Cognitive Work Analysis of a Sensor to Effecter System: Implications for Network Structures

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1 Abstract

This paper presents a Cognitive Work Analysis of a command and control experimental environment. The network facilitates the exchange of information between agents in the field and a series of centrally located commanders. The environment developed allows the manipulation of dependent variables to establish the most efficient network structure for a variety of different scenarios. Cognitive Work Analysis has been used to analyse and model the experimental system and hypothesise the implications of changes to the network structure and the resulting influence this will have on the system and the agents contained within. The analysis uses a *Work Domain Analysis* to capture the purpose of the system. A *Control Task Analysis* outlines the task required to fulfil the purpose of the system. This task is broken down in a *Strategies Analysis,* which explains the possible ways that the system can be configured to enable the same end state. A *Social Organisation and Cooperation Analysis* elucidates which of the actors within the system can perform the tasks required. Finally a *Worker*

Competencies Analysis describes the resulting behavioural characteristics the actors will exert depending on the level of tasks they are assigned.

Keywords: Cognitive Work Analysis; command and control; networks

2 The Domain

The system consists of two distributed teams located in an urban environment of approximately 20 hectares. The first team is made up of a number of reconnaissance units known as 'sensors'. Sensors have the ability to sweep a geographic area and identify targets that need to be neutralised. The second team is made up of effecters who are responsible for neutralising identified targets. In this simple experimental model sensors are the only actors that can detect targets and effecters are the only actors who can neutralise previously identified targets.

There are a number of ways that information can be transmitted between the sensors and effectors based on the way the system is configured. The system can be set up to enable information to be sent via the commanders with information travelling up the hierarchy and then back down to the units in the field, alternatively information can be sent peer to peer.

When sending peer to peer the network can be configured so that a sensor can be linked to an effecter. Alternatively the system can be configured so that the sensor has the ability to select the recipient of the information. The system is reconfigurable; the configuration choice will be influenced by a number of variables. These include:

- Number of units – how may sensors
- Ratio of effecters to sensors – how many effecters per sensor

- Ratio of targets to sensors – how many targets per sensor
- Complexity of task – are there a number of conflicting requirements
- Complexity of the target – is interpretation of the target required
- Ambiguity of information – is it clear what the information represents
- Type of information transmitted

3 Cognitive Work Analysis

Cognitive Work Analysis (CWA) is a structured framework for considering the development and analysis of complex socio-technical systems. The framework leads the analyst to consider the environment the task takes place within and the effect of the imposed constraints on the systems ability to perform its purpose. The framework guides the analyst through the process of answering the question of *why* the system exists; *what* activities are conducted within the domain as well as *how* this activity is achieved and *who* is performing it.

According to Sanderson (2003) CWA does not focus on how human-system interaction should proceed (*normative modelling*) or how human-system interaction currently works (*descriptive modelling*). Instead, it focuses on identifying properties of the work environment and of the workers themselves that define possible boundaries on the ways that human-system interaction might reasonably proceed, without explicitly identifying specific sequences of actions (*formative modelling*).

CWA was originally developed at the Risø National Laboratory in Denmark (Rasmussen et al, 1994). The framework has been developed and applied for a number of purposes including: system modelling (e.g. Hajdukiewicz, 1998); system design (e.g. Bisantz et al, 2003); training needs analysis (e.g. Naikar & Sanderson, 1999), training program evaluation and design (e.g. Naikar & Sanderson, 1999);

interface design and evaluation (Vicente, 1999); information requirements specification (e.g. Ahlstrom, 2005); tender evaluation (Naikar & Sanderson, 2001); team design (Naikar et al, 2003); and error management strategy design (Naikar & Saunders, 2003).

The framework has been applied in a variety of domains including: aviation (e.g., Naikar & Sanderson, 2001); process control (e.g., Vicente, 1999); nuclear power (e.g., Olsson & Lee, 1994); Naval (e.g., Bisantz et al, 2003); military command and control (e.g., Salmon et al, 2004); road transport (e.g., Stoner et al, 2003); health care (e.g., Miller, 2004); air traffic control (e.g., Ahlstrom, 2005); and manufacturing (e.g., Higgins, 1998).

According to Vicente (1999) CWA can be broken down into 5 defined phases.

Phase	Tool
Work Domain Analysis	Abstraction Decomposition Space
Control Task Analysis	Decision Ladder
Strategies Analysis	Information flow map
Social Organisation & Cooperation Analysis	All of the Above
Worker Competencies Analysis	Skills Rules Knowledge

3.1 Work Domain Analysis

The first phase work domain analysis (WDA) is used to describe the domain in which the activity takes place independent of any goals or activities. The first stage of this process is to build up an abstraction hierarchy (AH) of the domain.

The AH represents the system domain at a number of levels; at the highest level the AH captures the system's raison d'être; at the lowest level the AH captures the physical objects within the system. In this simple sensor-effecter paradigm the sole reason that the system exists is to detect and neutralise targets within a predefined area. The system is evaluated against its ability to enact its purpose. This can be measured by a number of criteria, including; the time it takes the effecter to receive a target; how quickly all of the targets can be neutralised (this could be achieved by neutralising them based on the targets geographical position); the speed at which threat is reduced (this could be achieved by neutralising the most dangerous targets first); and the number of errors made.

In many circumstances these criteria may be conflicting. An example of this conflict would be units approaching targets in threat priority order; the same effecter prioritising the targets by their geographical position, would approach the targets in a different order; this route is shorter and therefore faster to complete, however the target with the greatest threat may not be neutralised until last. It could also be argued that the speed to complete and error rates are conflicting constraints. The assumption being that; more careful time consuming planning reduces errors.

The bottom level of the AH shows each of the physical objects within the domain, in this case the nodes comprise all of the equipment and all of the actors within the domain. The level above this describes the functions that each of the objects can afford; in many cases an object may perform a number of functions, in the same way a particular function may be afforded by a number of objects.

The generalised functions in the middle of the AH are the functions required to perform the purposes of the system. Each of these levels can be linked by means-ends relationships using the why-what-how relationship. This analysis results in the AH shown in Figure 1.

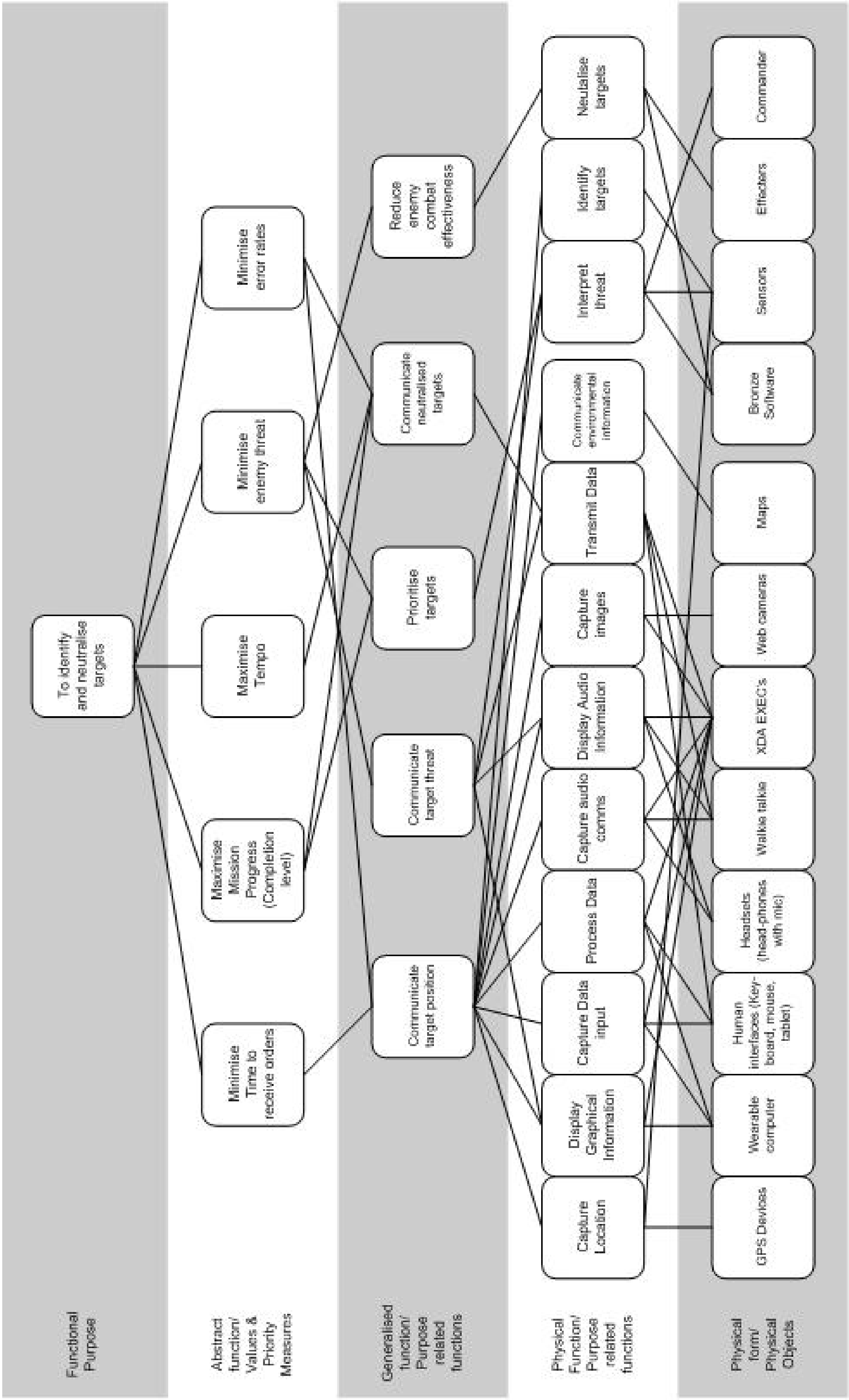

Figure 1 – Abstraction Hierarchy for Sensor-Effecter activity

The AH can then be decomposed into a number of categories' in this case three categories; system, subsystem and individual components. Once decomposed, the data can be plotted on the Abstraction-Decomposion Space.

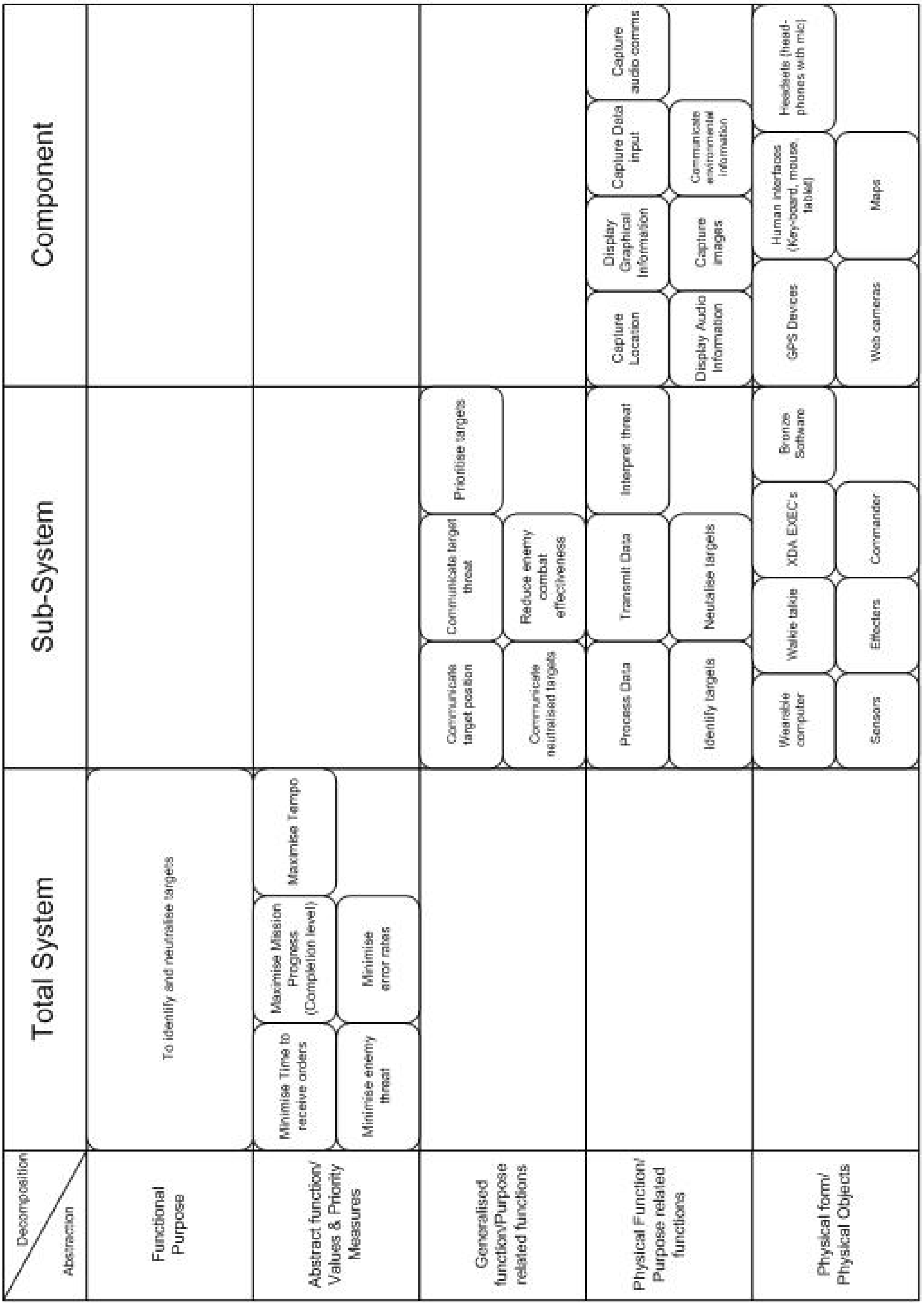

Figure 2 – Abstraction Decomposition Space for Sensor-Effecter activity

3.2 Control Task Analysis

The second stage of the analysis focuses on what has to be achieved independent of how the task is conducted or who will be doing it. The task of identifying a target and neutralising it is shown by following the path up the left hand side and down the right hand side in the decision ladder in Figure 3.

The spotting of a target is the activation for the system to start. Once a target is spotted information is recorded on the targets location and type (no inference or calculation is made). Assessment is then made to calculate the threat of the target. Once a threat has been assigned, the target is then considered relative to the task and the environment and a priority is placed. This prioritisation allows the target to be assigned to an effecter. A target is then identified and finally neutralised

In order to speed up this process it is possible to bypass some of the steps, removing some of the decision making processes allows the transition from spotting the target to neutralisation to be expedited. Figure 3 shows each of the possible leaps (circle to circle) and shunts (circle to square). Figure 3 illustrates that the shortest path for this paradigm is that the target is spotted, information recorded and this information is used to neutralise the target.

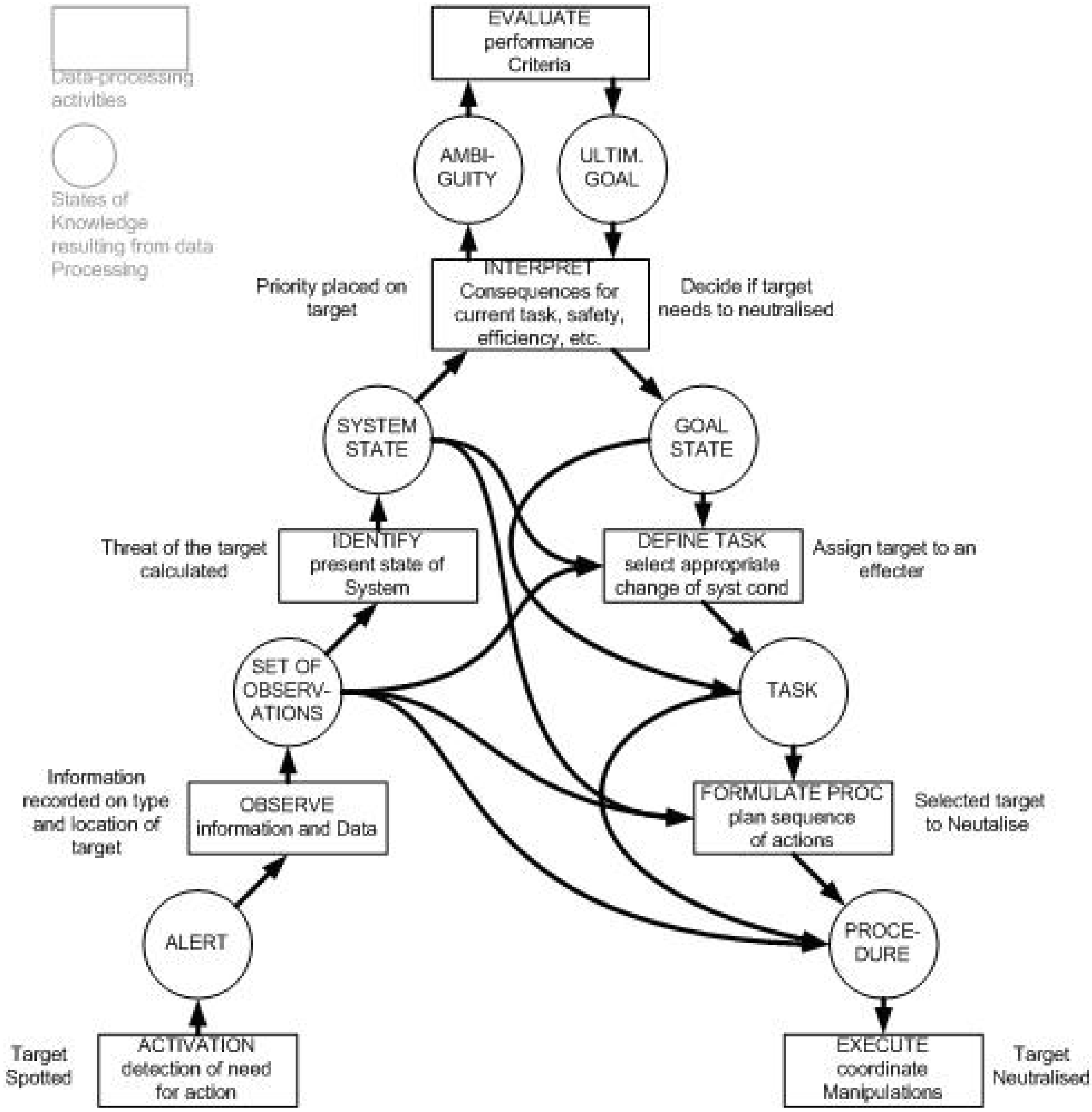

Figure 3 – Decision ladder for Sensor-Effecter activity shortened

Naikar et al (2005) introduce the contextual activity template for use in this phase of the CWA (see Figure 4). This template is one way of representing activity in work systems that are characterised by both work situations and work functions. Work situations are situations that can be decomposed based on recurring schedules or specific locations. Rasmussen (1994) describes work functions as, activity characterised by its content independent of its temporal or spatial characteristics (Rasmussen et al. 1994).

According to Naikar et al (2005) the work situations are shown along the horizontal axis and the work functions are shown along the vertical axis of the contextual activity template. The circles indicate the work functions and the boxes around each circle indicate all of the work situations in which a work function can occur (as opposed to must occur). The bars within each box indicate those work situations in which a work function will typically occur. This template therefore shows the context, defined by work situations, in which particular work functions can occur.

The work functions are similar to the generalised functions in the WDA (see Figure 1). Three distinctly different situations have been selected; in the field searching for targets; in the command centre; in the field neutralising targets. These situations can be considered different due to their geographical variation and their different constraints. Figure 4 shows that the constraints imposed on the system mean that two of the functions are bound by the situations (records information on the type and location; and neutralise the target). The functions of prioritising the targets and of assigning the threat can take place in any situation. Figure 4 illustrates that the function of calculating the threat of the targets is more likely to take place in the field whilst searching for targets.

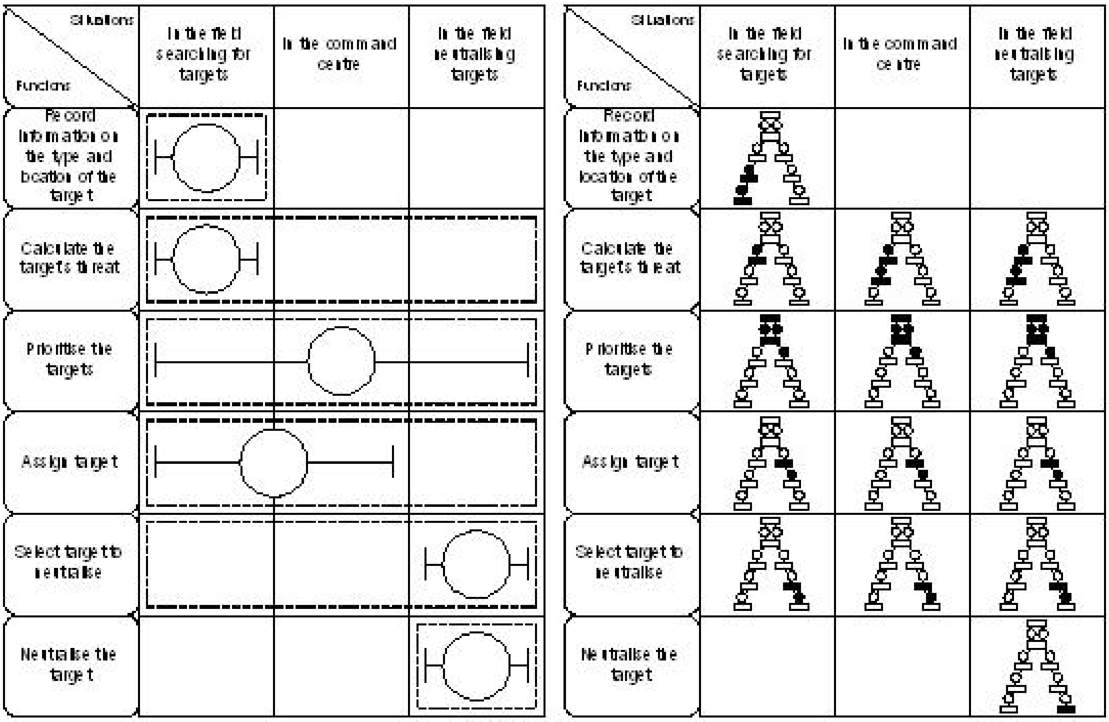

Figure 4 – Contextual activity template

The decision ladder introduced in Figure 3 can be used to communicate which stage of the task is being completed at any particular mix of work situation or function. The diagram on the right shows the contextual activity template overlaid with this information.

3.3 Strategies Analysis

There are a number of ways of achieving the same ends with the system described in the Abstraction Hierarchy. Each of these strategies uses different resources and distributes the workload in different ways.

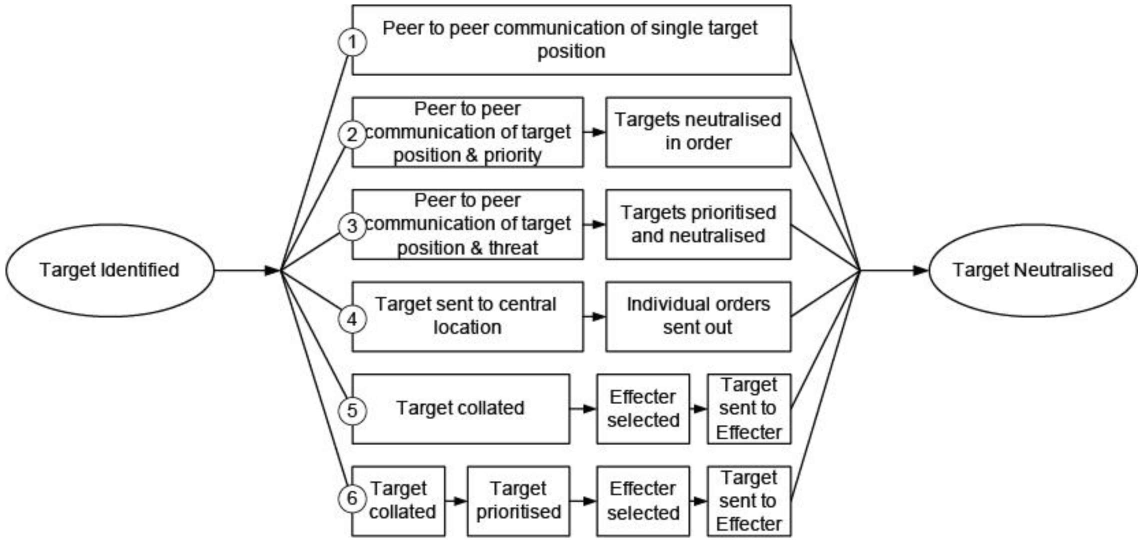

Figure 5 – Strategies analysis for Sensor-Effecter activity

In this case the start state is that a target is identified and the end state that the target is neutralised. Use of the decision ladder representation in Figure 6 illustrates that the strategy chosen affects the way in which the task is completed. The first strategy shows that the task is completed at a simplistic level with out threat calculation or prioritisation. This situation requires the targets to be neutralised as they are detected. An example of a more complex situation is situation 6, here the target is processed centrally and considered with all other targets, a priority is assigned and the appropriate effecter selected.

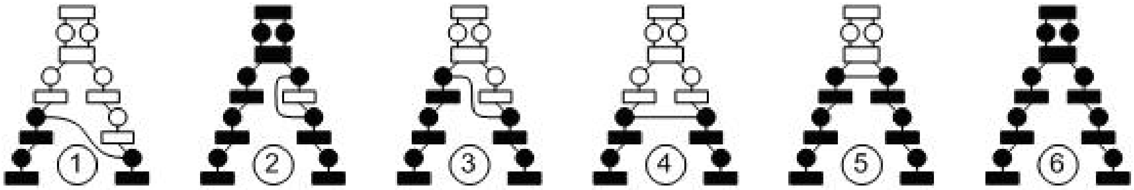

Figure 6 – Strategies analysis for Sensor-Effecter activity

3.4 Social Organisation & Cooperation Analysis

It is possible to map each of the actor types on to the existing tools in order to show who has the capability of doing what. Using arbitrary colours it is possible to show where each on the actor groups can conduct tasks.

Figure 7 – Key of actor type and colour

Figure 8 shows the abstraction-decomposition space (ADS) coloured to show the nodes that can be used by the key actor groups. The total system requirements have been left blank as these are generic and apply to all actors.

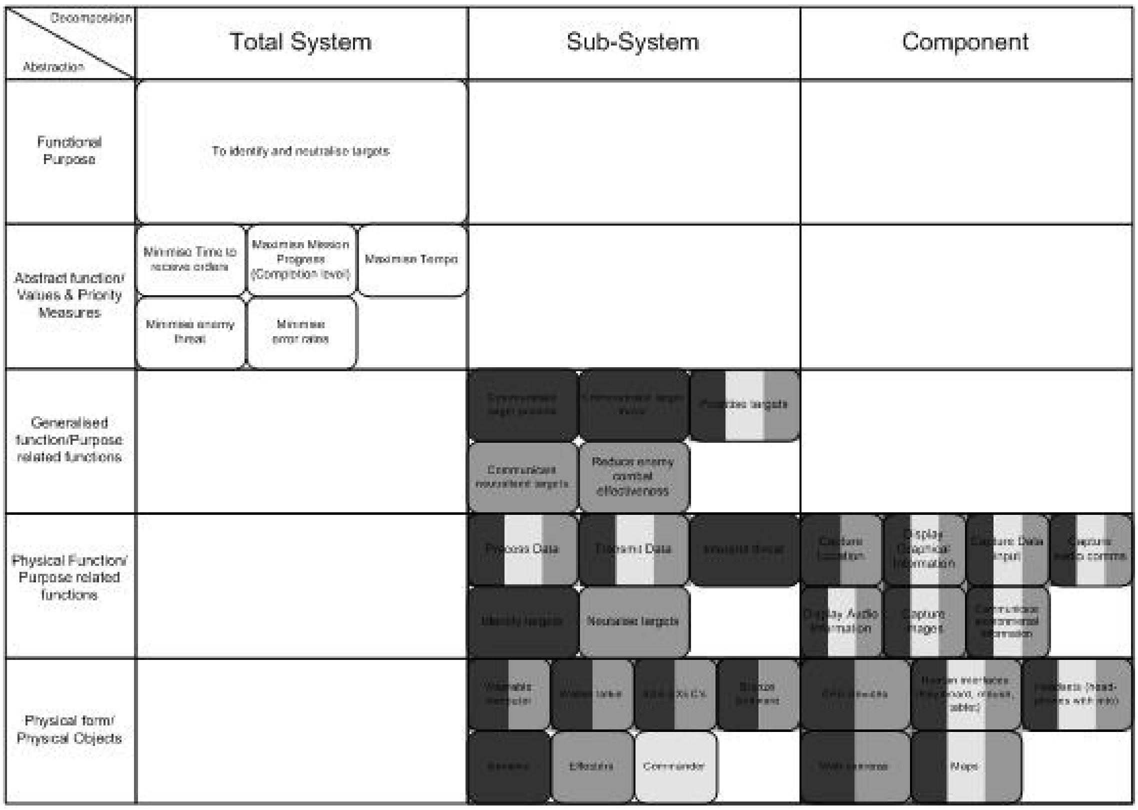

Figure 8 – ADS showing nodes used by each of the key actor groups

Figure 9 shows the decision ladder introduced in Figure 3 coloured to show where each of the actor types can conduct tasks. Due to the limitations of the system sensors are the only actors that can detect targets and effecters are the only actors who can neutralise previously identified targets (highlighted in Figure 4). This leads to the 'feet' of the ladder being coloured dark for the sensors and 'medium grey' for the effecters. In these cases they are the only actors physically capable of conducting these tasks. The remaining part of the decision ladder involves taking the basic information from the sensor, interpreting it and making a decision about which targets to neutralise. In this case this activity can be conducted by the sensor, the commander or the effecter. For this reason the nodes are tri-coloured.

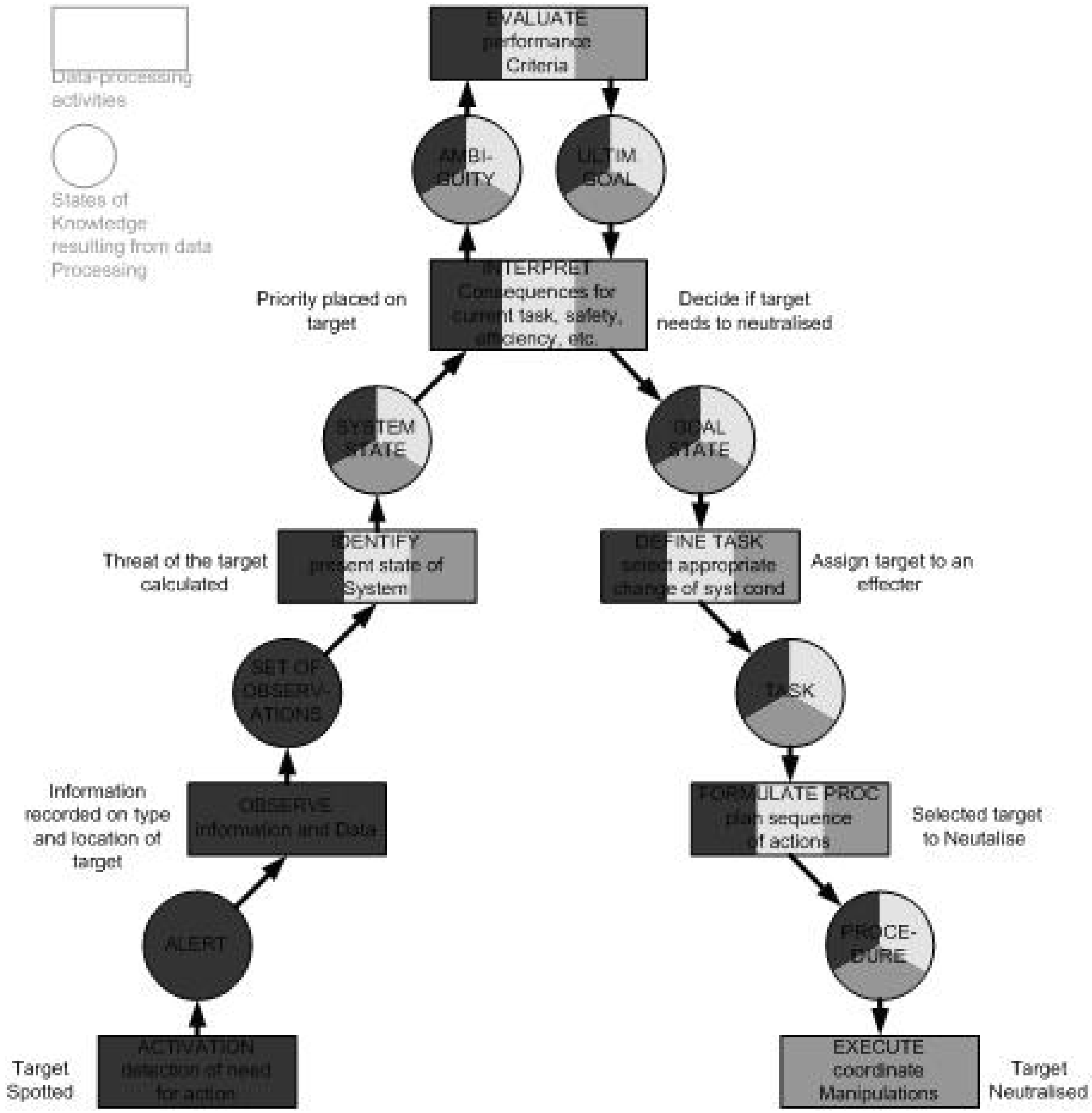

Figure 9 – Decision ladder showing tasks that can be conducted by actor types

Figure 10 shows that the strategies analysis diagram introduced in Figure 5 can also be coloured to show the actors engaging in the task. Here the initial state must start with the sensor and end with the effecter, however the strategy used in the middle can be enacted by the sensor, the commander or the effecter.

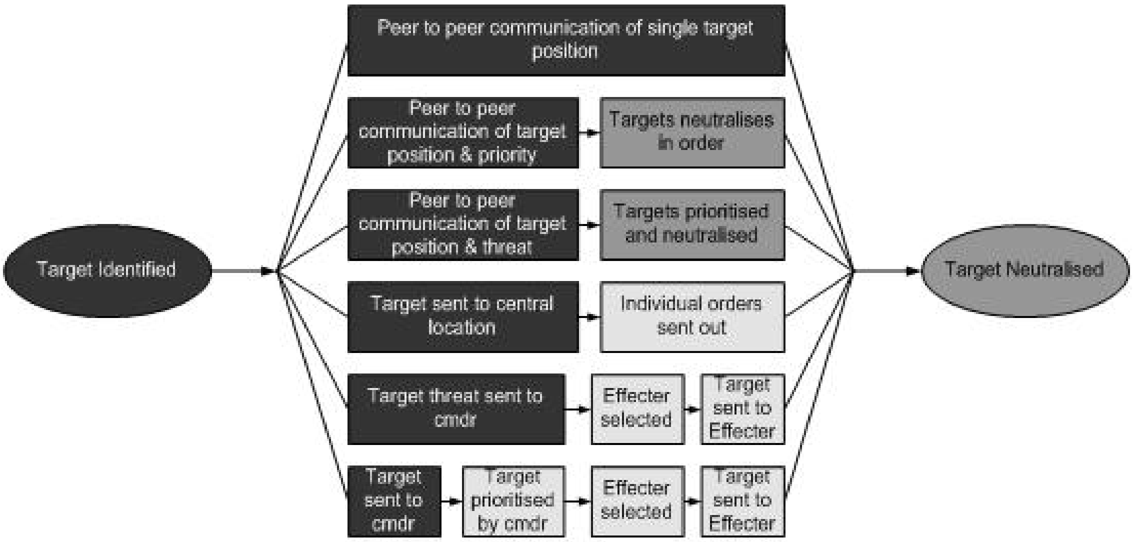

Figure 10 – Strategies analysis showing tasks that can be conducted by actor types

Experimentation is required to decide how the workload should be distributed. The dependant variables listed at the start of this document and the network configuration will affect this decision.

3.5 Worker Competencies Analysis

According to Vicente (1999) Skill based behaviour (SBB) is performed without conscious attention. SBB typically consists of anticipated actions and involves direct coupling with the environment. Rule Based Behaviour (RBB) is based on a set of stored rules that can be learned from experience or from protocol. Individual goals are not considered, the user is merely reacting to an anticipated event using familiar perceptual cues. Unlike SBB, users can verbalise their thoughts as the process is cognitive. When decisions are made that explicitly consider the purpose or goal of the system the behaviour can be considered to be Knowledge Based Behaviour (KBB). KBB is slow, serial and effortful because it requires conscious, focal attention.

The network structure will also be dependant on the behaviour level expected from the actors. The actors can work at three different behaviour levels dependant on the level of processing required to complete the desired activity. Figure 11 shows example responsibilities for each of the actors at the three behavioural levels.

	Skill based	Rule based	Knowledge based
Sensor	When an object is spotted send its position	When an object is spotted send its position and a description of its level of threat.	When an object is spotted send its position and its relative priority.
Commander	Send the received information to an effecter.	Match the target to the effecters based on position	Match the targets to effecters considering the position, threat and workload.
Effecter	Neutralise whatever pops up as soon as it pops up regardless of what you were doing	Neutralise the geographically closest object	Neutralise the most dangerous target as long as it will not cause a riot.

Figure 11 – SRK levels for each of the actors

4 Conclusions

This paper has described the sensor to effecter system at each of the five CWA levels. The analysis has described the domain and answered questions on *why* the system exists, *what* it should do, *how* it should do it and *who* should be enacting the various stages of the task.

The CWA demonstrate the flexibility of the network. Due to the physical nature of the sensors, they are essential to the system as they are the only method for capturing target positions. The effectors are also essential to the system as they are the only means of neutralising targets. The commander/command team have no unique role and are therefore are not essential to the system. The physical (skill based) actions of sensing and neutralising are fixed, however the more complicated tasks of interpreting, evaluating and defining the task can be assigned to anyone within the system.

By changing the roles and responsibilities of the groups of actors, it is possible to rapidly reconfigure the network to compensate for environmental changes. By focusing on the constraints the analysis captures every physically possible network configuration.

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