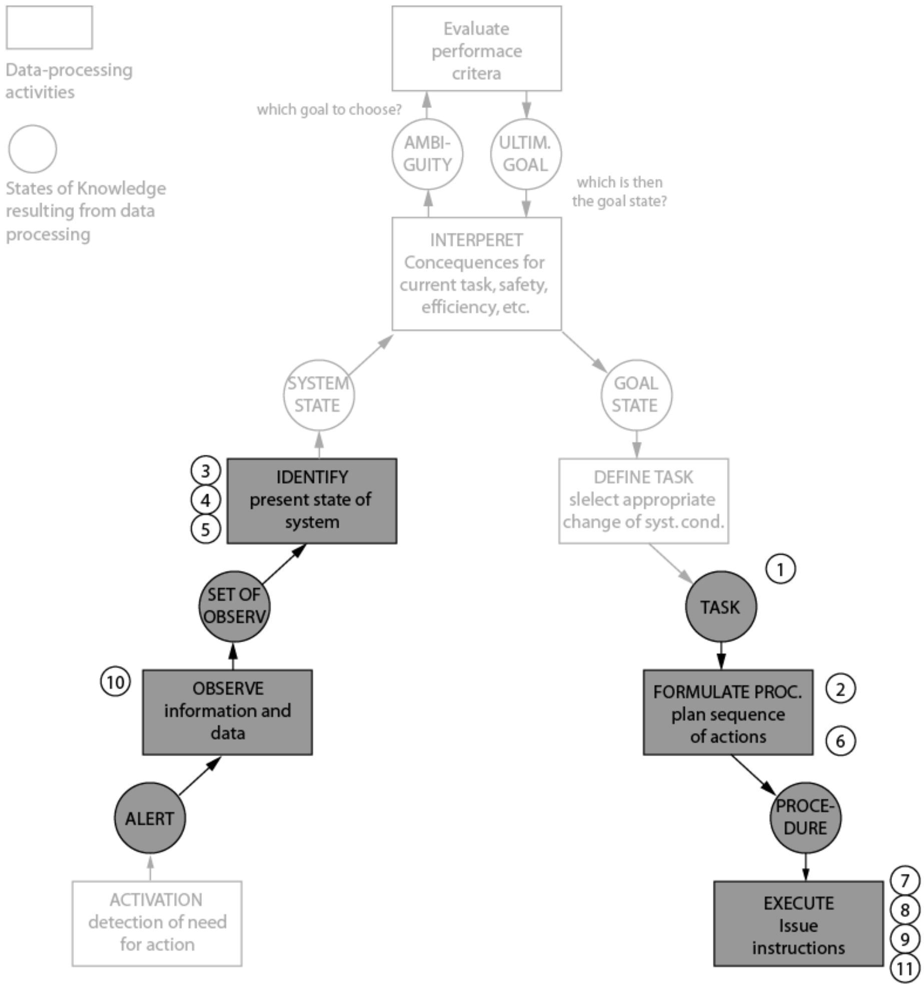


**Figure 2-13 - Example output of strategies analysis. Shaded regions refer to a specific role or actor; the numbered circles refer to task steps.**

### 2.7.4.4 Social and Organisation Analysis

Social organisation analysis involves identifying exactly how the work is distributed amongst the agents and artefacts within the system under analysis. In CWA this analysis usually proceeds by overlaying some of the previous representations. It would appear that the network techniques described in Figure 2-13 are also highly relevant to modelling this aspect of coordination between actors.

### 2.7.4.5 Work Competencies Analysis

Finally, worker competencies analysis involves the identification of the competencies that the agents involved are required to possess in order to perform the task(s) in the work domain. The worker competencies are classified using Rasmussen's Skill, Rule, Knowledge (SRK) framework. The SRK framework is a *"taxonomy for classifying how cognition is controlled by the way information is presented in the environment"*

(Sanderson, 2003, p. 250). As such its modelling attributes are more concerned with simplifying complexity, perhaps pointing the way to further distributed models of human cognition.

In terms of outcome measures, CWA provides various perspectives on purpose, intent, goals and capability (Chin et al., 1999), as well as to the attribution of information, systems and activities to tasks and timescales.

### 2.7.5 Example: Contextual Control Model

Whereas CWA is an integrative approach to modelling socio technical systems, Hollnagel's (1993) Contextual Control model is a contemporary example of how human performance within such systems might be represented. Hollnagel (1993) developed a Contextual Control approach to human behaviour, based on cognitive modes to explain the effects of the context in which people performed their actions. Rather than command and control being a pre-determined sequence of events, Hollnagel has argued that it is a constructive operation in which the operator actively decides which action to take according to the context of the situation together with his/her own level of competence. Although set patterns of behaviour may be observed, Hollnagel points out that this is reflective of both the environment as well as the cognitive goal of the person, both of which contain variability. In the Contextual Control Model (shown in Figure 2-14), four proposed modes of control are offered as follows.

1. *Scrambled Control* - is characterised by a completely unpredictable situation in which the operator has no control and has to act in an unplanned manner, as a matter of urgency.

2. *Opportunistic Control* - is characterised by a chance action taken due to time, constraints and again lack of knowledge or expertise and an abnormal environmental state.

3. *Tactical Control* - is more characteristic of a pre-planned action, where the operator will use known rules and procedures to plan and carry out short term actions.

4. *Strategic Control* - is defined as the ‘global view’, where the operator concentrates on long term planning and higher level goals.

All these modes of control are familiar within C4I scenarios.

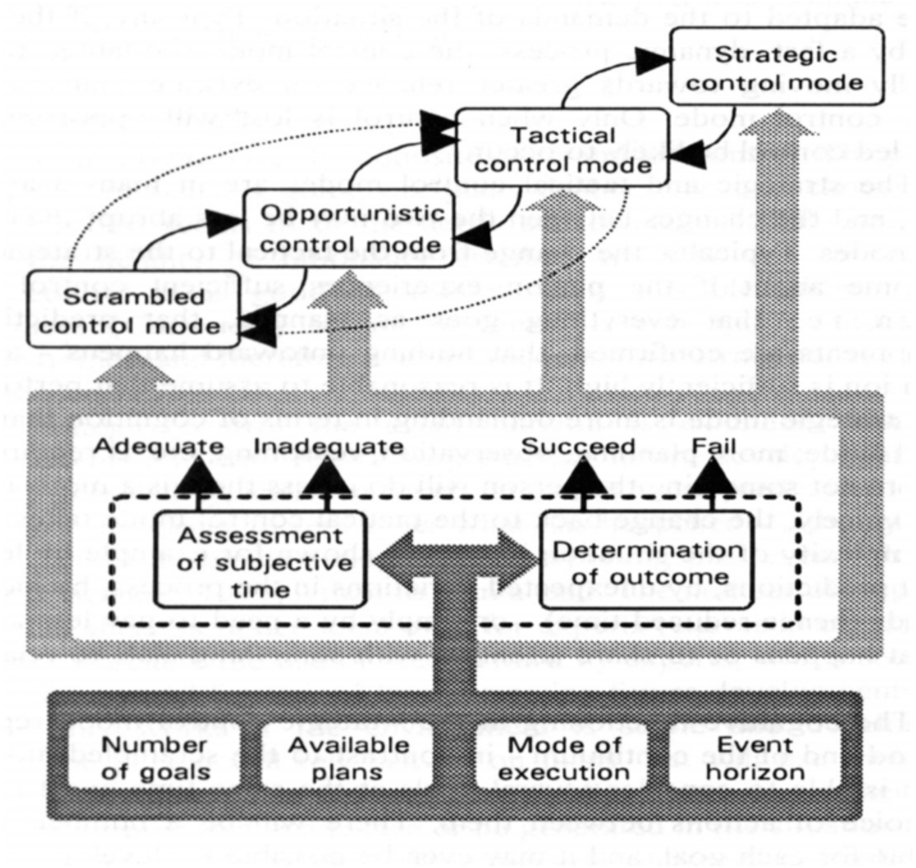


**Figure 2-14 - Hollnagel’s contextual control model.**

The degree of control is determined by a number of varying interdependent factors. Hollnagel considers that availability of subjective time is a main function of command and control - this means that as the operator perceives more time available so s/he gains more control of the task/situation. In fact one could argue that the fundamental purpose of C4I is to facilitate increases in subjectively available time and by doing so increasing 'decision superiority'; striving to operate at strategic/tactical levels of control. The factors affecting the perception of available time may include: the number of goals, the availability of plans to meet these goals, the modes of execution of those plans and the time available before (called the event horizon). At any point in time the system operator is attempting to optimise all of these criteria. Hollnagel’s model differs from Lawson’s in that it does not prescribe the sequence and relations of command and control activities; rather it proposes contextual differences in the control mode. There is some evidence to support this hypothesis. In a study of team behaviour in a supervisory control task, Stanton et al (2001) showed that the transitions between control modes were consistent with Hollnagel’s model.

## 2.7.6 Summary of Socio-Technical Systems

If socio-technical systems are regarded merely as mixtures of people and technology then the models reviewed in this section aim to characterize and predict the behaviour of people in context. Vincente's (1999) pioneering CWA method is a comprehensive integrative approach that places a particular emphasis on modelling the context from a cognitive perspective. What might be regarded as cognitive engineering models, e.g. Rasmussen's and Hollnagel's approaches, are 'general characterizations' of human behaviour in systems and in environments. Hollnagel's model places emphasis on subjectively available time and links it to four levels of 'control'. Rasmussen's model (as it is embodied in CWA) characterizes naturalistic decision making, expressing shortcuts and routes through a hierarchy of decision making. Functional models, in essence, break down the mixture of people and technology into purposeful elements with links and feedback. Process charts characterize socio-technical systems in terms of activity.

## 2.8 Summary of Modelling Review

This report defines four broad modelling typologies: Cybernetic, Network, Agent Based and Socio Technical.

The cybernetic modelling paradigm is concerned principally with the structural aspects of command and control, reducing it to functional entities linked through specific causal pathways according to a deterministic idiom. These models can be subject to various known inputs and the specification of the functional entities enables the resulting output to be completely described.

Network models blur somewhat the strict formalism of the cybernetic perspective. The focus widens to emphasise not just the functional entities themselves but the links that exist between them. The links can be defined according to various parameters, including communications between functional elements and logical relationships. When functional entities are linked in this manner a network is formed. The network rather than the functions can be summarised and analysed mathematically to reveal emergent properties. The emergent properties are not necessarily planned a priori thus the network approach provides an alternate perspective on, as well as a prediction of several C4I system attributes and outcomes.

Agent modelling perspectives appear to represent a form of synthesis between cybernetics and network models. Whereas cybernetic models attempt to model the 'aggregate behaviour' of a group of entities, doing so with often complex mathematics, agent approaches focus on the emergent behaviour arising from the interaction of (mathematically and computationally) simplistic entities. That is, complex group behaviour need not be a function of complex individual behaviour. Agent modelling results in less formal and more organic behaviour from which complex emergent properties arise.

Socio technical models of command and control emphasise the human role. Rather than the strict formalism of the previous approaches cognitive models tend to be a more general characterisation of agent behaviour (and psychology) in C4I systems. Socio technical systems, being a mixture of people and artefacts, aim to specify the environmental factors that influence human cognition and which form model constraints. Effective decision making and behaviour can be assumed to be the key emergent property, in which the interest is couched within the key determinates of C4I scenarios that facilitate or indeed hinder this outcome.

Table 4 below presents a summary of the four broad modelling perspectives identified. The summary is represented in terms of emergent properties.

**Table 4 - Summary of modelling perspectives and broad emergent properties**

| Modelling Perspective | Emergent Properties |
|---|---|
| Cybernetics | Structural C4I system parameters (such as casualties, survivability, mission success etc) in relation to known inputs |
| Networks | Characteristics of networks that enhance or constrain performance |
| Agents | Aggregate behaviour based on the interaction between entities. |
| Cognitive/STS Models | Constraints on effective human decision making and action. |

This report has already alluded to the fact that the possibilities and challenges underlying future NEC approaches are a primary motivation for a generic model of command and control. The expected outcomes of NEC are expressed as a benefits chain (MoD, 2004) shown in Figure 2-15 below.

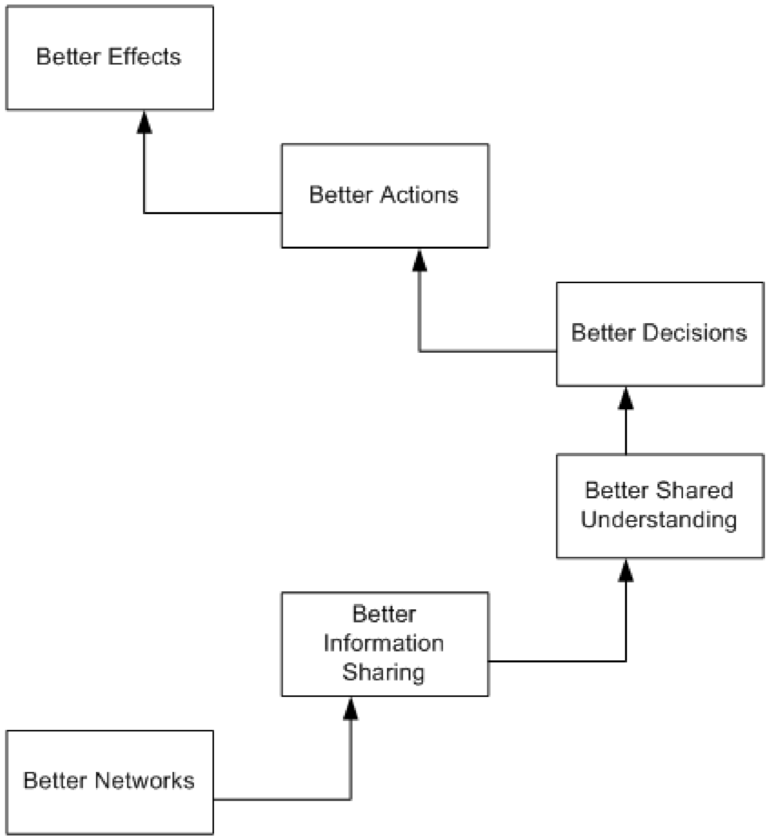


**Figure 2-15 – NEC benefits chain**

Whilst this report is not intended to be an exhaustive critique of individual models, it is however informative to relate the examples given above to the benefits chain as shown in Table 5.

**Table 5 - Informal classification of model types/typologies with defined NEC benefit criteria**

| Modelling Perspective | Example Model | Related Benefits |
|---|---|---|
| Cybernetic | Lawsons Model of C2 | Effects |
| | HEAT | Effects |
| Network | Hitchens N2 | Information Sharing |
| | HTA | Networks |
| | Social/Prop Nets | Information Sharing/Shared Understanding |
| Agent | WEA | Actions |
| | BOIDS | Actions |
| Cognitive/STS Models | Process Model | Actions |
| | Functional Model | Decisions/Actions |
| | CWA | Decisions/Actions |
| | COCOM | Decisions/Actions |

Table 5 represents a relatively informal classification. The cybernetic models can be associated with modelling 'effects', these can be regarded as the more structural parameters of mission success (such as destroy, find etc). The benefits related to the network models depend on the 'topic' of the network. Networks that possess links related to information and communication can be loosely associated with benefits of information sharing. Networks expressing the links between tasks and goals relate to 'NEC Networks', that is the physical instantiation of a real life NEC system. Propositional networks, related as they are to knowledge clearly speak towards benefits in shared understanding. Agent models all seem to relate to actions, being concerned with modelling 'aggregate' behaviour. Similarly, cognitive and STS models relate to cognition in context as it relates to the underlying determinates of human decision making and action in C4I systems.

Whilst individually each of the models and model types speak towards different aspects of C4I and NEC none of them can be considered a 'generic model' in itself. It can be argued that C4I is too multi-faceted for the modelling typologies dealt with so far to encompass the full range of dimensions and emergent behaviour relevant for military research. An intermediate modelling step is therefore required in order to:

- simplify complexity
- enable emergent properties and outcome metrics to be defined
- enable some of the modelling typologies identified above to be selected from and deployed intelligently in future research
- enable C4I scenarios from alternate domains and contexts to be modelled on a common platform and
- for these disparate scenarios to be easily compared

The manifestation of these aims is the 'generic process model' of C4I that is developed in the sections that follow.

# 3 Development of a Generic Process Model of Command and Control

## 3.1 Three Domains for Command and Control

The basis for the development of the generic model are field studies conducted in three domains. These were the emergency services (i.e., Police and Fire Service – McMaster, Baber & Houghton, 2005; Houghton, Baber & McMaster, and Houghton et al., in press), civilian services (i.e., National Grid, National Air Traffic Services, and Network Rail - Walker et al, in press) and armed services (Airforce E3D, Navy type 23 frigate and Army CAST brigade level exercise)[1]. It is the cumulative understanding of Command and Control, developed through a variety of domains, which led to the development of a generic model.

### 3.1.1 Emergency Services

Two command and control application areas were analysed in the emergency services: the fire service and the police. In the UK (and several other countries across Europe), the emergency services operate a tripartite control structure. Major incidents, which require high-level command are termed Gold. Typically, these occur when the coordination of a great many units is required. Usually such command is not required and command can be exercised on a local, tactical level, which characterises Bronze command. Between Gold and Bronze lies a strategic command level termed Silver.

#### 3.1.1.1 Fire Service

In order to study fire operations, observations were conducted at the Fire Service Training College. The training college provided access to command structures for ecologically valid exercises, without the potential risk associated with actual fires. During each exercise, an incident commander (the Assistant Divisional Officer or ADO) issues commands to the sectors being controlled. For a medium-to-large incident, within the Silver command level it is necessary to divide response into sectors, which can be either geographical (i.e., parts of the fire ground), or functional (for example, managing water supplies or a breath-apparatus crew). The exercises that were observed covered operations including the search for a hazardous chemical, fire in a chemical plant, and a road traffic accident.

[1] Individual reports covering all of these live C4I scenarios and subjecting them to the DTC HFI's EAST methodology are available.

#### 3.1.1.2 Police

Police operations were studied through observations in Force Command and Control (FCC) and Operational Command Unit (OCU) sites. The focus was on accidents requiring immediate response, that is, where suspects were on the premises or an incident was in progress. FCC Emergency Call Operators prioritise incidents as requiring immediate, early or routine response, according to their urgency. Incidents that are graded as “Immediate Response” are those that require an urgent Police presence, usually because there is a high risk of serious injury or death, or where there is a good chance of an arrest if the response is rapid (i.e. when the crime is still taking place). When an incident is prioritised “Immediate Response”, only the bare minimum of details are taken from the caller by the Emergency Call Operator (i.e. location, nature of emergency and caller’s name), which are then passed on to the OCU responsible for the area where the call originated. The Operations Centre within the OCU in question will then review the incident priority and allocate resources to respond to it. In the case of “Immediate Response” incidents, the Police are required to attend the scene within 10 minutes.

### 3.1.2 Civilian services

Three command and control applications areas were analysed in the civilian services: air traffic control, the rail network and the national electricity grid.

#### 3.1.2.1 Air Traffic Control

Air Traffic Control is a highly evolved process based on clearly defined procedures. The procedures used in normal operations are based on the aircraft flight plan, which describes its intended route. This route includes the starting location, beacons or reporting points that it will pass and its final destination airport. This information derives from the flight data strip computer and is presented to the controllers in the form of a flight progress strip by flight strip assistants. The flight data strip contains coded information showing particulars about the aircraft and its route. From this information the controller can determine the approximate time and position at which the aircraft will arrive in the sector. UK controlled airspace is divided into sectors, each of which is monitored by an air traffic control team. As an aircraft travels through these sectors, responsibility for controlling it transfers from one controller to another. Making sure that aircraft pass through this airspace and take off and land safely is the key responsibility of individual controllers.

#### 3.1.2.2 Railway Maintenance

Three scenarios were analysed in the UK rail industry. The activities under consideration were those involved in the setting up of safety systems required when carrying out maintenance of track. Under normal conditions a signaller has the key responsibility for controlling train movements and maintaining safety for an area of railway line. This control occurs remote from the line at a control centre (a signalbox or signalling centre). These can be located many miles from where activity could be taking place. During maintenance, another person takes responsibility (possession) for an area of the line. Communication and coordination is required to transfer responsibility between the signaller and track maintenance engineers. The track maintenance engineers also have to communicate and coordinate with various other personnel, such as those carrying out maintenance within their areas of control, drivers of trains and on track-plant which may be in the zone where maintenance is taking place (called the possession), and personnel implementing aspects of the possession (all of which may also be dispersed over a certain geographical area). The three specific maintenance scenarios analysed were: planned maintenance (the processes and activities for setting up a possession for a stretch of track so that planned maintenance can take place), emergency engineering work (the processes and activities for unplanned emergency engineering work on the line, such as when track or infrastructure has been damaged or has suddenly degraded) and ending track possession (the reversal of the processes and activities for planned maintenance).

#### 3.1.2.3 National Grid (High Voltage Electricity)

Three scenarios were analysed in the bulk electricity transmission industry (the National Grid). National Grid Transco own, maintain and operate the high voltage electricity transmission system in England and Wales. This complex and distributed system is comprised of 4500 miles of overhead lines, 410 miles of underground cables and 341 substations. The scenarios under analysis were observed at the Network Operations Centre (NOC) control room and in a number of geographically remote substations. Two outage scenarios were observed. There were three main parties involved in these, a party working at Substation A on the Substation B circuit, a party working at Substation B on the Substation A circuit (i.e., at either end of a 30 mile overhead line) and an overhead line party working in between. A return to service scenario was also observed. This scenario also involved a circuit between substations and the NOC. Observation focussed upon six main parties that were involved and the complex technological infrastructure that facilitated remote operations and communication.

### 3.1.3 Armed Services

Command and control applications were analysed within all three armed services: army, air-force and navy.

#### 3.1.3.1 Army

The study of command and control in the Army took place at the Command And Staff Training (CAST) exercises at the British Army’s Land Warfare Centre in Warminster. Observations of both Brigade Headquarters and Battle Group Headquarters were undertaken. The studies were focused on the planning process, known as the Combat Estimate, war-gaming and simulation of the enactment of the plan. The plan is considered adequate when it meets the commander's intent, provides clear guidance to all sub-units and enough detail to allow the effects of the available combat power to be synchronised at critical points (MoD, 2005b). Flexibility is described in terms of the agility and versatility required to respond to the situation (and enemy) as events occur. Timeliness, finally, is about ensuring that there is 'sufficient' time for the battle procedure to be enacted. The Combat Estimate is summed up (and often referred to) as the seven questions. These questions break down the process by which plans are made and actions taken; they summarise the activities and outcomes of the different stages of the process.

#### 3.1.3.2 Air Force

The scenario analysed in the RAF took place on board an E3D AWACS (Airborne Warning and Control System) aircraft and covers the operations for a simulated war exercise. The RAF ran a training course for Combined Qualified Weapons Instructors (CQWI). The evaluation of this training course took place over a two-week period. A simulated war exercise was carried out each day involving three key teams of personnel: ground based support, the E3D (AWACS) team and the fighter pilots. Ground based support includes all personnel assigned to the mission whom are not flying in the simulated war exercise. The term “fighter pilots” refers to both fighter and bomber pilots who took part in the exercise. These pilots flew a variety of aircraft which numbered between 20 and 40 for each mission. The purpose of the E3D team was to provide support for both ground and fighter personnel. Their role involved providing a global picture of the war from the sky as it developed. This information was relayed to ground support staff and to individual fighter pilots. All personnel were kept up to date with where fighters were in relation to one another and of any fatalities. There are 18 crewmembers that operate the aircraft and make surveillance and support for ground and fighters possible. Observers were present on board the E3D aircraft and monitored the communications of a number of key people throughout the exercise.

#### 3.1.3.3 Navy

The Royal Navy allowed a team of researchers access to one of their training establishments - the Maritime Warfare School – on HMS Dryad in Southwick, Hampshire. Observations were made during Command Team Training (CTT). This programme involved training the Command Team of a warship in the skills which would be necessary for them to defend their ship in a multi-threat environment; *“assimilate, interpret and respond correctly to the information received from external sources while reporting, directing and managing their and other units in the joint conduct of maritime operations”* (Hoyle, 2001,p3). The training programme was conducted in a representative Type 23 Ship ‘Operations Room Simulator’ (ORS). The simulator room is slightly enlarged to allow for staff observation but otherwise was to scale. In addition to this simulator room there was a room which included a team of personnel who helped make any threats seem more realistic, i.e. they portrayed other ships and aircraft as well as personnel from other parts of the ship. Three scenarios (air threat, subsurface threat and surface threat) were observed. The Anti-Air Warfare Officer (AAWO) was the main agent observed in the air threat scenario and the (Principal Warfare Officer) PWO was the main agent observed for the subsurface and surface threat scenarios. Other agents were heard and seen interacting with either the AAWO or the PWO.

## 3.2 Common Features of the Domains and Application of Command and Control

Despite the differences in the domains, the command and control applications share many common features. That is at some level they can be regarded as 'generic'.

- First, they are typified by the presence of a central, remote, control room. Data from the field are sent to displays and/or paper records about the events as they unfold over time.

- Second, there is (currently) considerable reliance on the transmission of verbal messages between the field and the central control room. These messages are used to transmit reports and command instructions.

- Third, a good deal of the planning activities occurs in the central control room, which are then transmitted to the field. There are collaborative discussions between the central control room and agents in the field on changes to the plan in light of particular circumstances found in-situ.

- Fourth, and finally, the activities tend to be a mixture of proactive command instructions and reactive control measures.

It is hypothesised that one of the determinants of the success or failure of a command and control system will be the degree to which both the remote control centre and agents in-the field can achieve shared situational understanding about factors such as: reports of events in the field, command intent, plans, risks, resource capability, and instructions. This places a heavy reliance on the effectiveness of the communications and media between the various parties.

## 3.3 Taxonomies of Command and Control Activities

Analysis of the task analyses from these three domains led to the development of a taxonomy of command and control activities, as indicated in Table 6. The resultant data from the observational studies and task analyses were subject to content analysis, in order to pick out clusters of activities. These clusters were subjected to thematic analysis consistent with a ‘grounded theory’ approach to data-driven research. It was possible to allocate most of the tasks in the task analysis to one of these categories. To this extent, the building of a generic model of command and control was driven by the data from the observations and task analyses.

**Table 6 - Taxonomy of command and control activities**

| Category | Table No. | Definition of activities |
|---|---|---|
| Receive | 7 | Receipt of data or information, a request or an order |
| Plan | 8 | Planning activities and planning decisions |
| Rehearse | 9 | Rehearsal of plan prior to action |
| Communicate | 10 | Transfer of verbal, written or pictorial information |
| Request | 11 | Request for data and information or assistance |
| Monitor | 12 | Monitoring and recording of effects of plan implementation |
| Review | 13 | Reviewing the effectiveness of plans or actions |

The detailed taxonomies may be found in the following seven Tables. The ‘receive’ taxonomy, as shown in Table 7, identifies activities that are associated with receiving orders, requests, data and information that relate to past, present or future events. This information can act as a trigger for new command and control tasks, or modifications of ongoing tasks. Thus the information may be either feed-forward or feedback.

**Table 7 - The 'receive' activities taxonomy**

| Domains | Emergency Services | | Civilian Services | | | Armed Services | | |
|---|---|---|---|---|---|---|---|---|
| Receive taxonomy | Police | Fire | NATS | NGT | NR | Army | Navy | Air |
| Incoming calls | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Paper message | | ■ | | | | ■ | ■ | ■ |
| Face to face | | | ■ | | ■ | ■ | ■ | ■ |
| Diary of work | | | | ■ | | | | |
| Incoming alarms | ■ | ■ | | ■ | | | | |
| Identity exchange | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Live displays | | | ■ | ■ | ■ | | | |
| Pre planned/pre-defined activities | ■ | ■ | ■ | ■ | ■ | | | |
| Database | | | ■ | ■ | | | | |
| Handover | | | ■ | | ■ | | | |
| Procedures/systems (implicit comms) | ■ | ■ | ■ | | ■ | | | |

The 'planning' taxonomy, as shown in Table 8, describes all of the activities associated with the preparation, assessment and choice of the plan. These activities include gathering of information, assessing options, discussing effects and prioritising alternative courses of action.

**Table 8 - The 'planning' activities taxonomy**

| **Domains** | **Emergency Services** | | **Civilian Services** | | | **Armed Services** | | |
|---|---|---|---|---|---|---|---|---|
| **Planning taxonomy** | Police | Fire | NATS | NGT | NR | Army | Navy | Air |
| **Review of location of assets** | ■ | ■ | ■ | ■ | ■ | ■ | | |
| **Establish status of assets and resources** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| **Request status of current activities** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Gather information (site, intel, environs)** | ■ | ■ | | ■ | ■ | ■ | ■ | ■ |
| **Integrate information** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Get people to site** | ■ | ■ | | ■ | ■ | ■ | | |
| **Develop mission timings** | | | | | | ■ | | |
| **Identify areas of interests** | ■ | ■ | ■ | ■ | ■ | ■ | | |
| **Identify decision points** | | | | | | ■ | | |
| **Undertake environmental analysis** | ■ | ■ | ■ | ■ | ■ | ■ | | |
| **Determine options (own and enemy)** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| **Identify potential conflicts** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Identify tactics (own and enemy)** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| **Check if information is sufficient** | | | | ■ | ■ | | | |
| **Consult other parties** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Discuss effects** | | ■ | | ■ | ■ | ■ | ■ | |
| **Assess options** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| **Select between alternative plans** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| **Assign assets to tasks** | ■ | ■ | | | | ■ | ■ | |
| **Assess risks with plan** | ■ | ■ | | ■ | ■ | ■ | | |
| **Communicate plan to other parties** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |

The 'rehearsal' taxonomy, as shown in Table 9, identifies activities that are associated with rehearsal of the plan prior to implementation. Most of the domains discuss the plan with the other parties, with the exception of ATC. The army also run a war-game on a map to consider the synchronisation of potential effects and likely courses of enemy responses.

**Table 9 - The 'rehearsal' activities taxonomy**

| Domains | Emergency Services | | Civilian Services | | | Armed Services | | |
|---|---|---|---|---|---|---|---|---|
| **Rehearsal taxonomy** | Police | Fire | NATS | NGT | NR | Army | Navy | Air |
| **Discuss plan verbally** | ■ | ■ | | ■ | ■ | ■ | ■ | ■ |
| **Move assets on map to rehearse plan** | | | | | | ■ | | |

The 'communicate' taxonomy, as shown in Table 10, refers to all of the activities associated with remote communication from the control centre. When the plan is communicated verbally, there is a read-out and read-back procedure, which may also act as a verbal rehearsal, although it does not formally belong in the 'rehearsal' taxonomy.

**Table 10 - The 'communicate' activities taxonomy**

| Domains | Emergency Services | | Civilian Services | | | Armed Services | | |
|---|---|---|---|---|---|---|---|---|
| **Communicate taxonomy** | **Police** | **Fire** | **NATS** | **NGT** | **NR** | **Army** | **Navy** | **Air** |
| **Exchange identities** | ■ | ■ | ■ | ■ | ■ | | ■ | ■ |
| **Issue instructions/ orders** | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Read-back instructions** | ■ | ■ | ■ | ■ | ■ | | | ■ |
| **Confirm read-back** | | | ■ | ■ | ■ | | | ■ |
| **Record date and tim of instructions** | ■ | ■ | ■ | ■ | ■ | | | |

The ‘request’ taxonomy, as shown in Table 11, refers to the manner in which the command and control centre asks for information and support from other parties. This includes agents in the field, other agencies, and other personnel in the command centre.

**Table 11 - The ‘request’ activities taxonomy**

| Domains | Emergency Service | | Civilian Services | | | Armed Services | | |
|---|---|---|---|---|---|---|---|---|
| **Request taxonom** | **Police** | **Fire** | **NATS** | **NGT** | **NR** | **Army** | **Navy** | **Air** |
| **Request status fro personnel** | | | | | | | | |
| **Request informatio from other parties** | | | | | | | | |
| **Pass information onto other parties** | | | | | | | | |
| **Request additiona resources or asset** | | | | | | | | |
| **Request support from other service** | | | | | | | | |

The ‘monitor’ taxonomy, as shown in Table 12, refers to all of the activities associated with keeping track of the changing situation and events being performed remotely. These activities include recording any changes to the plan as they occur.

**Table 12 - The 'monitor' activities taxonomy**

| Domains | Emergency Services | | Civilian Services | | | Armed Services | | |
|---|---|---|---|---|---|---|---|---|
| **Monitor taxonomy** | **Police** | **Fire** | **NATS** | **NGT** | **NR** | **Army** | **Navy** | **Air** |
| **Track assets (and enemy)** | | | | | | | | |
| **Identify conflict with plan** | | | | | | | | |
| **Allocate resource and assets to tasks** | | | | | | | | |
| **Control resources and assets** | | | | | | | | |
| **Record change to plan** | | | | | | | | |

The 'review' taxonomy, as shown in Table 13, refers to all of the activities associated with an after-action review of the successful and less successful aspects of the activities. This includes formal procedures, informal records, incident reports and accident tribunals.  The armed forces tend to be very thorough in applying this analysis at the end of every engagement, whereas the civilian and emergency services tend to be more informal unless there is an accident or near miss.

**Table 13 - The 'review' activities taxonomy**

| Domains | Emergency Services | | Civilian Services | | | Armed Services | | |
|---|---|---|---|---|---|---|---|---|
| Review taxonomy | Police | Fire | NATS | NGT | NR | Army | Navy | Air |
| Effectiveness of actions | ■ | ■ | | | | ■ | ■ | ■ |
| Deviation from plan | | | | | ■ | ■ | ■ | ■ |
| Key decision points | ■ | ■ | | ■ | | ■ | ■ | ■ |
| Internal updates and reports | ■ | ■ | | | | ■ | ■ | ■ |
| Loss of situation awareness | | | ■ | | | ■ | ■ | ■ |
| Lessons learnt | | | | | | ■ | ■ | ■ |

## 3.4 Construction of Model

From the taxonomies, and an analysis of the previous command and control models, it was possible to develop a generic process model as shown in Figure 3-1. Construction of the model was driven by the data collected through observation from the different domains, and the subsequent thematic analysis and taxonomic development. In the tradition of grounded theory the generic command and control model was as a result of our observations, rather than an attempt to impose any preconceived ideas of command and control. This may account for many of the differences in the current model developed in the course of the current research and those that have come before it.

It is proposed that the command and control activities are triggered by events at the top of the Figure, such as the receipt of orders or information. These provide a mission and a description related to the current situation and events in the field. The gap between the mission and the current situation lead the command system to determine the effects that will narrow that gap. This in turn requires the analysis of resources and constraints in the given situations. From these activities plans are developed, evaluated and selected. The chosen plans are then rehearsed before being communicated to agents in the field. As the plan is enacted, feedback from the field is sought to check that events are unfolding as expected. Changes to the mission or the events in the field may require the plan to be updated or revised. When the mission has achieved the required effects, the current set of command and control activities may come to an end.

The model in Figure 3-1 distinguishes between 'command' activities, in the shaded triangle on the left-hand side of the Figure, and 'control' activities, in the shaded triangle on the right-hand side of the Figure. Command comprises proactive, mission-driven planning and co-ordination activities. Control comprises reactive, event-driven, monitoring and communication activities. The former implies the transfer of mission intent whereas the latter implies reaction to specific situations.

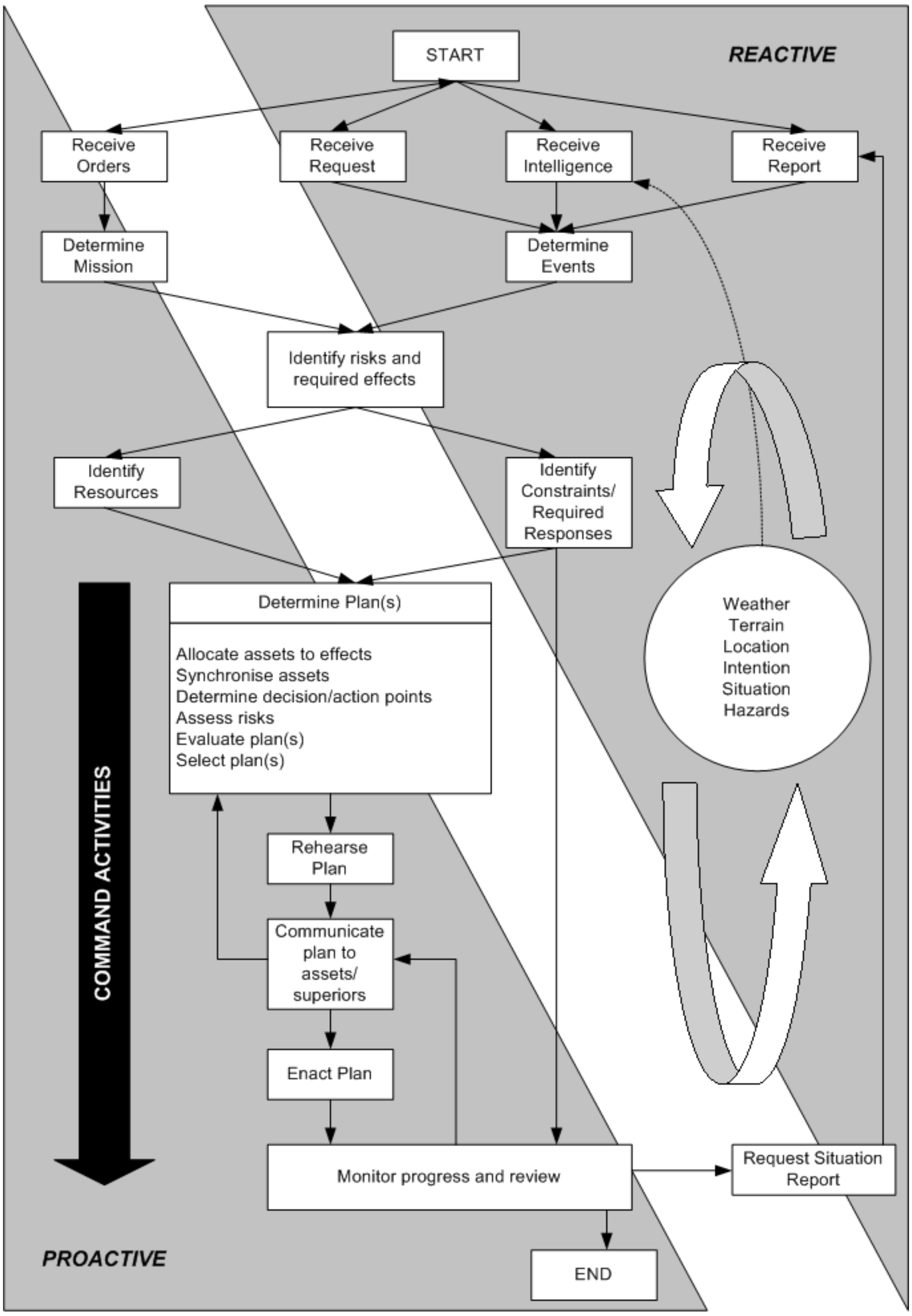


**Figure 3-1 - Generic process model of command and control.**

## 3.5 Network Enabled Capability

Network Enabled Capability invariably leads to a decentralisation of command, often right down to the level of personnel in the field. This suggests a fundamental shift in the way that command is performed. Command becomes much less rigid and prescriptive and rather more to do with setting goals and rules. In the field scenarios that have been examined such 'networks' are uncommon. The Fire Service (where the arriving commander who is closest to the incident will take charge of it) and perhaps to some extent Air Traffic Control (where individual controllers decide and negotiate amongst themselves) are two of the more cogent examples. How does the process model take account of NEC trends such as these? Clearly within the model the critical difference between a 'decentralised' and 'centralised' paradigm is the level at which "command" reaches from the top to the bottom. For example, under a centralised paradigm one can imagine 'command staff' identifying resources, whereas under a decentralised paradigm 'the man on the ground' may perform the same task. The key point appears to be that centralisation/decentralisation (i.e. NEC) does not appear to change the 'process' (model) merely the 'ownership' of the process elements.

## 3.6 Model Validity

As the process model is derived from the analysis of the three different domains, it should also explain the activities that go on in each of them.

In the military domain, such as the army, the scenario begins with orders from a higher level in the command chain. These orders form the mission that has to be turned into a plan. The plan starts as an outline of the required effects on a map. These effects have to be turned into alternative courses of action that would result in the required effects, taking any intelligence of what the enemy is doing into account. Each of the courses of action is evaluated in terms of the resources required and possible risks. The most optimal plan is selected, although alternative courses of action are kept in reserve. The plan is rehearsed though a war gaming exercise and then communicated to the assets in the field, who might have to undertake lower level planning to meet their mission. If all levels of the organisation are content with the plan then it is put into action. Regular field reports are requested and the effects of the changing situation are feedback to check if events are unfolding as anticipated. Deviations from planned events may require more planning to determine if changes in the course of action are required. Changes in the plan are feed up and down the command chain. When the mission objectives have been achieved, the scenario ends.

In the emergency services domain, such as the fire service, the scenario begins with an emergency call from a member of the public, or from another emergency service. As much information as possible about the event is recorded so that preliminary planning may be undertaken. Template plans for different types of event can be applied, such as ‘Domestic House Fire’, ‘Road Traffic Accident, and ‘Chemical Tanker Spillage’. This can operate as a means of guiding the initial responses to the emergency, and getting the right kind of vehicles, equipment and people to the event. If the event turns out to be as expected, much of the incident planning can be left to the field operative, such as determining the appropriate course of action and implementing the plan. Feedback to central command will confirm this. If the event turns out to be more extensive or different to that anticipated, then details of the scenario may have to be fed back to central command and the plan worked out there first. Then the chosen course of action will be communicated to the assets in the field and regular reports requested to check that the effects are as anticipated. If a new situation comes to light, then new courses of action may have to be planned for. More complex incidents may require multi-agency cooperation, which will also be managed from central command. When all danger is removed from the situation and the incident is cleaned up, the scenario may be ended.

In the civilian domain, such as ATC, the scenario begins with receipt of a call from an aircraft to request clearance to enter specified airspace. The mission objectives are overarching for all scenarios and is expressed as the safe and efficient transport of aircraft within and between sectors. There are rules for aircraft separation and set procedures if this separation is compromised. An aircraft may request a descent so that it can land at an airport. The ATCO has to assess the effects and risks, and determine a sequence of actions that will achieve the desired outcome. The exact set of actions will be affected by a number of factors, such as the workload of the ATCO, weather conditions, and number of aircraft and complexity of airspace. The ATCO will, in effect, mentally anticipate the likely outcome of the planned actions for the aircraft in question and those in the near airspace. The chosen course of action will be written onto the flight strip and communicated to the pilot. The rules require a read-back for every instruction given. The ATCO will monitor the progress of the aircraft, to check that the pilot is progressing as planned. If the aircraft does not appear to be making progress, the ATCO will request a situation update from the pilot. The scenario ends when the aircraft leaves the sector being monitored by the ATCO.

## 3.7 Summary

Thus it is possible to use this model to

- provide a common platform for reviewing command and control activities in disparate domains
- explaining some of the complexity of different command and control domains

and in so doing simplifying some of that complexity.

# 4 Conclusions

The generic process model of command and control developed in the course of the research appears to have some differences to the C4I specific models that were highlighted in the review of modelling literature. These individual models were (amongst others) Lawson's (1981) control theoretic model, Hollnagel's (1993) control modes model, Rasmussen (1974) and Vicente's (1999) decision ladder model, and Smalley's (2003) functional command and control model.

The model in Figure 3-1 contains all of the information processing activities within Lawson's model (shown in Figure 2-1), but with greater fidelity and relevance to command and control activities. There is no explicit representation of a 'desired state' in the newer mode; rather this is expressed in terms of 'required effects' which may be open to change in light of changes in the mission or events in the world. It is also worth noting that the 'desired state' remains static in Lawson's model, which is a weakness of the approach.

Whilst much of the command and control activities are implicitly listed in Hollnagel's model (shown in Figure 2-14) under 'goals', 'plans', 'execution' and 'events', the new model makes all of these activities explicit. The model does not indicate the effects of temporal change on the command and control activities. The model does however distinguish between the proactive 'command' activities and the reactive 'control' activities. It is probable that in higher tempo situations the command and control system is more likely to be in a reactive mode (i.e., the right-hand side of Figure 3-1). Conversely, it is probable that in lower tempo situations the command and control system is more likely to be in a proactive mode of operation (i.e., the left-hand side of Figure 3-1).

The new task based model does not attempt to distinguish between knowledge and system states in the way that Rasmussen and Vicente's decision ladder model does. The decision ladder model has the inherent flexibility of shortcuts (which the analyst is required to identify), which can be used to indicate different levels of expertise. This makes the decision ladder model a better explanation of individual behaviour, but less applicable to the description of the activities in a command and control system. The generic decision ladder model could be used to described any system, but it lacks the fidelity of Smalley's model for command and control. The decision ladder model does not attempt to distinguish between command and control activities, nor proactive and reactive behaviour.

As with Smalley's model (shown in Figure 2-10), the new model does distinguish between 'command' activities and 'control' activities, and between 'internal' and 'external' co-ordination. The new model does not attempt to distinguish between 'information processing' and 'decision support' functions, primarily as the purpose of the generic model was to remain independent of technology and allocation of function. As with Smalley's model, the newer model also has a high degree of fidelity with regard to the command and control activities. This was seen as a strength of both of the models. Whereas Smalley's model was based solely on military command and control the newer model was based on a broader domain base. Both models provide a basis for research investigations into command and control activities.

By conducting observations across several domains, the aim of this work has been to develop a generic framework for command and control. In order to progress this into a coherent theory the next phase of the work is to explore how the various domains perform operations within each heading and to ask how the removal or disruption of activity under a heading will impair performance within a given domain. An approach to this would be to employ the WESTT (workload, error, situational awareness, time and teamwork) tool.

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# ANNEX A Air Traffic Control

These are a selection of HTA's used to build the generic process model taxonomies above. The reader is directed in addition to the individual live C4I scenario reports.

## A.1 Air Traffic Control Approach Scenario

Task 0
TASK: Deal with aircraft (MNX881) traversing LATCC NWDEP sector en-route to landing at London Luton airport

Plan 0: WHILE 4 do 1 AND 2 THEN 3

- 1 Conduct control of aircraft (MNX881) through sector
-

Plan 1: do 1 THEN 2 and repeat as required
1.1 Formulate plan for MNX881's next manoeuvre
Plan 1.1: Do in order 1-3
1.1.1 Review traffic in sector
Plan 1.1.1: do 1 IF required do 2 AND 3
1.1.1.1 Scan radar
1.1.1.2 Review strips
1.1.1.3 Integrate information from radar & strips
1.1.2 Consider MNX881's flight plan
1.1.3 Decide on next instruction to give MNX881

1.2 Issue instructions to MNX881
Plan 1.2: Do in order 1-5
1.2.1 Issue instruction to descend to flight level one hundred
Plan 1.2.1: do 1 THEN 2 WHILE 4 AND 3
1.2.1.1 Use RT to issue instruction "Manx 881 descend flight level 100 expedite descent"
1.2.1.2 [Pilot] provide acknowledgement "descend flight level 100 expedite"
1.2.1.3 Monitor read-back of instruction
1.2.1.4 Update strip information
1.2.2 Issue instruction to descend to flight level nine zero
Plan 1.2.2: do 1 THEN 2 WHILE 4 AND 3
1.2.2.1 Use RT to issue instruction "Manx 881 descend flight level 90 expedite descent"
1.2.2.2 [Pilot] provide acknowledgement "descend flight level 90 expedite"
1.2.2.3 Monitor read-back of instruction
1.2.2.4 Update strip information
1.2.3 Issue instruction to descend to flight level eight zero
Plan 1.2.3: do 1 THEN 2 WHILE 4 AND 3
1.2.3.1 Use RT to issue instruction "Manx 881 descend flight level 80 expedite descent"

1.2.3.2 [Pilot] provide acknowledgement "descend flight level 80 expedite"
1.2.3.3 Monitor read-back of instruction
1.2.3.4 Update strip information

1.2.4 Issue instruction to descend to flight level seven zero
Plan 1.2.4: do 1 THEN 2 WHILE 4 AND 3

1.2.4.1 Use RT to issue instruction "Manx 881 descend flight level 70 expedite descent"
1.2.4.2 [Pilot] provide acknowledgement "descend flight level 80 expedite"
1.2.4.3 Monitor read-back of instruction
1.2.4.4 Update strip information

1.2.5 Issue instruction to descend to flight level six zero
Plan 1.2.5: do 1 THEN 2 WHILE 4 AND 3

1.2.5.1 Use RT to issue instruction "Manx 881 descend flight level 60 expedite descent"
1.2.5.2 [Pilot] provide acknowledgement "descend flight level 60 expedite"
1.2.5.3 Monitor read-back of instruction
1.2.5.4 Update strip information

2 Maintain traffic separation within sector
Plan 2: do 1 THEN 2 AND 3 IF required

2.1 Review traffic situation
Plan 2.1: do 1 and 2 in any order THEN 3

2.1.1 Review strips
2.1.2 Scan radar
2.1.3 Integrate information from strips and radar

2.2 Evaluate need for action
Plan 2.2: do in any order

2.2.1 Determine whether A/C in sector are adequately separated
2.2.2 Determine whether there are any potential conflicts in sector
2.2.3 Consider A/C flight plans

2.3 Decide action to be taken
Plan 2.3: do 1 to 5 in any order as required THEN 6 THEN 7

2.3.1 Review relevant A/C's flight plans
2.3.2 Integrate with other traffic in sector
2.3.3 Assess manoeuvre options
2.3.4 Decide whether one or more A/C require manoeuvring
2.3.5 Evaluate options
2.3.6 Continue transit of flight through sector according to original flight plan
2.3.7 Check chosen option does not lead to new conflict

3 Transfer MNX881 to Luton approach controller
Plan 3: do 1 to 3 in any order. IF aircraft is at agreed level AND aircraft is approaching planned exit point AND aircraft is not in conflict THEN 4 to 6 in order

3.1 Verify that MNX881 is at the agreed level

3.2 Verify that MNX881 is at or appoaching exit position

Verify that the MNX881 is not in conflict

3.4 Instruct MNX881 to contact next sector frequency
Plan 3.4: Do in order 1-2
3.4.1 Provide instruction "Manx 881 report your cleared level to Luton approach 129 decimal 5 5"
3.4.2 [Pilot] provide acknowledgement "1 2 9 5 5 with the cleared level Manx 881"

3.5 Mark strip with diagonal line through centre

3.6 Remove strip from active bay
Plan 3.6: Do in order 1-2
3.6.1 Remove paper strip from plastic holder
3.6.2 Pass strip and holder across desk to coordinator

4 Deal with other aircraft

## A.2 Air Traffic Control Departure Scenario

Task 0
TASK: Deal with aircraft (BMA9CW) traversing LATCC NWDEP sector after take-off from London Heathrow airport

Plan 0: WHILE 4 do 1 AND 2 THEN 3

1 Conduct control of BMA9CW through sector
Plan 1: do 1. IF 1 complete THEN 2 THEN 3. Repeat 2 THEN 3 as required

1.1 Accept BMA9CW into sector
Plan 1.1: Do in order 1-5
1.1.1 [Pilot] state to NWDEP controller "London Midland 9 Charlie whisky with you passing 2000 for 6000 feet on a Woburn departure"
1.1.2 Request that aircraft send identifying signal "Midland 9 Charlie Whisky roger squawk ident"
1.1.3 Provide information to aircraft "there is no ATC speed restriction"
1.1.4 [Pilot] provide acknowledgement "ident no speed Midland 9 Charlie Whisky"
1.1.5 Monitor pilot response
Plan 1.1.5: Do in order 1-3
1.1.5.1 Monitor radar display
1.1.5.2 Check CCTV display
1.1.5.3 Monitor pilot readback

1.2 Formulate plan for A/C's next manoeuvre
Plan 1.2: Do in order 1-3

1.2.1 Review traffic in sector
Plan 1.2.1: do 1 IF required do 2 AND 3
1.2.1.1 Scan radar
1.2.1.2 Review strips
1.2.1.3 Integrate information from radar & strips
1.2.2 Consider flight plan of aircraft
1.2.3 Decide on next instruction to give A/C

1.3 Issue instructions to BMA9CW
Plan 1.3: Do in order 1-4
1.3.1 Issue instruction to BMA9CW to leave marker on a set heading and to begin a climb to a specified flight level
Plan 1.3.1: do 1 THEN 2 WHILE 3 AND 4.
IF 3 AND 4 complete THEN do 5
1.3.1.1 Use RT to issue instruction "leave Burnham heading three one zero degrees expedite the climb to one four zero Midland nine Charlie Whisky"
1.3.1.2 [Pilot] provide acknowledgement "leave Burnham heading three one zero degrees expedite the climb to one four zero Midland nine Charlie Whisky"
1.3.1.3 Monitor read-back of instruction
1.3.1.4 Update strip information
1.3.1.5 Communicate with adjacent controller
Plan 1.3.1.5: do 1 AND 2
1.3.1.5.1 Use pen to indicate approximate path of aircraft on adjacent controllers screen
1.3.1.5.2 State to adjacent controller that "this one going up"
1.3.2 Issue first instruction for BMA9CW to change direction
Plan 1.3.2: do 1 THEN 2 WHILE 3 AND 4
1.3.2.1 Use RT to issue instruction "midland nine Charlie whisky turn right heading three two five"
1.3.2.2 [Pilot] provide acknowledgement "right heading three two five midland nine Charlie whisky"
1.3.2.3 Monitor read-back of instruction
1.3.2.4 Update strip information
1.3.3 Issue second instruction for BMA9CW to change direction
Plan 1.3.3: do 1 THEN 2 WHILE 3 AND 4
1.3.3.1 Use RT to issue instruction "midland nine Charlie whisky turn right heading three six zero degrees"
1.3.3.2 [Pilot] provide acknowledgement "right heading north midland nine Charlie whisky"
1.3.3.3 Monitor read-back of instruction
1.3.3.4 Update strip information
1.3.4 Issue third instruction for BMA9CW to change direction
Plan 1.3.4: do 1 THEN 2 WHILE 3 AND 4
1.3.4.1 Use RT to issue instruction "midland nine Charlie whisky turn right heading zero three zero degrees"
1.3.4.2 [Pilot] provide acknowledgement "right heading zero three zero degrees midland nine Charlie whisky"

1.3.4.3 Monitor read-back of instruction
1.3.4.4 Update strip information

2 Maintain traffic separation within sector
Plan 2: do 1 THEN 2 AND 3 IF required

2.1 Review traffic situation
Plan 2.1: do 1 OR 2 in any order THEN 3
2.1.1 Review strips
2.1.2 Scan radar
2.1.3 Integrate information from strips and radar

2.2 Evaluate need for action
Plan 2.2: do in any order
2.2.1 Determine whether A/C in sector are adequately separated
2.2.2 Determine whether there are any potential conflicts in sector
2.2.3 Consider A/C flight plans

2.3 Decide action to be taken
Plan 2.3: do 1 to 5 in any order as required THEN 6 THEN 7
2.3.1 Review relevant A/C's flight plans
2.3.2 Integrate with other traffic in sector
2.3.3 Assess manoeuvre options
2.3.4 Decide whether one or more A/C require manoeuvring
2.3.5 Evaluate options
2.3.6 Continue transit of flight through sector according to original flight plan
2.3.7 Check chosen option does not lead to new conflict

3 Transfer BMA9CW to next sector
Plan 3: do 1 to 3 in any order. IF aircraft is at agreed level AND aircraft is approaching planned exit point AND aircraft is not in conflict THEN 4 to 6 in order

3.1 Verify that BMA9CW is at the agreed level

3.2 Verify that BMA9CW is at or appoaching exit position

3.3 Verify that the BMA9CW is not in conflict

3.4 Instruct BMW9CW to contact next sector frequency
Plan 3.4: Do in order 1-2
3.4.1 Provide instruction "Midland nine Charlie Whisky report heading to London one three zero decimal nine two"
3.4.2 [Pilot] provide acknowledgement "heading now to one three zero decimal nine two Midland nine Charlie Whisky"

3.5 Mark strip with diagonal line through centre

3.6 Remove strip from active bay
Plan 3.6: do 1 AND 2 AND 3

3.6.1 Remove paper strip from plastic holder
3.6.2 Pass strip and holder across desk to coordinator
3.6.3 State to adjacent controller "straight in for that guy please"

4 Deal with other aircraft

## A.3 Air Traffic Control Holding Scenario

Task 0
TASK: Deal with aircraft (SHT7H) traversing and holding within LATCC BNN sector
Plan 0: WHILE 4 do 1 AND 2 THEN 3
1 Conduct control of SHT7H through sector BNN

Plan 1: do 1. IF 1 complete THEN 2 THEN 3. Repeat 2 THEN 3 as required

1.1 Accept SHT7H into sector
Plan 1.1: do 1 WHILE 2 do 3 AND 4 do in order 1-4
1.1.1 [Pilot] state to BNN controller "London shuttle seven hotel with you descending flight level one five zero heading one four five"
1.1.2 [Pilot] provide acknowledgement "Shuttle seven hotel London roger"
1.1.3 Monitor pilot response
1.1.4 Update flight strip
Plan 1.1.4: Do in order 1-2
1.1.4.1 Locate strip in active bay
1.1.4.2 Write on strip

1.2 Formulate plan for SHT7H's next manoeuvre
Plan 1.2: Do in order 1-3
1.2.1 Review traffic in sector
Plan 1.2.1: do 1 IF required do 2 AND/OR 3 THEN 4 as required
1.2.1.1 Scan radar
1.2.1.2 Review strips
1.2.1.3 Consult CCTV
1.2.1.4 Integrate information from radar, strips and CCTV
1.2.2 Consider flight plan of aircraft
1.2.3 Decide on next instruction to give A/C

1.3 Issue instructions to SHT7H
Plan 1.3: Do in order 1-3
1.3.1 Issue instruction to SHT7H to descend
Plan 1.3.1: do 1 THEN 2 WHILE 3 do 4 AND 5
1.3.1.1 Look at radar display
1.3.1.2 Use RT to issue instruction "Shuttle seven hotel descend flight level one four zero"
1.3.1.3 [Pilot] provide acknowledgement "descending flight level one four zero shuttle seven hotel"
1.3.1.4 Monitor read-back of instruction
1.3.1.5 Update strip information

1.3.2 Issue instruction for SHT7H to resume own navigation to set beacon
Plan 1.3.2: do 1. WHILE 1 do 2. WHILE 3 do 4 AND 5. do 6
1.3.2.1 Look at radar display
1.3.2.2 Use RT to issue instruction "Shuttle seven hotel resume own navigation direct to Bovingdon"
1.3.2.3 [Pilot] provide acknowledgement "own navigation direct to Bovingdon shuttle seven hotel"
1.3.2.4 Monitor read-back of instruction
1.3.2.5 Update strip information
1.3.2.6 Point to aircraft on adjacent controller's screen
1.3.3 Issue instructions for SHT7H to hold at Bovingdon
Plan 1.3.3: do 1 THEN 2 THEN 3.
WHILE 4 do 5 AND 6. do 7 when required THEN 8
1.3.3.1 Look at CCTV display
1.3.3.2 Communicate with adjacent controller
Plan 1.3.3.2: Do in order 1-2
1.3.3.2.1 Refer to adjacent controller's radar display
1.3.3.2.2 Highlight possible conflict
Plan 1.3.3.2.2: Do in order 1-3
1.3.3.2.2.1 [adjacent controller] point at aircraft on radar screen
1.3.3.2.2.2 [adjacent controller] state that aircraft is "locked on a heading going down to 9 now, go left"
1.3.3.2.2.3 State that "going to slow that Shuttle down"
1.3.3.3 Use RT to issue instruction "Shuttle seven hotel expect to hold at Bovingdon delay less than ten you can reduce now to holding speed"
1.3.3.4 [Pilot] provide acknowledgement "roger that's copied reduce to holding speed shuttle seven hotel"
1.3.3.5 Monitor read-back of instruction
1.3.3.6 Update strip information
1.3.3.7 Inform Heathrow controller what flight level aircraft will be leaving the stack
Plan 1.3.3.7: Do in order 1-2
1.3.3.7.1 Consult active flight strips
1.3.3.7.2 communicate with heathrow controller
Plan 1.3.3.7.2: Do in order 1-6
1.3.3.7.2.1 Establish contact with Heathrow controller by pressing touchscreen
1.3.3.7.2.2 [LHR Control] answer incoming phone call with 'Heathrow'
1.3.3.7.2.3 State to LHR controller "re-release at Bovingdon shuttle seven hotel at eleven"
1.3.3.7.2.4 [LHR Control] acknowledge information with "shuttle seven hotel at eleven
1.3.3.7.2.5 Conclude call by saying "cheers"
1.3.3.7.2.6 Press touch screen to terminate telephone call
1.3.3.8 Issue instructions for SHT7H to descend within the stack

Plan 1.3.3.8: Do in order 1-3

1.3.3.8.1 Issue instruction for SHT7H to descend to flight level one three zero

Plan 1.3.3.8.1: do 1. do 2 AND 3. do 4 AND 5. IF 5 satisfactory THEN 6

1.3.3.8.1.1 Look at radar display

1.3.3.8.1.2 Look at active strips

1.3.3.8.1.3 Issue instruction "Shuttle seven hotel descend flight level one three zero"

1.3.3.8.1.4 [pilot] acknowledge instruction by stating "descend flight level one three zero shuttle seven hotel

1.3.3.8.1.5 Monitor pilot read-back

1.3.3.8.1.6 Move strip to new position

1.3.3.8.2 Issue instruction for SHT7H to descend to flight level one two zero

Plan 1.3.3.8.2: do 1. do 2 AND 3. do 4 AND 5. IF 5 satisfactory THEN 6

1.3.3.8.2.1 Look at radar display

1.3.3.8.2.2 Look at active strips

1.3.3.8.2.3 Issue instruction "Shuttle seven hotel descend flight level one two zero"

1.3.3.8.2.4 [pilot] acknowledge instruction by stating "descend flight level one two zero shuttle seven hotel

1.3.3.8.2.5 Monitor pilot read-back

1.3.3.8.2.6 Move strip to new position

1.3.3.8.3 Issue instruction for SHT7H to descend to flight level one one zero

Plan 1.3.3.8.3: do 1. do 2 AND 3. do 4 AND 5. IF 5 satisfactory THEN 6

1.3.3.8.3.1 Look at radar display

1.3.3.8.3.2 Look at active strips

1.3.3.8.3.3 Issue instruction "Shuttle seven hotel descend flight level one one zero"

1.3.3.8.3.4 [pilot] acknowledge instruction by stating "descend flight level one one zero shuttle seven hotel

1.3.3.8.3.5 Monitor pilot read-back

1.3.3.8.3.6 Move strip to new position

2 Maintain traffic separation within sector

Plan 2: do 1 THEN 2 AND 3 IF required

2.1 Review traffic situation

Plan 2.1: do 1 OR 2 OR 3 in any order THEN 4 if required

2.1.1 Review strips

2.1.2 Scan radar

2.1.3 Consult CCTV

2.1.4 Integrate information from strips and radar

2.2 Evaluate need for action

Plan 2.2: do in any order
2.2.1 Determine whether A/C in sector are adequately separated
2.2.2 Determine whether there are any potential conflicts in sector
2.2.3 Consider A/C flight plans

2.3 Decide action to be taken
Plan 2.3: do 1 to 5 in any order as required THEN 6 THEN 7
2.3.1 Review relevant A/C's flight plans
2.3.2 Integrate with other traffic in sector
2.3.3 Assess manoeuvre options
2.3.4 Decide whether one or more A/C require manoeuvring
2.3.5 Evaluate options
2.3.6 Continue transit of flight through sector according to original flight plan
2.3.7 Check chosen option does not lead to new conflict

3 Hand over SHT7H to Heathrow Director
Plan 3: do 1 to 3 in any order. IF aircraft is at previously agreed level AND aircraft is approaching planned exit point AND aircraft is not in conflict THEN 4 to 6 in order

3.1 Use radar display to verify that SHT7H is at the agreed level

3.2 Use radar display to verify that SHT7H is at or appoaching exit position

3.3 Use radar display to verify that the SHT7H is not in conflict

3.4 Instruct SHT7L to contact the Heathrow director
Plan 3.4: do 1 THEN 2 AND 3
3.4.1 Provide instruction "Shuttle seven hotel contact Heathrow director one one nine decimal seven two"
3.4.2 [Pilot] provide acknowledgement "one one nine decimal seven two with Heathrow shuttle seven hotel"
3.4.3 Monitor pilot read-back

3.5 Mark strip with diagonal line through centre

3.6 Remove strip from active bay

4 Deal with other aircraft

## A.4 Air Traffic Control Overflight Scenario

Task 0
TASK: Deal with aircraft BRT424 overflying BNN sector
Plan 0: WHILE 2 AND 4 do 1 THEN 2
1 Conduct control of BRT424 through sector

Plan 1: do 1 THEN 2 THEN 3 do 4 THEN 5 until all instructions issued
1.1 Scan radars for next aircraft into sector

1.2 [Pilot] inform BNN controller "London British four two four on a frequency level at one hundred own navigation Cowley"

1.3 Respond to aircraft call onto frequency
Plan 1.3: Do in order 1-2
- 1.3.1 Formulate initial plan for aircraft entering sector
- Plan 1.3.1: do 1 to 3 as appropriate THEN 4
  - 1.3.1.1 Extract flight information from BRT424's strip
  - 1.3.1.2 Review strips from all other known aircraft
  - 1.3.1.3 Scan radar
  - 1.3.1.4 Integrate all information to determine safe plan for new aircraft
- 1.3.2 Accept aircraft BRT424 into sector
- Plan 1.3.2: do 1 WHILE 2. WHILE 4 do 3
  - 1.3.2.1 Issue instruction "British four two four continue present heading climb flight level one two zero"
  - 1.3.2.2 Update strip information
  - 1.3.2.3 Insert pending strip into active bay
  - 1.3.2.4 [Pilot] provide acknowledgement "continue present heading climb flight level one two zero British four two four"

1.4 Issue instructions to BRT424
Plan 1.4: Do in order 1-4
- 1.4.1 Issue first instruction for BRT424 to climb on present heading
- Plan 1.4.1: do 1 AND 4 THEN 2 THEN 3
  - 1.4.1.1 Use RT to issue instruction "British four two four turn right heading zero four zero degrees"
  - 1.4.1.2 [Pilot] provide acknowledgent "right heading zero four zero degrees British four two four"
  - 1.4.1.3 Monitor read-back of instruction
  - 1.4.1.4 Update strip information
- 1.4.2 Issue second instruction for BRT424 to climb on present heading
- Plan 1.4.2: do 1 AND 3 THEN 2 AND 4 THEN 5
  - 1.4.2.1 Use RT to issue instruction "British four two four climb flight level one four zero"
  - 1.4.2.2 [Pilot] provide acknowledgement "climb flight level one four zero British four two four"
  - 1.4.2.3 Update strip information
  - 1.4.2.4 Monitor read-back of instruction
  - 1.4.2.5 Communicate with adjacent controller
  - Plan 1.4.2.5: do 1 AND 2
    - 1.4.2.5.1 Point at adjacent controllers screen
    - 1.4.2.5.2 Inform adjacent controller that "he's going to come to Barkway then turning 15"
- 1.4.3 Contact Welyn controller to request additional height for BRT424
- Plan 1.4.3: Do in order 1-3
  - 1.4.3.1 press touchscreen control to activate voice comm. with Welyn controller
  - 1.4.3.2 Communicate with Welyn controller

Plan 1.4.3.2: Do in order 1-4
1.4.3.2.1 Welyn controller answer call with "Welyn"
1.4.3.2.2 Make request "just north of Hendon British four two four can I have higher please"
1.4.3.2.3 [Welyn] yes you can take flight level one eight zero
1.4.3.2.4 Conclude call with acknowledgement "one eight zero thank you"
1.4.3.3 Communicate with adjacent controller
Plan 1.4.3.3: do 1 AND 2 THEN 3
1.4.3.3.1 Point to aircraft on adjacent controllers radar display
1.4.3.3.2 State "going up to 18 on that heading"
1.4.3.3.3 Adjacent controller identify possible conflict "watch out for my shamrock just gone left - disregard"
1.4.4 Issue third instruction for BRT424 to climb on present heading
Plan 1.4.4: do 1 AND 3 WHILE 2 do 5 AND 4
1.4.4.1 Use RT to issue instruction "British four two four climb flight level one eight zero"
1.4.4.2 [Pilot] provide acknowledgement "climb flight level one eight zero British four two four"
1.4.4.3 Update strip information
1.4.4.4 Move strip up the active strip holder
1.4.4.5 Monitor read-back of instruction

1.5 Formulate plan for BRT424's next manoeuvre
Plan 1.5: do 1 AND 2 THEN 3
1.5.1 Review traffic in sector
Plan 1.5.1: do 1 OR 2 as required THEN 3 repeat as necessary
1.5.1.1 Scan radar
1.5.1.2 Review strips
1.5.1.3 Integrate information from radar and strips
1.5.2 Consider flight plan of aircraft
1.5.3 Decide on next instruction to give BRT424

2 Maintain traffic separation within sector
Plan 2: do 1 THEN 2 AND 3 IF required

2.1 Review traffic situation
Plan 2.1: do 1 OR 2 in any order THEN 3
2.1.1 Review strips
2.1.2 Scan radar
2.1.3 Integrate information from strips, radar and CCTV

2.2 Evaluate need for action
Plan 2.2: do in any order
2.2.1 Determine whether A/C in sector are adequately separated
2.2.2 Determine whether there are any potential conflicts in sector
2.2.3 Consider A/C flight plans

2.3 Decide action to be taken

Plan 2.3: do 1 to 5 in any order as required THEN 6 THEN 7

2.3.1 Review relevant A/C's flight plans
2.3.2 Integrate with other traffic in sector
2.3.3 Assess manoeuvre options
2.3.4 Decide whether one or more A/C require manoeuvring
2.3.5 Evaluate options
2.3.6 Continue transit of flight through sector according to original flight plan
2.3.7 Check chosen option does not lead to new conflict

3 Transfer BRT424 to next sector
Plan 3: do 1 to 3 in any order. IF aircraft is at agreed level AND aircraft is approaching planned exit position AND aircraft is not in conflict THEN 4 to 6 in order

3.1 Verify that BRT424 is cleared to agreed level

3.2 Verify that BRT424 is at or approaching exit position

3.3 Verify that BRT424 is not in conflict

3.4 Instruct BRT424 to contact next sector frequency
Plan 3.4: Do in order 1-2

3.4.1 Provide instruction "British four two four report your heading to London one three zero decimal nine two"
3.4.2 [Pilot] provide acknowledgement "heading to one three zero decimal nine two British four two four"

3.5 Mark strip with diagonal line through centre

3.6 Remove strip from active bay
Plan 3.6: do 1 AND 2 AND 3

3.6.1 Remove paper strip from plastic holder
3.6.2 Discard strip and holder
3.6.3 State "released"

4 Deal with other aircraft

## A.5 Air Traffic Control Shift Handover Scenario

Task 0
TASK: Conduct ATC Shift Hand Over
Plan 0: do 1 AND 2 WHILE 3

1 [in-coming controller] controller establish control of radar sector
Plan 1: do 1 THEN 2 WHILE 3. IF shared understanding not reached THEN 4 to 6 in order

1.1 Prepare to take control of radar sector
Plan 1.1: Do in order 1-2

1.1.1 Stand behind out-going controller
1.1.2 Make out-going controller aware of presence

1.2 Identify aircraft under sector's control
Plan 1.2: Do in order 1-3
1.2.1 Receive current controllers explanation of current traffic situation
1.2.2 Observe information pointed act or strips
1.2.3 Observe A/C pointed at on radar

1.3 Deal with information from adjacent controller
Plan 1.3: do 1 AND 2
1.3.1 [adjacent controller] point to A/C on radar display
1.3.2 [adjacent controller] relay height and heading information
1.4 Ask out-going controller any remaining questions
1.5 Acknowledge receipt of sector control
1.6 Plug in headset

2 [out-going controller] transfer control of radar sector at end of shift
Plan 2: Do in order 1-2

2.1 Deploy P.R.A.W.N.S. mneumonic
Plan 2.1: do 1 THEN 2. do 3, 4 ,5 if required. do 6
2.1.1 Inform controller of barometric pressure by stating that "pressure's high"
2.1.2 Inform controller of runway currently in use by stating that "easterlies all the way round"
2.1.3 Provide information about area sectors
Plan 2.1.3: do in any order as required
2.1.3.1 Inform controller that area sectors are banboxed or split
2.1.3.2 Inform controller of frequencies for banboxed/split sectors
2.1.3.3 Provide any relevent information concerning the handover of traffic/coordination between units etc.
2.1.4 Provide information on weather conditions
Plan 2.1.4: do in any order as required
2.1.4.1 Provide information about visibility
2.1.4.2 Provide information about wind
2.1.4.3 Provide weather avoidance information
2.1.5 Provide instructions on non-standard priority information
2.1.6 Use strips to point out aircraft under sector control
Plan 2.1.6: do 1 THEN 2 AND 3. repeat for all 5 aircraft currently in sector
2.1.6.1 Point out information on strips
2.1.6.2 Point out aircraft on radar
2.1.6.3 Explain current traffic situation to receiving controller

2.2 Acknowledge release of sector control

3 Deal with control of aircraft through sector

# ANNEX B Fire Service

These are a selection of HTA's used to build the generic process model taxonomies above. The reader is directed in addition to the individual live C4I scenario reports.

## B.1 Fire Service Chemical Incident

Task 0.

Task: Station Officer (SO) to deal with fire incident

Context: You have been called to a 6 pump chemical fire at local chemical manufacturers. It is situated on a 4 acre site within a residential area directly off a major thoroughfare and is well known for AFA's but there is no history of fires or chemical incidents. An industrial fire brigade at the site consists of 4 personnel and one Land Rover chemical unit. Their role is mainly to deal with minor spillages and any small fires on the 24 hour site and to provide support to the Local Authority brigade at larger incidents.

Upon arrival you notice lots of workers out on the pavement either side of the entrance. People are still evacuating (calmly) the site as you park alongside the PDA (3 pumps, Emergency Support Unit and Foam Tender) adjacent to the Admin block. You can see at the centre of the site a large plume of grey/black smoke being punctuated violently by fireballs pouring out of the chemical store adjacent to the manufacturing block.

Performance: Progress and resource incident safely

Plan 0.
do in order

1. deal with pre-attendance phase of incident
Plan 1 - do 1 THEN 2 THEN 3 AND 4

1.1 [SO] respond to incoming pager message from fire control
1.2 [SO] use UHF radio in vehicle to listen to developing situation
(note: some brigades have laptops or GIS mapping in cars so that SO can receive more detailed situational updates)
1.3 [SO] drive to incident
1.4 [SO] form initial plans of action

2. deal with initial phase of incident

Plan 2 - do in order

2.1 arrive at scene of incident
Plan 2.1 - do 1 THEN 2 OR 3 OR 4
2.1.1 [SO] use UHF radio to call fire control and book on 'in attendance'
2.1.2 [SO] find command tender
2.1.3 [SO] find crew manager [CM]
2.1.4 [SO] find other crew member(s)

2.2 [SO] perform initial incident assessment
Plan 2.2 - do 1 AND 2 AND 3 THEN 4 THEN 5 THEN 6 THEN 7
2.2.1 [SO] gather information from CM
Plan 2.2.1 - do 1 AND 2
2.2.1.1 [SO] ask CM about possible chemicals involved
2.2.1.2 gather information on site evacuation plan
2.2.1.3 [SO] gather from CM information on topology of site and surrounding area
Plan 2.2.1.3 - do in any order
2.2.1.3.1 gather information on site access
2.2.1.3.2 gather information on site layout
2.2.1.3.3 gather information on wider area
2.2.1.3.4 gather information on prevailing wind direction
2.2.1.3.5 gather information on land gradient (run-off)
2.2.1.3.6 gather information on site drainage
2.2.1.3.7 gather information on proximity of hazard to public
2.2.2 [SO] establish status of current resources
Plan 2.2.2 - do in any order
2.2.2.1 gather information on number of pumps present
2.2.2.2 gather information on number of pumps iminent
2.2.2.3 gather information on water supply
2.2.2.4 gather information on pump/crew activities/locations
2.2.2.5 gather information on involvement of other emergency services
Plan 2.2.2.5 - do in any order
2.2.2.5.1 gather information on police involvement
2.2.2.5.2 gather information on ambulance service involvement
2.2.2.5.3 gather information on number and role of industrial fire fighters
2.2.3 [SO] establish safety/risk of hazard area
Plan 2.2.3 - do in any order
2.2.3.1 consider structural integrity of affected buildings
2.2.3.2 consider possible risk of explosion
2.2.3.3 consider access to/from affected area
2.2.3.4 consider risk to wider area/public
2.2.4 [SO] perform initial risk assessment
2.2.5 [SO] record initial risk assessment
2.2.6 [SO] formally assume control of incident
Plan 2.2.6 - do in order
2.2.6.1 [SO] communicate to CM that control has been passed to SO
[CM] use UHF radio to inform fire control that command

has passed to SO
[CM] use tender marker board to communicate change of
control to firefighters
2.2.7 [SO] establish status of current activities
Plan 2.2.7 - do 1 AND 2
2.2.7.1 establish status of site evacuation
Plan 2.2.7.1 - do in any order
2.2.7.1.1 establish what buildings have been evacuated
2.2.7.1.2 establish how many evacuees
2.2.7.1.3 establish location of muster point
2.2.7.1.4 calculate number of unaccounted/missing persons
2.2.7.2 establish status of site information
Plan 2.2.7.2 - do in order
2.2.7.2.1 determine location of site manager
Plan 2.2.7.2.1 - do in any order
2.2.7.2.1.1 [SO] get CM to ask site fire team
2.2.7.2.1.2 [SO] get CM to ask evacuees who was evacuating them
2.2.7.2.1.3 [CM] requests firefighters to ask evacuees who is evacuating them
2.2.7.2.1.4 [SO] establish number of employees
2.2.7.2.1.5 [SO] establish number of fatalities/ industries
2.2.7.2.2 [SO] instruct CM to organise a quick visual reconnaisance of site
2.2.7.2.3 [CM] nominate a Junior Officer [JO] to carry out quick visual reconnaissance

2.3 [SO] formulate initial plan of action
Plan 2.3 - do in any order
2.3.1 use risk assessment
2.3.2 consider command mode
2.3.3 consider tactical mode
2.3.4 assess whether ESU is required

2.4 [SO] communicate plan to evacuate site
Plan 2.4 - do in order
2.4.1 [SO] communicate defensive mode
Plan 2.4.1 - do in order
2.4.1.1 [SO] use marker board or lights on control tender
2.4.1.2 [SO] instruct CM to inform control of incident status (using UHF radio)
2.4.1.3 [SO] instruct CM to use VHF radio to inform firefighters of defensive mode
2.4.2 [SO] communicate plan to personnel
Plan 2.4.2 - do in order
2.4.2.1 [SO] liaise with CM
2.4.2.2 [SO] use UHF radio to inform control of plan
2.4.2.3 [Fire Control] inform police control of plan

2.5 [SO] carry out plan (site evacuation)
Plan 2.5 - do in order
2.5.1 [SO] instruct CM to withdraw personnel from site
2.5.2 [SO] instruct Police to advise affected households of hazard
2.5.3 [SO] contact fire control and seek confirmation of ambulance attendance
2.5.4 [SO] instruct CM to carry out site evacuation
2.5.5 [CM] instruct JO's to carry out site evacuation

3. [SO] deal with fire spread phase of incident
Plan - do in order

3.1 [SO] formulate plan for fire spread
Plan 3.1 - do in order
3.1.1 assess risk of explosion
3.1.2 consider allowing chemical store to burn out

3.2 [SO] record risk assessment

3.3 [SO] carry out plan for fire spread
Plan 3.3 - do in order
3.3.1 protect surrounding area (isolate chemical store)
Plan 3.3.1 - do 1 AND 2
[SO] instuct CM to organise spraying of chemical
manufacuring building and open solvent store
Plan 3.3.1.1 - do 1 AND 2 AND 3
3.3.1.1.1 [CM] to organise branches to be put on existing lines
3.3.1.1.2 [CM] to organise the use of spray plates
3.3.1.1.3 [CM] to organise deployment of monitors
3.3.1.2 [CM] contain contaminated water run-off
Plan 3.3.1.2 - do 1. IF intercepting drains overflowing THEN 2
3.3.1.2.1 monitor state of intercepting drains
3.3.1.2.2 [CM] deploy containment measures
3.3.2 [SO] receive regular updates on situation from CM via VHF radio
3.3.3 [SO] informs fire control (via UHF radio) of need for aerial appliance

4. [SO] deal with presence of cyanide at incident
Plan 4 - do in order

4.1 [SO] perform immediate crew protection tasks
Plan 4.1 - do in order
4.1.1 inform crew manager of presence of cyanide
4.1.2 inform fire control of presence of cyanide
4.1.3 stop any offensive tactics

4.2 [SO] gather further information for involvement of Cyanide in fire
Plan 4.2 - do in order
4.2.1 assess likelihood of cyanide being present in smoke plume

4.2.2 assess direction of smoke plume
4.2.3 consult specialist chemical advice
Plan 4.2.3 - do 1 THEN 2 AND/OR 3 AND/or 4
4.2.3.1 [SO] contact fire control (via UHF radio)
4.2.3.2 [Fire Control] contact Chemdata
4.2.3.3 [Fire Control] contact Chemsafe
4.2.3.4 [Fire Control] contact Hazmat officer

4.3 [SO] formulate plan for involvement of Cyanide in fire

4.4 [SO] carry out plan for involvement of Cyanide in fire
Plan 4.4 - do in order
4.4.1 [SO] change status of incident to Major Incident
Plan 4.4.1 - do in order
4.4.1.1 contact fire control and inform them of major incident status
4.4.1.2 [Fire Control] despatch resources to scene (according to Local Authority plans)
4.4.1.3 [SO] communicate status change around site
Plan 4.4.1.3 - do 1 AND 2
4.4.1.3.1 [SO] communicate status change via VHF radio
4.4.1.3.2 [SO] use marker boards on control tender
4.4.1.4 [SO] carry out risk assessment
4.4.1.5 [SO] record risk assessment
4.4.2 [SO & Police] carry out hazard mitigation measures for nearby properties
Plan 4.4.2 - do in order
[SO] contact control on UHF radio and request immediate police assistance in public safety measures
4.4.2.2 [Fire Control] relay message to police control
4.4.2.3 [Police Control] relay message to police incident commander
4.4.2.4 [Police] organise muster point and evacuation facilities
4.4.2.5 [Police] use PA to provide instructions to affected householders
4.4.3 [SO] contact control (UHF radio) and request Hazmat officer
4.4.4 [SO] instruct CM to widen outer cordon
4.4.5 [SO] instruct CM to establish decontamination area
4.4.6 [SO] wait for further resources

5. [SO] resource and manage incident to conclusion
Plan 5 - do 1 AND 2. Upon arrival of Group Manager/Incident Commaner to Scene do 3

5.1 [SO] establish command structure as resources become available
Plan 5.1 - do 1 AND 2
5.1.1 [SO] assign roles within command structure
5.1.2 [SO] assign functions to roles

5.2 implement plan to manage incident to conclusion
Plan 5.2 - WHILE 2, do 1 THEN 3 AND 4, THEN 5 THEN 6 THEN 7 AND 9. do 8.
5.2.1 [SO] sectorise the incident (geographical)
5.2.2 [SO] allow chemical store to burn itself out

5.2.3 [SO] instruct relevant sector to protect chemical manufacturing building
5.2.4 [SO] instruct relevant sector to search manufacturing building
5.2.5 [SO] inform site of changes to mode and tactics
Plan 5.2.5 - do 1 AND 2
5.2.5.1 [SO] communicate status change via VHF radio
5.2.5.2 [SO] use marker boards on control tender
5.2.6 [SO] inform control of changes to mode and tactics
5.2.7 [SO] deal with rescue situation
5.2.8 [SO] use reduced night watch to let store burn out
5.2.9 [SO] perform decontamination activities

5.3 [SO] hand over control to Group Manager (Group Manager becomes Incident Commander)

## B.2 Fire Service Road Traffic Accident Scenario

Task 0

Task: Respond to RTA

Context: Friday 16th January 09:00. Weather: Cold - remnants of overnight frost, very light northerly wind 3-5 knots. Tanker, heading south west carrying 20,000 litres of Methyltrichlorosilane is involved in a collision with a car at the junction of the A44 and A361 in Chipping Norton. The trailer comes to rest at the top of the hill straddling the junction trapping the occupants of the car, and injuring the lorry driver. The tanker's valve group is damaged.

Performance: Resource and progress incident safely

Plan 0
do in order

09:00
1. initiate response to incident
Plan 1 - do 1 THEN 2

1.1 [member of the public] contact Local Authority Control via 999 (on mobile) and report RTA

1.2 Mobilise resources
Plan 1.2 - do in order
1.2.1 Mobilise local resources
Plan 1.2.1 - do in order
1.2.1.1 [Local Authority Control] instruct Chipping Norton fire station to mobilise 2 tenders [bell]
1.2.1.2 [Chipping Norton Fire Station] contact retained fire fighters

1.2.1.3 [Retained Firefighters] receive message to attend incident on pager
1.2.1.4 [Retained Firefighters] proceed to fire station
1.2.1.5 [Retained Firefighters] dispatch to RTA from fire station

1.2.2 Mobilise special resources
Plan 1.2.2 - do in any order

1.2.2.1 [Local Authority Control] request attendance of RTA/ Rescue unit from Oxford
1.2.2.2 [Local Authority Control] request attendance of environmental pump from Oxford
1.2.2.3 [Local Authority Control] request attendance of support pump from Oxford
1.2.2.4 [Local Authority Control] notify HMEPO
1.2.2.5 [Local Authority Control] notify DO
1.2.2.6 [Local Authority Control] inform Hazmat officer

1.2.3 Mobilise Watch Manager
Plan 1.2.3 - do in order

1.2.3.1 [Local Authority Control] contact Watch Manager (on pager)
1.2.3.2 [Watch Manager] drive to incident

1.2.4 Obtain responses from resources
Plan 1.2.4 - do in order

1.2.4.1 [Environmental Pump] contact Local Authority Control and book mobile
1.2.4.2 [Support Pump] contact Local Authority Control and book mobile
1.2.4.3 [RTA/Rescue Unit] contact Local authority Control and book mobile
1.2.4.4 [Watch Manager] contact Local Authority Control and book mobile
1.2.4.5 [Environmental Pump/Support Pump/RTA unit/Watch Manager] advise local authority control of 25/30 minute ETA

09:04 Clear liquid beginning to run out of the damaged valve group. Some bystanders trying to assist with the injured driver and trapped occupants of the car

Drivers of the queing traffic from all directions are starting to get impatient and are curious as to what is causing the hold up. People are getting out of their cars.

2. [Watch Manager] deal with pre-attendance phase of incident
Plan 2 - do 1 AND 2 AND 3 THEN 4 AND 5 AND 6

2.1 deal with traffic conjestion
Plan 2.1 - do 1. do 2 AND 2 interchangeably

2.1.1 [Watch Manager] contact control requesting information on alternative routes
2.1.2 [Local Authority Control] provide general route information and advise that alternative routes unlikely to shorten ETA
2.1.3 [Incident Commander (Chipping Norton Station Officer)] contact

control on UHF radio, make following report, "heavy congestion...experiencing difficulty in reaching incident".

2.2 request pre-attendance information (UHF radio)
Plan 2.2 - do in any order
2.2.1 [Watch Manager] ask Local Authority Control for contacts for Tanker company
2.2.2 [Watch Manager] ask Local Authority Control for wind direction
2.2.3 [Watch Manager] ask Local Authority Control whether tanker is ruptured
2.2.4 [Watch Manager] ask Local Authority Control who/what has been mobilised
2.2.5 [Watch Manager] ask Local Authority Control to be put through to Officer in Charge
2.2.6 [Watch Manager] ask Local Authority Control to confirm attendance of ambulance
2.2.7 [Watch Manager] ask Local Authority Control to contact Police

2.3 provide requested information (UHF radio)
Plan 2.3 - do 1 to 5 in response to tasks 2.2.1 to 7. do 6 when required
2.3.1 [Local Authority Control] inform Watch Manager that tanker information unknown at present
2.3.2 [Local Authority Control] inform Watch Manager that wind direction yet to be assertained
2.3.3 [Local Authority Control] inform Watch Manager that tanker is not ruptured, but is leaking
2.3.4 [Local Authority Control] inform Watch Manager that 2 tenders from Chipping Norton have been mobilised
2.3.5 [Local Authority Control] inform Watch Manager that ambulance and police have been notified
2.3.6 [Local Authority Control] inform Watch Manager that communication will be interrupted due to volume of other calls

2.4 provide situational updates
Plan 2.4 - do 1 AND 2
2.4.1 Local Authority Control provide situational updates
Plan 2.4.1 - do in order
2.4.1.1 [Local Authority Control] inform Watch Manager that environmental pump booked mobile at 09:03
2.4.1.2 [Local Authority Control] inform Watch Manager that both pumps from Chipping Norton booked in attendance at 09:17
2.4.1.3 [Local Authority Control] inform Watch Manager that Oxford pumps extending ETA by 10 mins due to heavy traffic
2.4.1.4 [Local Authority Control] inform Watch Manager that Hazchem placard has been identified as 4WE: Dry Agent - Contain - CPC
2.4.1.5 [Local Authority Control] inform Watch Manager that

HMEPO and DO are mobile
2.4.1.6 [Local Authority Control] send fax "Summary Chemical Data" to on-scene command tender
2.4.1.7 [Local Authority Control] inform Watch Manager that Chipping Norton crew are pulling back
2.4.2 Incident Commander provide situational updates
Plan 2.4.2 - do in order
2.4.2.1 [Incident Commander] make informative message on UHF radio, "RTA at the junction of A44 & A361 in Chipping Norton. 1 chemical tanker and 1 motor vehicle involved. 2 persons trapped"
2.4.2.2 [Incident Commander] make assistance message on UHF radio, "make pumps 6, ambulances 2"
2.4.2.3 [Incident Commander] inform Local Authority Control that Hazchem placard has been identified as 4WE: Dry Agent - Contain - CPC
2.4.2.4 [Incident Commander] contact Local Authority Control on UHF radio and "Request chemical data on substance UN no. 1250"

2.5 mobilise further resources
Plan 2.5 - do in any order
2.5.1 [Local Authority Control] mobilise 1 pump from Hook Norton (using bell)
2.5.2 [Local Authority Control] mobilise 1 pump from Charlbury (using bell)
2.5.3 [Local Authority Control] mobilise 1 pump from Moreton-in-Marsh (using bell)
2.5.4 [Local Authority Control] mobilise 1 pump from Stow (using bell)
2.5.5 [Oxford Control] mobilise Hazmat officer
Plan 2.5.5 - do in order
2.5.5.1 [Oxford Control] contact Hazmat Officer (using pager)
2.5.5.1 [Hazmat Officer] advise control ETA 30 minutes

2.6 [Watch Manager] request Oxford Control to enable talk through to on-scene pump
Plan 2.6 - do 1 AND 2 interchangeably
2.6.1 [Watch Manager] request information from on-scene crew (pump operator responds)
Plan 2.6.1 - do in order
2.6.1.1 [Watch Manager] ask pump operator status of casualities
2.6.1.2 [Watch Manager] ask pump operator how casualities are trapped
2.6.1.3 [Watch Manager] ask pump operator about status of cordons
2.6.2 [pump operator] provide requested information
Plan 2.6.2 - do 1 THEN 2
2.6.2.1 [Pump Operator] confirm to Watch Manager that 2 persons are trapped
2.6.2.2 [Pump Operator] inform Watch Manager that current position provides limited visibility of scene

09:30 Watch Manager arrives at scene

A quantity of the spilled liquid is running down the hill of the A44. Leak is now definitive, rate of approx 60 litres per minute. Small pools starting to form at the bottom of the hill.

Some of the bystanders are now experiencing varying degrees of skin/eye irritation. Panic is setting in, people are trying to run/drive away. Skin and eye irritation now being experienced by the occupants of the vehicles at the bottom of the hill. Some of the vehicles are being abandoned after failed attempts to turn around.

3. Deal with initial phase of attendance at scene
Plan 3 - do in order

3.1 [Watch Manager] use UHF radio to book in attendance

3.2 [Watch Manager] don fire kit

3.3 gather information
Plan 3.3 - do in order
3.3.1 liaise with Incident Commander
Plan 3.3.1 - do in order
3.3.1.1 locate Incident Commander
inform Incident Commander that [Watch Manager] is present and reviewing incident (but not yet assuming control)
3.3.1.3 request situation report from Incident Commander
Plan 3.3.1.3 - do 1 AND 2 interchangeably
3.3.1.3.1 [Incident Commander] inform Watch Manager of initial actions
Plan 3.3.1.3.1 - do in order
3.3.1.3.1.1 [Incident Commander] inform Watch Manager that four personnel were sent in wearing BA, 2 to the person trapped by the legs in the car and 2 to the tanker driver
3.3.1.3.1.2 [Incident Commander] inform Watch Manager that an exclusion zone was attempted but difficult due to lack of resources and panic
3.3.1.3.1.3 [Incident Commander] inform Watch Manager that Sub was tasked with gathering information on the leaking product
3.3.1.3.1.4 [Incident Commander] inform Watch Manager chem-data was requested on 1250
3.3.1.3.2 [Incident Commander] inform Watch Manager of initial situation status
Plan 3.3.1.3.2 - do in order
3.3.1.3.2.1 [Incident Commander] inform Watch Manager that car driver requires hydraulic tools, and that tanker driver is concussed and still in cab
3.3.1.3.2.2 [Incident Commander] inform Watch

Manager that some of the chemical has pooled near the scene, the rest is running down the hill
3.3.1.3.2.3 [Incident Commander] inform Watch Manager that a number of bystanders are seeking help with skin burns
3.3.1.3.2.4 [Incident Commander] inform Watch Manager that 2 of the 4 BA wearers are suffering from severe burns to the neck and wrists
3.3.1.3.2.5 [Incident Commander] inform Watch Manager that Police are currently standing off
3.3.1.3.3 [Watch Manager] request command board
3.3.1.3.4 [Watch Manager] request message log
3.3.1.3.5 [Watch Manager] ask Incident Commander if there is anything else to relate
3.3.1.3.6 [Incident Commander] inform Watch Manager that strategy has been focused on keeping people back from the incident and gathering information
3.3.2 [Local Authority Control] send full Chemdata fax to command tender
3.3.3 [Watch Manager] consult full Chemdata fax

3.4 perform risk assessment
Plan 3.4 - do in order
3.4.1 [Watch Manager] perform activity review
Plan 3.4.1 - do in any order
3.4.1.1 perform quick visual check of general scene
3.4.1.2 check for casualties
3.4.1.3 check for people experiencing chemical related problems
3.4.2 [Watch Manager] assess explosion risk (chemical has created flammable atmosphere)
3.4.3 [Watch Manager] record risk assessment

3.5 [Watch Manager] formally assume control of incident from current Incident Commander

09:35 Incident Commander now reverts back to their normal role of Crew Manager; Watch Manager now reverts to Incident Commander

4. Implement and resource plan to prevent further deterioration of incident
Plan 4 - do 1 AND 2 AND 3 THEN 4 AND 5 AND 6 AND 7

4.1 deal with arrival of further resources
Plan 4.1 - do in order of arrival
4.1.1 [Environmental Pump] contact Local Authority Control and book in attendance
4.1.2 [Support Pump] contact Local Authority Control and book in attendance

4.2 [Incident Commander] scale up incident

Plan 4.2 - do in order

4.2.1 [Incident Commander] declare Major Incident Status

Plan 4.2.1 - do in order

4.2.1.1 [Incident Commander] contact Local Authority Control on UHF radio and inform them that the scene has been declared a major incident

4.2.1.2 [Incident Commander] communicate status around scene

Plan 4.2.1.2 - do 1 AND/OR 2

4.2.1.2.1 communicate major incident using marker board

4.2.1.2.2 communicate major incident by putting out an Informative Message on VHF radio

4.2.2 [Incident Commander] instruct Local Authority Control to put out a local alert

4.2.3 [Incident Commander] instruct Local Authority Control to put Police and Ambulance in Silver Command

4.2.4 [Local Authority Control] bring local alert plans into action

Plan 4.2.4 - do 5, THEN 1 to 4

4.2.4.1 [Local Authority Control] request attendance of environment agency

4.2.4.2 [Local Authority Control] inform Chipping Norton hospital of incident

4.2.4.3 [Local Authority Control] inform Chipping Norton hospital of preparations for evacuation

4.2.4.4 [Local Authority Control] inform Chipping Norton Secondary school of preparations for evacuation

4.2.4.5 [Local Authority Control] mobilise resources for major incident in line with county plans

4.3 [Incident Commander] set up command centre

Plan 4.3 - do in order

4.3.1 [Incident Commander] coordinate command activities

Plan 4.3.1 - do in order

4.3.1.1 [Incident Commander] nominate command tender

4.3.1.2 [Incident Commander] co-ordinate radio channels

4.3.1.3 [Incident Commander] set up contact points

4.3.1.4 [Incident Commander] send Informative Message on VHF radio detailing command post and radio channels

4.3.1.5 [Incident Commander] use marker board to detail command post and radio channels

4.3.1.6 [Incident Commander] contact Oxford Control on UHF radio and request information on make up of impending appliances

4.3.2 set up command structure

Plan 4.3.2 - do in order

4.3.2.1 [Incident Commander] assign roles to personnel

4.3.2.2 [Incident Commander] assign functions to roles

4.3.2.3 [Incident Commander] sectorise incident

Plan 4.3.2.3 - do in order

4.3.2.3.1 [Incident Commander] nominate sector 1 as RTA zone

4.3.2.3.2 [Incident Commander] nominate sector 2 as Environmental zone
4.3.2.3.3 [Incident Commander] nominate sector 3 as Evacuation zone
4.3.2.3.4 [Incident Commander] nominate sector 4 as Evacuation zone
4.3.2.3.5 [Incident Commander] nominate general sector for decontamination zone support
4.3.2.4 [Inicdent Commander] consider crew reliefs
4.3.3 [Incident Commander] perform risk assessment for plan
4.3.4 [Incident Commander] record risk assessment for plan
4.3.5 [Incident Commander] change operational mode
Plan 4.3.5 - do in order
4.3.5.1 [Incident Commander] set mode to offensive
4.3.5.2 [Incident Commander] communicate mode change
Plan 4.3.5.2 - do in order
4.3.5.2.1 [Incident Commander] contact Local Authority Control and inform them of mode change
4.3.5.2.2 [Incident Commander] use VHF radio to communicate mode change around scene
4.3.5.2.3 [Incident Commander] use marker board/lights on command tender

4.4 release trapped drivers
Plan 4.4 - do in order
4.4.1 [Incident Commander] request heavy cutting equipment to be brought to sector 1
Plan 4.4.1 do in any order
4.4.1.1 [Incident Commander] request combi tool
4.4.1.2 [Incident Commander] request air tools (to avoid sparks)
4.4.2 [Incident Commander] relay brief chemical safety information using VHF radio
4.4.3 [Incident Commander] Instuct Crew Manager to send 2 Junior Officers equipped with appropriate PPE to release car driver
4.4.4 [Incident Commander] Instuct Crew Manager to send 2 Junior Officers equipped with appropriate PPE to release lorry driver

4.5 plug chemical leak
Plan 4.5 - do in order
4.5.1 [Incident Commander] instruct Crew Manager to send 2 Junior Officers equipped with appropriate PPE to tackle valve group
Plan 4.5.1 - do in order
4.5.1.1 [Junior Officers] attempt to stem flow from valve group
4.5.1.2 [Junior Officers] assess feasibility of decanting remaining chemical
4.5.1.3 [Junior Officers] use VHF radio to request car to be moved away from scene
4.5.2 [Incident Commander] use VHF radio to request details of tanker company

4.5.3 [Incident Commander] instruct Local Authority Control to request attendance of an empty tanker to decant remaining chemical

4.6 ensure public safety
Plan 4.6 - do 1 AND 2 AND 3
4.6.1 set up and maintain inner cordon
Plan 4.6.1 - do in order
4.6.1.1 [Incident Commander] use UHF radio to contact Local Authority Control and request Police help in setting up 40m inner cordon
4.6.1.2 [Incident Commander] use UHF radio to contact Local Authority Control and request that Police maintain 40m inner cordon until instructed otherwise
4.6.2 [Police] close town centre to all incoming traffic
Plan 4.6.2 - do 1 AND 2 AND 3
4.6.2.1 [Police] set up road block on A44 on western outskirts of Chipping Norton
4.6.2.2 [Police] set up road block on A44 on easter outskirts of Chipping Norton
4.6.2.3 [Police] set up further road blocks on B4450, A361, B4026
4.6.3 [Police] patrol local area and use PA to tell people to stay indoors with windows closed

4.7 deal with chemical
Plan 4.7 - do 1 to 4 AND 6 AND 7 AND 5
4.7.1 [Incident Commander] instruct Crew Manager to set up decontamination zone in support of sectors 3 and 4
4.7.2 [Incident Commander] provide decontamination safety brief
4.7.3 [Incident Commander] instruct Crew Manager to set up dry agent zone
4.7.4 [Junior Officers] deploy dry agent to accident scene
4.7.5 [Incident Commander] consider availability of other useful decontamination materials such as builders merchants and cement
4.7.6 [Junior Officers] seal the road with chemical booms
4.7.7 [Junior Officers] use decontamination facilities to direct spill onto available open ground

09:53 DO arrives on scene

5. [Incident Commander] transfer control to DO

6. [DO] implement, resource and modify plan to satisfactory conclusion

# ANNEX C Railway

These are a selection of HTA's used to build the generic process model taxonomies above. The reader is directed in addition to the individual live C4I scenario reports.

## C.1 Railway Emergency Maintenance

Task 0.

Task: Arrange emergency protection measures needed to ensure trains do not enter area where emergency engineering works are required.

Context: An undefined stretch/area of track

Performance: Progress and resource protection safely and efficiently according to applicable railway Group Standards

Personnel: S = Signaller
COSS = Controller Of Site Safety

Plan 0 - do in order

1. [COSS] agree arrangements with the Network Rail area operations manager

2. [COSS] detail request for line protection with relevant signaller
Plan 2 - do in order

2.1 [COSS] initiate communication with S
Plan 2.1 - do in order
2.1.1 [COSS] call signaller using signal post telephone (SPT)
2.1.2 [S] state box and panel number
2.1.3 [COSS] state name, job title and location

2.2 [COSS] detail request to [S]
Plan 2.2 - do in order
2.2.1 [COSS] state the location and type of work that is required
2.2.2 [COSS] state that it is an emergency

3. [S] ensure that potentially affected lines are clear of all trains
Plan 2.3.4 - do in order
3.1 [S] study signal dislays for existing train movements

3.2 [S] consider planned maintenance work using WON as appropriate

3.3 [S] consult timetable system

4. [S] accept/reject request
Plan 4 - IF the work to be protected arises from an incident, fault or failure that is affecting the normal passage of trains AND/OR personnel are needed to attend to deal with the situation AND/OR no other procedures are suitable AND the signal box can stay open while this procedure is in use AND the work does not involve placing any obstruction on the railway THEN 1 THEN 2 ELSE 3

4.1 [S] accept that emergency protection can be granted

4.2 [S & COSS] agree protection arrangements
Plan 4.2 - do in order
4.2.1 [S & COSS] agree on the lines that will be affected
4.2.2 [S & COSS] agree on the locations (i.e. signals) between which the work will take place
4.2.3 [S & COSS] agree on how long the work should take
4.2.4 [S & COSS] agree on the time when the work must be completed or suspended
4.2.5 [S & COSS] agree on the time permission can be given for the work to start (or resume)
4.2.6 [S & COSS] agree on the protection procedure to use
4.2.7 [S & COSS] agree on which signals (if any) will be kept at danger to protect the work
4.2.8 [S & COSS] reach a clear understanding about arrangements

4.3 [S] place (or keep) signals at danger to protect the work
Plan 4.3 - do in order
4.3.1 [S] operate signal controls
4.3.2 [s] use reminder devices

4.4 [S] reject request

5. [S & COSS] complete necessary forms
Plan 5 - do in order

5.1 [S & COSS] perform procedure for completing part A of form RT3181
Plan 5.1 - do 1 AND 2 AND 3. IF disagreement arises in information imparted in 2 between S & COSS
THEN 4 ELSE/THEN 5 THEN 6.
5.1.1 [S & COSS] write appropriate details in section A of form RT3181
5.1.2 [COSS] read to the signaller the completed details of section A
Plan 5.1.2 - do in order
5.1.2.1 [COSS] read back time and date
5.1.2.2 [COSS] read back name
5.1.2.3 [COSS] read back location
5.1.2.4 [COSS] read back telephone number
5.1.2.5 [COSS] read back employer
5.1.2.6 [COSS] read back signaller and signal box name
5.1.2.7 [COSS] read back location and duration of work

5.1.2.8 [COSS] confirm that emergency protection is being used
5.1.2.9 [COSS] confirm signals to be maintained at danger
5.1.3 [S] check that information is correct
5.1.4 [S & COSS] resolve any points of disagreement
5.1.5 [S] state authority number and the time to COSS
5.1.6 [COSS] readback information

5.2 [S & COSS] write appropriate details in section D of form RT3181

6. [S] grant permission
Plan 6 - do 1 THEN 2

6.1 [S] grant permission for work to start

6.2 [COSS] readback information

7. [COSS] commence emergency work

## C.2 Railway Hand Back Possession Scenario

Task 0.

Task: Person in Charge of Possession (PICOP) to enact procedure for handing back authority to the relevant signaller for a stretch of line previously in their charge.

Context: An undefined stretch/area of track
There is 1 Engineering Supervisor and associated team

Performance: Progress and resource works safely and efficiently according to previously agreed timescale and in accordance with applicable railway Group Standards.

Personnel: PICOP = Person In Charge Of Possession
S = Signaller
ES = Engineering Supervisor
COSS = Controller Of Site Safety
CP#1 = Competent Person number 1
CP#2 = Competent Person number 2

Plan 0. - do in order

1. [ES/COSS] ensure that it is possible for the worksite to be closed
Plan 1 - do in order.

[ES] locate COSS (face to face)

1.2 [ES] request that COSS signs Part 4 of form RT3199

[COSS] delete relevent statement(s) in Part 3 of form RT3199

1.4 [COSS] complete (sign and date) Part 4 of form RT3199

2. [PICOP/ES/CP#2] remove work site marker boards
Plan 2 - do in order

2.1 [ES/PICOP] establish permission to begin removing work site marker boards
Plan 2.1 - do 1 to 3 in order. IF there are no authorised train movements AND/OR
general awareness of movement authority suggests an absence of train movements THEN 4 to 8 in order

2.1.1 [ES] establish communication with PICOP
Plan 2.1.1 - do in order

2.1.1.1 [ES] use mobile phone to call PICOP
2.1.1.2 [PICOP] state name and job title
2.1.1.3 [ES] state name and job title

2.1.2 [ES] request from PICOP permission to remove the marker boards
2.1.3 [PICOP] check that no train movements have been authorised to proceed towards the worksite
2.1.4 [PICOP] state to ES that marker boards can be removed
2.1.5 [ES] read back instructions
2.1.6 [PICOP & ES] end communication

2.2 [ES] instruct CP#2 to remove work site marker boards
Plan - do in order

2.2.1 [ES] establish communication with CP#2
Plan 2.2.1 - do in order

2.2.1.1 [ES] use mobile phone to call CP#2
2.2.1.2 [CP#2] state name and location
2.2.1.3 [ES] state name and job title

2.2.2 [ES] instruct CP#2 to remove marker boards
2.2.3 [CP#2] read back instructions
2.2.4 [CP#2 & ES] end communication

[CP#2] physically remove work site marker boards

2.4 [CP#2] communicate to ES that work site marker boards have been removed according to instructions given in step 2.2.2
Plan 2.4 - do in order

2.4.1 [CP#2] use mobile phone to call ES
2.4.2 [ES] state name and job title
2.4.3 [CP#2] state that marker boards have been removed
2.4.4 [ES] read back information
2.4.5 [ES & CP#2] end communication

3. [PICOP/ES] close worksite

Plan 3. - do in order

3.1 establish whether worksite is clear and safe for trains to pass
Plan 3.1 - do in order
3.1.1 [ES] establish communication with PICOP
Plan 3.1.1 - do in order
3.1.1.1 [ES] use mobile phone to call PICOP
3.1.1.2 [PICOP] state name and job title
3.1.1.3 [ES] state name and job title
3.1.2 [ES/PICOP] exchange information on train movements and safety
Plan 3.1.2 - do in order
3.1.2.1 [ES] state that worksite is clear and safe for trains to pass
3.1.2.2 [ES] state current time
3.1.2.3 [PICOP] repeat back relevent information
3.1.2.4 [ES/PICOP] end communication

3.2 complete relevent forms
Plan 3.2 - do 1 AND 2 THEN 3
3.2.1 [PICOP] write time and date that worksite closed in Part 4 of form RT3198
3.2.2 [ES] complete (sign and date) Part 3 of form RT3199
3.2.3 [ES] send RT3199 to PICOP by method previously agreed (by post)

4. [PICOP/SIGNALLER/CP#1] remove possession protection
Plan 4. - do in order

4.1 [PICOP] ensure that all worksites are closed
Plan 4.1 - do 1 AND/OR 2
4.1.1 [PICOP] use current awareness
4.1.2 [PICOP] use finish times and other data contained in form RT3198

4.2 [PICOP] establish communication with signaller
Plan 4.2 - do in order
4.2.1 [PICOP] use mobile phone to call signaller
4.2.2 [SIGNALLER] state signal box and panel number
4.2.3 [PICOP] state name, job title and WON item number

4.3 [PICOP] provide relevent information to SIGNALLER
Plan 4.3 - do in order
4.3.1 [PICOP] state that the possession is ready to be given up
4.3.2 [PICOP] state that detonator protection will now be removed
4.3.3 [PICOP] state that possession limit boards will now be removed
4.3.4 [SIGNALLER] repeat back information
4.3.5 [PICOP & SIGNALLER] end communication

4.4 remove detonators and possession limit boards
Plan 4.4 - do in order
4.4.1 [PICOP] establish communication with CP#1
Plan 4.4.1 - do in order
4.4.1.1 [PICOP] call CP#1 using mobile phone

4.4.1.2 [CP#1] state name and location
4.4.1.3 [PICOP] state name and job title
4.4.2 [PICOP] communicate instructions to CP#1
Plan 4.4.2 - do in order
4.4.2.1 [PICOP] instruct CP#1 to remove detonators
4.4.2.2 [PICOP] instruct CP#1 to remove possession limit boards
4.4.2.3 [CP#1] repeat back instructions imparted in 1 & 2
4.4.2.4 [PICOP & CP#1] end communication
4.4.3 [CP#1] physically remove detonators and possession limit boards
4.4.4 [CP#1] communicate to PICOP that detonators and possession limit boards have been removed according to the instructions given in step 4.5.2
Plan 4.4.4 - do in order
4.4.4.1 [CP#1] use mobile phone to call PICOP
4.4.4.2 [PICOP] state name and job title
4.4.4.3 [CP#1] state that detonators and possession limit boards have been removed
4.4.4.4 [PICOP] read back information
4.4.4.5 [PICOP & CP#1] end communication

4.5 [PICOP] enter time and date that protection was withdrawn in Part 6 on form RT3198

5. close possession
Plan 5. - do in order

5.1 [PICOP] establish communication with SIGNALLER
Plan 5.1 - do in order
5.1.1 [PICOP] call SIGNALLER using mobile phone
5.1.2 [SIGNALLER] state signal box and panel number
5.1.3 [PICOP] state name, job title and WON item number

5.2 [PICOP & SIGNALLER] provide required information
Plan 5.2 - do in order
5.2.1 [PICOP] inform the SIGNALLER that the line is clear and safe for trains to run
5.2.2 [SIGNALLER] read back information

5.3 record and confirm train register information
Plan 5.3 - do in order
5.3.1 [SIGNALLER] complete train register
5.3.2 [PICOP] request that signaller reads back the train register entry
5.3.3 [SIGNALLER] provide requested information
5.3.4 [PICOP] provide further information for train register
Plan - do in any order
5.3.4.1 state name
5.3.4.2 state employer
5.3.4.3 state time
5.3.4.4 state location
5.3.5 [SIGNALLER] record further information provided in step 5.3.4 in train register

5.4 [SIGNALLER] restore protecting signals to normal working

5.5 [SIGNALLER& PICOP] end communication

6. [S] resume normal working

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