

Jenkins *et al*

Using Cognitive Work Analysis to explore activity allocation within military domains

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Abstract

Cognitive Work Analysis (CWA) is frequently advocated as an approach for the analysis of complex sociotechnical systems. Much of the current CWA literature within the military domain pays particular attention to its initial phases; Work Domain Analysis and Contextual Task Analysis. Comparably, the analysis of the social and organisational constraints receives much less attention. Through the study of a helicopter Mission Planning System (MPS) software tool, this paper describes an approach for investigating the constraints affecting the distribution of work. The paper uses this model to evaluate the potential benefits of the social and organisational analysis phase within a military context. The analysis shows that, through its focus on constraints the approach provides a unique description of the factors influencing the social organisation within a complex domain. This approach appears to be compatible with existing approaches and serves as a validation of more established social analysis techniques.

Keywords: Activity allocation; Aviation; Planning; Military; CWA

Relevance

As part of the Ergonomic design of mission planning systems, the Social Organisation and Cooperation Analysis phase of Cognitive Work Analysis provides a constraint based description informing allocation of function between key actor groups. This approach is useful because it poses questions related to the transfer of information and optimum working practices.

1 Introduction

Constraint based analysis, be it in the form of Cognitive work analysis (CWA; Rasmussen *et al*, 1994; Vicente, 1999) or Ecological interface Design (EID; Burns & Hajdukiewicz, 2004; Vicente, 2002; Vicente & Rasmussen, 1990, 1992) has a plethora of applications within military domains (e.g. Burns *et al*, 2000; Chin *et al*, 1999; Cummings & Guerlain, 2003; Jenkins *et al*, in press; Lamoureux *et al*, 2006; Lintern *et al*, 2004; and Naikar & Saunders, 2003). The application of Work domain analysis and control task analysis, have a received significant attention. As this paper will show there has been little exploration of the social and organisation phase of CWA in either the military domain or the wider CWA field. The analysis of the constraints framing interaction and allocation of function are essential considerations for design in complex sociotechnical systems. These constraints as Watson & Sanderson (2007) point out are not explicitly considered in EID (which focuses on the work domain analysis and worker competencies analysis of CWA). This paper will attempt to address this imbalance by exploring the potential benefits of the Social Organisation and Cooperation Analysis (SOCA) phase of CWA.

This paper will first introduce the Mission Planning System (MPS) analysed, following this the choice of CWA as analysis approach will be discussed. The data collection process will be explained, along with the analysis results and conclusions.

1.1 The mission planning system

Mission planning is an essential part of flying a military aircraft. Whilst in the air, pilots are required to process in parallel, cognitively intense activities including; time keeping, hazard perception, and off-board communication. These activities are all conducted whilst attending to the task of navigating through a three-dimensional airspace. Pilots are required to constantly evaluate the effects their actions have on others within the domain. Decisions need to be made that consider; any number of both military and non-military services, organisations and civilian groups. Calculations need to be made based upon a number of physical considerations, these include; environmental constraints, aircraft performance and payloads. Pilots also need to balance mission objectives with rules of engagement and high order strategic objectives. Pre-flight planning is one essential method used to alleviate some of the pilot's airborne workload. This planning process, which was formerly conducted on paper maps is now supported by a digital software based planning tool; the Mission Planning System (MPS). The MPS software tool described is currently used by the UK army to develop and assess mission plans for attack helicopters. The MPS software tools provides and processes digital information on; battlefield data,

threat assessment, intervisibility, engagement zones, communication details, transponder information, and IFF (Identification Friend or Foe) settings. In short, the MPS is used to plan and assess single and multiple aircraft sortie missions. Whilst for the purposes of this paper, a specific MPS tool was used, it is contended that the analysis could apply to many other software based mission planning tools in both military and civilian domains.

Mission plans are generated prior to take off on PC based MPS terminals. Key information developed in the software tool is transferred to the aircraft via a digital storage device called a 'Data Transfer Cartridge' (DTC). Information is presented on the Aircraft's onboard flight display. This multi-function display can be used by the pilot for to assist in navigation and target identification. This process is represented graphically in Figure 1.

----- Figure 1 about here please -----

The digitisation of the planning process has a number of benefits. By performing multiple parallel calculations, the computer is able to consider a huge number of variables that would be inconceivable in a paper based system. When combined with complex algorithms, this allows for greater accuracy in modelling factors such as fuel burn rates. The design of the user interface for the software system has the potential to significantly affect the performance of the operators.

The visualisation of the plan is constrained to a limited screen real estate. Therefore, the navigation and clustering of data need to be carefully considered. The design of these digital systems needs to be contemplated in light of new constraints and freedoms.

Based upon the new capabilities and constraints within a digital system it is possible to rethink task distribution. Activity can be distributed amongst the team through a simple network allowing tasks to be completed collaboratively. A number of approaches have been successfully applied in the past to model these interactions within command and control domains. These include: Social Network Analysis (Houghton *et al*, 2006); Event Analysis of Systematic Teamwork (EAST; Walker *et al*, 2006); and models of team situation awareness (Stanton *et al*, 2006; Gorman *et al*, 2006). These approaches tend to focus on current activity. The approach presented in this paper aims to inform the design of future generations of the mission planning system through the use of an event independent analysis technique.

1.2 Why Cognitive Work Analysis

The MPS system is used to develop plans in an extremely complex environment. We can gain some perspective of this, by considering it against Woods's (1988) four dimensions for complexity:

- *Dynamism of the system*: The system is extremely dynamic; it changes frequently without intervention from the user. Whilst control orders that

govern the airspace are used to limit this dynamism; mission start times are often subject to change, thus making previous assumptions invalid.

- *Parts, variables and their interconnections*: There are a number of services and organisations operating within the airspace and ground environment. These groups often have competing aims and objectives.
- *Uncertainty*: As a result of the 'Fog of War', data can frequently be erroneous, incomplete or ambiguous. This makes it difficult to make predictions about future events.
- *Risk*: Potentially, decisions made within the environment made have life and death consequences.

Based upon Woods's (1988) heuristics, there is no doubt that the environment the MPS serves is extremely complex. Zsombok & Klein (1997) describe battlefields as environments that have high stakes; are dynamic, ambiguous, time stressed, and in which goals are ill defined or competing. This is, without even considering the additional acts of flying and navigating. This level of complexity is here to stay; Hollnagel (1992) points out that complexity cannot be removed, only hidden, and to hide complexity is risky.

An approach is required to model the MPS domain that is independent of time or specific context. Normative analysis techniques focus on how the system currently performs, or how the system should perform. The models they produce are therefore, only applicable for specific examples, Jenkins *et al* (in press) point out that these models soon become invalid as system parameters

change. According to Naikar & Lintern (2002) normative approaches specifying temporally ordered actions, result in workers being ill prepared to cope with unanticipated events. For this analysis a formative approach was required that, through its focus on constraints would allow the analyst to exhaustively, but concisely, describe the system under analysis. Vicente's (1999) description of Cognitive Work Analysis (CWA) addresses these requirements. Although initially developed for closed-loop, intentional, process control domains; CWA has been successfully applied to a number of open-loop military systems (e.g. Burns *et al*, 2000; Naikar *et al*, 2003). Burns *et al* (2000) apply Ecological Interface Design (an approach evolved from CWA) to model shipboard command and control. They use this example to explore how the Work Domain Analysis (WDA) model can be extended to apply to open-loop systems with boundaries that are much harder to define than their closed-loop counterparts. Burns *et al* (2000) justify the use of their approach by drawing upon similarities between decision making in naval command and control and the process control domains described by Rasmussen *et al* (1994) and Vicente (1999). Burns *et al* (2000) point out the safety critical nature of both domains as well as the underlying physical constraints.

Vicente (1999) describes CWA as a composite made up of a number of phases. Each of these phases considers different types of constraints; each having its own distinct role and various representational methods, a summary of these can be found in Figure 2.

----- Figure 2 about here please -----

As Figure 2 shows, the products of CWA describe the system in terms of its constraints: The Work Domain Analysis (WDA) models the systems purpose(s), functions, components, and capabilities. The Control Task Analysis (ConTA) models the known recurring activities occurring during mission planning. The Social Organisation and Cooperation Analysis (SOCA) identifies the key actors involved in the mission planning process and models the constraints governing the tasks that they can and cannot undertake.

The described analysis builds upon the work of Burns *et al* (2000) in exploring the appropriateness of CWA in open-loop complex systems. Burns *et al* (2000) limited their analysis to the initial phase of CWA (WDA). Whilst subsequent work in the same domain by Lamoureux *et al* (2006) as well as other command and control examples (Naikar *et al* 2006) extended this analysis to the second phase. There has been little attempt in the literature to extend the CWA framework beyond these two phases. The social and organisational analysis phase builds upon the products of previous phases. This analysis described involved constructing: an Abstraction Hierarchy, Abstraction Decomposition Space, and Contextual Activity Template for use within the SOCA phase. According to Rehak *et al* (2006) it is through a process of viewing the same domain in a variety of ways that many design innovations arise.

1.3 Data Collection

Access was granted to a number of Subject Matter Experts (SMEs). These SMEs were able to provide the analysts with a high level of domain understanding. The SMEs also provided an essential contribution to the validation of the CWA products. The four SMEs were made up of a combination of flight instructors and serving airmen. An initial two day meeting was held to introduce the planning process and the MPS software tool. The data collection process involved a number of SME interviews and walkthroughs of mission planning tasks. In total, three meetings were held at Brunel University, each lasting approximately five hours. Two subsequent visits were also made to 'The Army Flying School' based at Middle Wallop. The data collected during these sessions was used to create; the Abstraction Hierarchy (AH; see section 2.1), Contextual Activity Template (CAT; see section 2.2), and Social Organisation and Co-operation Analyses (SOCA). The analysis was conducted using the Human Factors Integration Defence Technology Centre's (HFIDTC) CWA software tool (Jenkins *et al*, 2007). Each analysis draft was subsequently validated by the SMEs and updated based upon their feedback.

2 Analysis Results

As Figure 2 shows the social organisation and cooperation analysis (SOCA) phase builds upon the previous phases of CWA. The first three phases of the analysis are actor independent. The SOCA phase revisits the products

produced, considering the constraints governing which actors can be involved with each activity. It is therefore important to consider the initial phases of CWA before considering the SOCA phase.

2.1 Work Domain Analysis

The initial phase of CWA; Work Domain Analysis (WDA) is used to describe the constraints governing the domain in which the activity takes place. This description is independent of any goals or activities. The first stage of this process involves constructing an Abstraction Hierarchy (AH). The AH represents the system at a number of levels of abstraction; at the highest level the system's *raison d'être* is recorded; whilst the lowest level the AH captures the physical objects within the system. The MPS AH is presented in Figure 3. The systems *functional purpose* has been defined as; 'To plan missions to enact higher command intent'. For the aim of this analysis this is considered to be the sole purpose of the system. The second level down, the *values and priority measures*; capture the metrics that can be used to establish how well the system is performing in relation to its *functional purpose*. These include: Mission Completion (Adherence to Commander's Intent); Adherence to Rules of Engagement; Self Preservation; Minimise Unnecessary Casualties; Flexibility (adaptability); and the suitability of outputted data (DTC / UDM). Each of these measures has the potential to positively or negatively influence the overall *functional purpose*. At the very bottom level of the hierarchy, the *physical objects* that make up the system are recorded. In this case they are limited to the process of planning, rather than the flight of the aircraft or the engagement

of targets. Examples include: maps and satellite imagery; orders; weather forecasts; flying regulations; along with information on weapons, airframes, sights and sensors. The level above, *object related processes*, captures all of the affordances of the *physical objects*. For example; the airspace freedom and constraints can be elicited from the Airspace Control Order (ACO); and terrain understanding can be elicited from maps. At the *object related processes* level, the affordances should be independent of the system purpose. The AH is linked together by the *purpose related functions* level in the middle of the hierarchy; this level puts the identified *object related processes* into context the measures that they can influence.

----- Figure 3 about here please -----

----- Figure 4 about here please -----

Using the ‘why-what-how’ relationship each of the levels can be linked by means-ends relationships. Any node in the AH can be taken to answer that question of ‘*what*’ it does. The node is then linked to all of the nodes in the level directly above to answer the question ‘*why*’ it is needed. It is then linked to all of the nodes in the level directly below that answer the question ‘*how*’ this can be achieved. Taking the example of payload required (see Figure 4), we can first

address the issue of *why* do we need to determine the payload required. By following the means-ends-links out of the top of the node, we can see that payload required is important for: mission completion, to ensure targets can be attended to; self preservation, to neutralise threats; and for flexibility, to allow for changes to the mission objectives. Looking at the links from the bottom of the node we can see *how* we determine the payload required: through having a weapons capability understanding, to determine the required ordnance for each target; through understanding the enemy disposition, to account for physical limitations of certain weaponry; and through an understanding of other friendly unit's dispositions, to eliminate the possibility of friendly fire incidents.

One of the main advantages of WDA is that the output is truly activity independent. The model generated in Figure 3 is applicable for the MPS software as well as for the previous paper based system. The objects in the lowest two levels may change as new technology is introduced, however; the system purpose, the way in which this measured, and the object related processes are unlikely to change. By considering the hierarchy from a top down perspective, it is possible to view the system in a technologically agnostic way. This allows the analyst or designer to conceive of a completely new system.

The product of WDA is often also represented on an Abstraction-Decomposition Space (ADS). The ADS is developed by classifying each of the nodes in the AH into a number of levels of decomposition. In this case the system was decomposed into; total system, subsystem, and individual components. The

functional purpose(s) of the system in most cases will apply to the total system. Similarly the individual physical objects are likely to be either components or subcomponents. The MPS ADS is presented in Figure 5. The ADS is a more compact representation, however, without the means-ends links the structural relationship between the nodes is not clear.

----- Figure 5 about here please -----

In the process of developing the WDA for use in the SOCA, a number of benefits were elicited. The WDA leads the analyst and the SME to consider the domain independent of any activity taking place. This focus on why the system exists, rather than how the system should work, often enables the system to be considered in a new light. This consideration of the system at different levels of abstraction provides the designers of future iterations of the software with a greater appreciation of the tool and its overriding objectives. To conduct recurring tasks, the current MPS software requires operators to have multiple windows open at any one time to access the required data. It is postulated that the data structure and in turn, the window design of the current MPS, has been based on a reductionist approach to systems engineering. Designers and programmers with both a functional and physical understanding are much better informed when designing user interfaces. By tracing the means ends links within the AH, the design team can investigate task flow and information

grouping requirements for each stage of the process. A design informed by an AH could eliminate the need to have Multiple windows open to conduct an activity.

The AH representation has the potential to aid the development of training programs for the MPS software. Training is currently based on explaining each of the windows within the software tool. A training plan derived from higher levels of abstraction within the AH would result in new trainees developing a *functional* (i.e. understanding of the different functions involved and the relationships between them) rather than a *physical* understanding of the mission planning process (i.e. understanding of how each component window works). It is expected that this approach would lead to great advantages in expediting the training process.

2.2 Control Task Analysis

In order to further understand the domain, it is often advantageous to look at common recurring activities in more detail. The second phase of the analysis; Control Task Analysis models these known recurring tasks. The analysis focuses on what has to be achieved independent of how the task is conducted, or who is undertaking it. Naikar *et al* (2005) introduce the contextual activity template for use in this phase of the CWA (see Figure 6). The contextual activity template is one way of representing activity in work systems that are characterised by both work situations, and work functions. Rasmussen *et al* (1994) describe work functions as activity characterised by its content,

independent of its temporal or spatial characteristics. These functions are then plotted against work situations. These work situations can be classified and decomposed based on recurring schedules or specific locations. The Contextual Activity Template, therefore, is a matrix showing which activities can occur in which situation. According to Naikar *et al* (2005) the matrix should be structured so that the work situations are shown along the horizontal axis and the work functions are shown along the vertical axis. The dotted boxes indicate all of the work situations in which a work function *can* occur (as opposed to must occur). The bars within each box indicate the situations in which a function will *typically* occur. In this case the work situations have been delineated to include: a MPS terminal on the ground; in the aircraft on the ground (prior to takeoff); on the ground at a 'Forward Armament and Refuelling Point' (FARP); and in the air. The specific situations were chosen as each is bound by a unique set of environmental and technological constraints. The functions captured are considered to be known recurring tasks, in this case the choice of the functions was heavily informed by the *purpose related functions* level from the AH (see Figure 3).

By examining the Contextual Activity Template in Figure 6 it is possible to draw both specific, as well as broader observations. Specific observations give an understanding of individual constraints, for example: target engagement planning can take place anywhere, but is not likely to take place whilst the aircraft is on the ground. It is also possible to build a broader image of the system by looking at patterns within the Contextual Activity Template, for

example; it is rather salient that the only function that typically occurs in all situations is 'timing calculations'; this is due to the complexity of the system and the need for adaptation. It is also salient that in this domain all of the function *can*, and *typically* do take place on the MPS terminal on the ground. Due to a number of mainly technical constraints, some of the functions can only take place on the ground with the MPS system (such as calculations of safe heights; inter-visibly calculations; radar programming; resource allocation; understanding of critical information for cockpit; and determining the minimum mission equipment). There are, however, other functions that can take place in other locations but typically do not. From discussions with the SMEs it was clear the emphasis of the planning is to get most of the functions completed on the ground, thus leaving only minor alterations to take place in later situations where the aircrew are required to prioritise other activities. It can be seen from the dotted boxes that the majority of the functions (11 of the 17) can be conducted in all situations. Even with the additional capability and flexibility provided by a network enabled system, there appears to still be a strong emphasis on upfront, rather than on-the-fly planning. We can explore this phenomenon further by looking at the roles of actors in the SOCA phase.

----- Figure 6 about here please -----

2.3 Social Organisation and Cooperation Analysis

Social Organisation & Cooperation Analysis (SOCA) addresses the constraints governing how the team communicates and cooperates. The analysis also allows the constraints affecting the allocation of available resources to be modelled. In the vast majority of systems, it is desirable to determine how social and technical components can be combined and configured to enhance overall performance. In the case of complex socio-technical systems, this ‘ideal configuration’ is unlikely to be fixed; rather, the optimum configuration will be dependant on both the work functions and the work situation. The first two phases of the analysis have developed constraint based descriptions of the system in terms of the functional capabilities of the systems (WDA) and in terms of the constraint affecting the activity (ConTA). Using these descriptions as templates, it is possible to consider how these constraints affect the distribution of work and the allocation of function. Actors can be mapped onto these representations to show where they *can* have an influence on the system. This mapping allows the analyst to see a graphical summary of the constraints dictating who has the capability of doing what. At this stage the focus is entirely on capability, no judgement is made on which actor is best placed to perform a function. In this example the key actors were identified by the SMEs as:

- CAOC/Fires – CAOCs (Combined Air Operations Centre) work at a tri-service level to coordinate air operations. They de-conflict aircraft movements in both time and space. The CAOCs are responsible for

producing the Air Tasking Order (ATO) and Airspace Control Orders (ACO)

- Aircrew – The aircrew fly the aircraft and are ultimately responsible for the planning and subsequent execution of the plan.
- Sqn MPS Operator – The Squadron MPS operator works more in an administrative role. They assist the aircrew in creating plans and transferring data.
- Ops officer / commander – The ops officer is normally involved with the planning of future operations. The Commander is normally involved in current actions.
- EWO – The Electronic Warfare officer is a technical specialist available in an advisory capacity. The EWO can provide information about enemy and friendly capabilities. Advice is also given on the best tactics to neutralise threats.

An arbitrary colour is attributed to code each of the actors (see Figure 7)

----- Figure 7 about here please -----

Figure 8 shows the ADS coded to indicate where each of the actors can influence the system. The coding is limited to the *purpose related functions* and the *object-related process* levels of the hierarchy. The higher levels representing the function purpose and values and priority measures are

considered to be applicable to all actors in the system, in the interest of clarity these are not coded. This modification of the ADS provides a concise graphical summary which forms the basis for the coding of the Contextual Activity Template.

----- Figure 8 about here please -----

----- Figure 9 about here please -----

The Contextual Activity Template can be coded to show which actors can perform work functions in different situations (see Figure 9). Cells occupied by more than one actor indicate that activity *can* be supported by either or all of the identified actors. At this stage there is no consideration of which of the actors is best placed to conduct the activity, nor is there consideration of the best way of completing the activity, be it; collaboratively, cooperatively or by one actor in isolation. At this stage the emphasis is placed on modelling the constraints rather than addressing the optimum working practice. The coding of the cells in the contextual activity template with actor groups has the potential to inform decisions about collaborative and cooperative working. By considering who can conduct which tasks, in which situations, it is possible to develop strategies for training based upon requirements for information sharing and decision making.

Examination of Figure 9 reveals that once the aircraft has left the ground all of the identified activities (with the exception of the timing calculations) can only be reasonably conducted by the aircrew. Technological constraints prohibit airborne collaborative working. With advances in networking technologies it may be possible to remove some of these constraints; however, there are also significant cultural barriers to be addressed relating to trust and acceptance before responsibility should be delegated away from the pilot. Further study would be needed to establish the effect of real-time airborne collaborative planning. Figure 9 also shows that whilst planning on the ground the aircrew have the capability of performing each of the identified work functions. The remainder of the actors work in a capacity to assist the pilots in developing their plans. Due to time constraints it is often required that work functions are conducted in parallel. In these situations collaborative and cooperative working is essential. Not only does the Contextual Activity Template capture the constraints but it also allows the analyst to consider how workload is distributed within the team within given work situations.

3 Conclusions

This paper has introduced some of the potential benefits of exploring the SOCA phase of CWA with complex sociotechnical systems. The approach taken has been to reuse the constraint based description of the first two phases (WDA and ConTA) to explore the social and organisational constraints. In the process of conducting the WDA and the ConTA a number of short and long term benefits

were extracted. The short term benefits include the applicability of the WDA for informing the redevelopment of the MPS training syllabus structure. Based upon its means ends links, the structure of the abstraction hierarchy forms the basis for lesson sequencing and teaching structure. It is the opinion of the authors that redeveloping MPS training in this way will lead to a more activity-focused teaching structure rather than the current application-focused training. One of the long terms benefits of the approach lies in its ability to guide future development of the MPS based on a functional, rather than physical interface. The CWA indicates that future MPS redesign would significantly benefit from task orientated groupings of information. Restructuring the interface would provide users with all of the information they required at any one time within the same window. This grouping of information would also prompt the user to consider context specific information. The ConTA provides the developers with a greater understanding of the situations in which the activity is likely to take place. This understanding has the potential to inform the design of situation specific interfaces. These interfaces could be used to cluster and display pertinent information dependant on the current work situation.

The analysis of the MPS software tool revealed that it offers significant enhancements to the mission planning process. Planning with the MPS software can potentially be; quicker, far more detailed and produce less planning errors. Further, the MPS software supports collaborative planning and automates many of the laborious and error prone components of the manual planning process. Despite this conclusion, our research also suggests that,

although the MPS has the necessary functionality to support efficient mission planning; ultimately the design of the software's user-interface is under optimised. The current design of the user interface makes it difficult for users to navigate to related data. This is predicted to have a negative impact on; planning time, training time, user errors and frustration. The examined system represents one stage of the transition from an analogue to a fully network enabled system. From an analysis of the system it is clear that there are technological constraints limiting the system flexibility, particularly within the distribution of tasks, however, there also seem to be other factors preventing the system from fully exploiting the new technology capabilities. The current MPS system appears to be little more than a digitisation of the analogue process, with activities in the digital system conducted in the same way as they were in the analogue system. An approach has been taken to automate manual processes in the planning activity; however, the current system contains a significant amount of flexibility that has yet to be exploited.

The results from the SOCA phase (Figure 9) graphically show the distribution of activity between the actors within the system. It is clear that the aircrew are still responsible for the majority of the activity within the domain; particularly after the aircraft has taken off. As discussed this is primarily due to technological constraints, however, the interface design has a significant role in supporting distributed working. The current design of the MPS software does not actively support collaborative working. The analysis in Figure 9 clearly shows that many of the activities required in the first work situation (on the ground using MPS

terminals) can be conducted by a range of different actor groups. The analysis has highlighted that through the addition of data sharing protocols and a simple local area network, many of these activities could be conducted in parallel. This could allow the planning processes to be significantly expedited. Stanton *et al* (2006) found that to fully exploit the benefits of distributed planning activities within complex systems, there is a need for compatibility in situation awareness. A networked system presenting a 'common picture' could assist in the development of this shared situation awareness. The framework presented also forms a basis for further exploration of work allocation, whilst the approach discussed in this paper has concentrated on the modelling of constraints, it is contended that this representation forms a basis for exploring, in detail, the allocation of function between actors within each cell. From the developed description of constraints potential combinations of working practices can be identified and evaluated to determine optimal practices.

When the formative systems approach used in the SOCA is compared to more 'traditional' normative approaches (EAST; Walker *et al* 2006), it is clear that normative methods provide a much better basis for after action review. These normative approaches are therefore more suitable for diagnosing what has and should have happened, rather than predicting or postulating what can happen. The strength of CWA is that it provides an externally observable; constraints based description of the world built from a model of individual cognition. Although methods such as EAST may fall short in describing formative behaviour, arguably they provide deeper systems based description of

cognition. It is for this reason that these methodologies are complimentary for fulfilling the aim of modelling complex sociotechnical systems.

Social network analysis tells us where links exist between agents. In many cases (Houghton *et al*, 2006) the importance of these interactions is then derived from their frequency. SOCA on the other hand explains the constraints limiting the allocation of activity between the actor groups. By using the later phases of CWA to focus on the alternative strategies and system configurations, redundancy can be identified. This level of redundancy available informs the importance of a link. Without any redundancy a link is pertinent, however, an important link identified by SNA may not be required within a system if there is another way of achieving the same end state. This more formative approach therefore compliments SNA by providing a validation of the statistical metrics based upon frequency of use.

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6 Biographies

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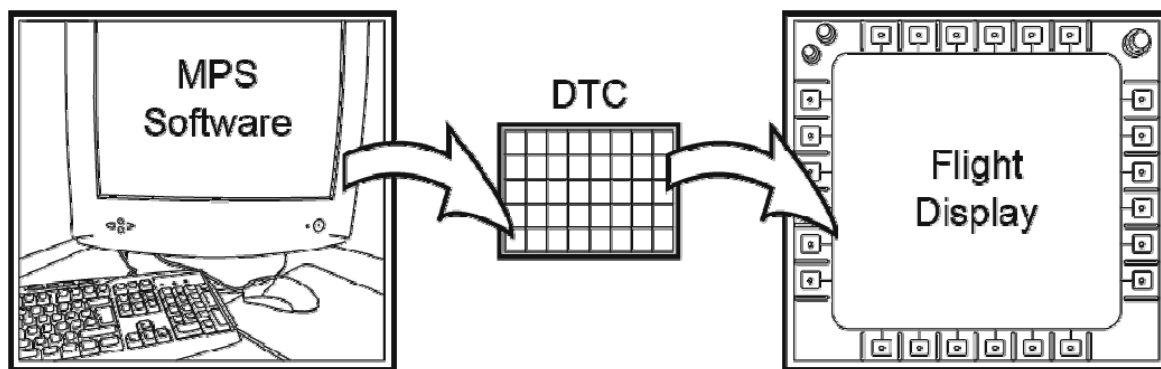


Figure 1 – The planning process transferring information between terminal and the aircraft

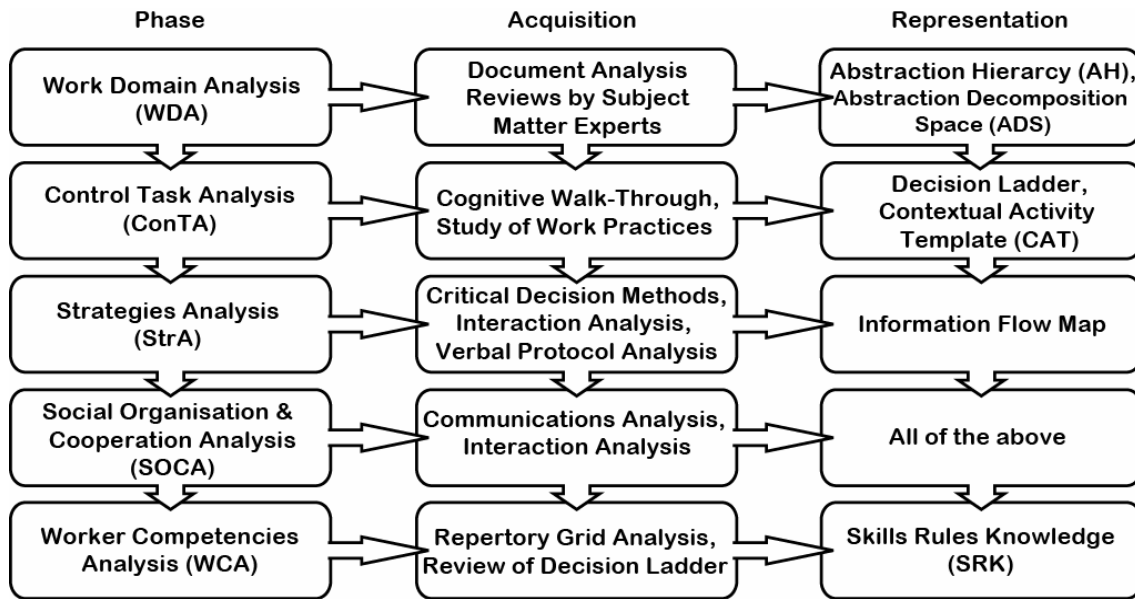


Figure 2 – The five phases of CWA according to Vicente (1999) (Acquisition methods added from Lintern *et al*, 2004).

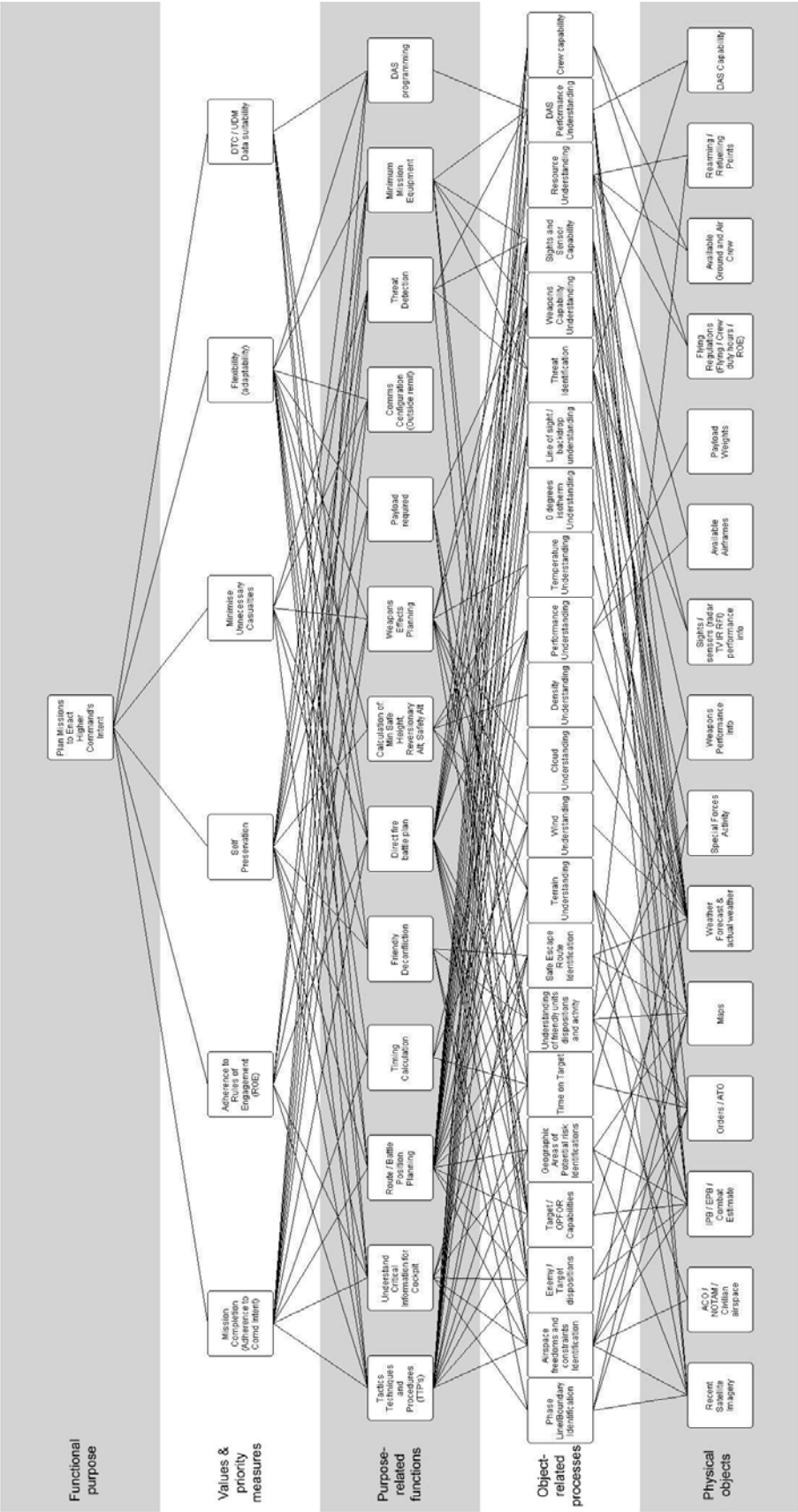


Figure 3 – MPS Abstraction Hierarchy

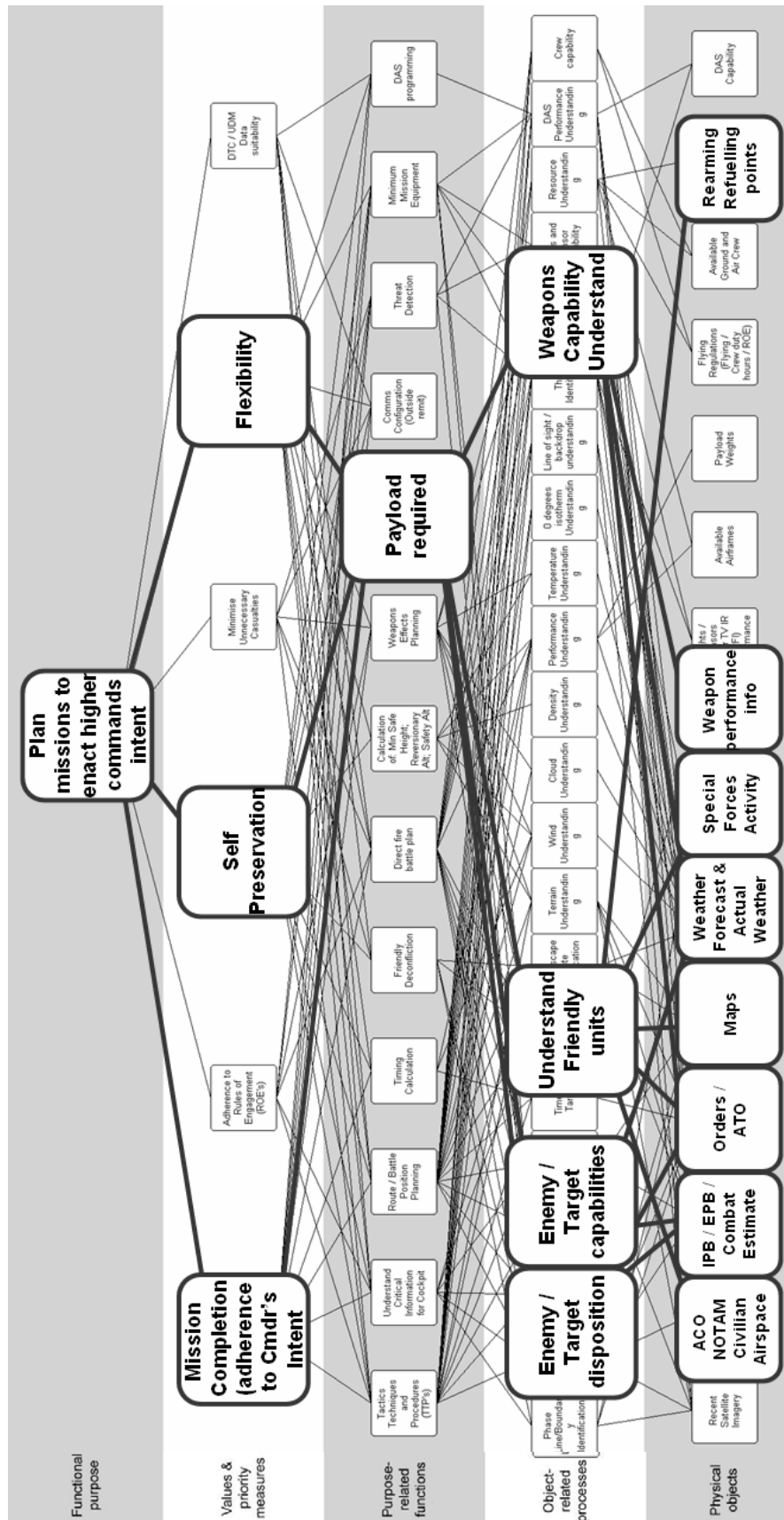


Figure 4 – Example

Decomposition Abstraction	Total System	Subsystem	Component
Functional purpose	Plan Missions to Enact Higher Command's Intent		
Values & priority measures	<div>Mission Completion (Adherence to Comd Intent)</div> <div>Self Preservation</div> <div>Flexibility (adaptability)</div> <div>Adherence to Rules of Engagement (ROE)</div> <div>Minimise Unnecessary Casualties</div>	DTC / UDM Data Suitability	
Purpose-related functions		<div>Payload Required</div> <div>Tactics Techniques and Procedures (TTDPs)</div> <div>Weapons Effects Planning</div> <div>Direct Fire Battle Plan</div> <div>Understand Critical Information for Combat</div> <div>Corms Configuration (Outside remit)</div> <div>Route / Battle Position Planning</div> <div>Friendly Deconfliction</div> <div>Threat Detection</div> <div>Timing Calculation</div> <div>Calculation of: Min Safe Height, Reversionary Alt, Safety Alt</div> <div>Minimum Mission Equipment</div>	DAS Programming
Object-related processes		<div>Target / OPFOR Capabilities</div> <div>Threat Identification</div> <div>Weapons Capability Understanding</div> <div>Understanding of Friendly Units Dispositions and Activity</div> <div>Performance Understanding</div> <div>Resource Understanding</div>	<div>Crew Capability</div> <div>Safe Escape Route Identification</div> <div>U degrees Isotherm Understanding</div> <div>Phase Line/Boundary Identification</div> <div>Airspace Freedoms and Constraints</div> <div>Enemy / Target Dispositions</div> <div>Cloud Understanding</div> <div>Sights and Sensor Capability</div> <div>IPB / EPB / Combat Estimate</div> <div>Orders / ATO</div> <div>Maps</div> <div>Geographic Areas of Potential Interest</div> <div>Density Understanding</div> <div>Temperature Understanding</div>
Physical objects			<div>Recent Satellite Imagery</div> <div>Weather Forecast & actual weather</div> <div>Flying Regulations (Flying / Crew duties, etc)</div> <div>NOTAM / Civilian Aircraft</div> <div>Special Forces Activity</div> <div>Available Airframes</div> <div>Signs / sensors (radar TV IR, etc)</div> <div>Rearming / Refuelling Points</div> <div>Payload Weights</div> <div>Weapons Performance Info</div> <div>DAS Capability</div>

Figure 5 – MPS Abstraction Decomposition Space

Using CWA to explore activity allocation

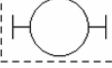

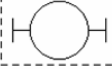





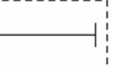
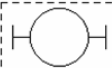
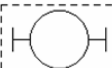
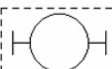
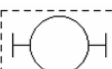






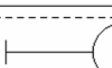








Situations Functions	Ground	Ground (Aircraft)	Ground (Farp)	Air
Route Planning				
Target Engagement Planning				
Payload Calculation				
Timing Calculation				
Tactics Development				
Calculation of: min safe height; reversionary alt; safety alt				
Inter-visibility Calculation				
Comms Configuration (Outside remit)				
Aircraft Performance Understanding				
Threat Detection				
Aircraft Weight Calculation				
Weapons Programming				
Radar Programming				
Radar Priority Scheme				
Resource Allocation				
Understand critical info for cockpit				
Minimum Mission Equipment				

Figure 6 – Contextual Activity Template

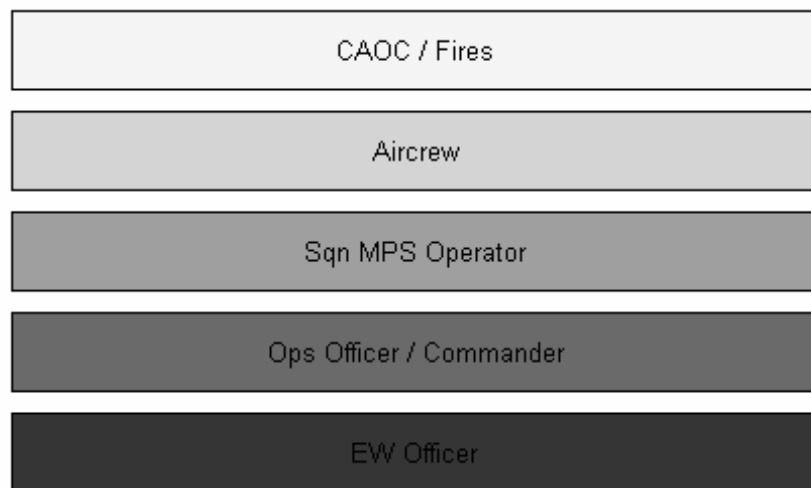


Figure 7 – Colour key for actors in the domain

Decomposition Abstraction	Total System	Subsystem	Component			
Functional purpose	Plan Missions to Enact Higher Command's Intent					
		Mission Completion (Adherence to Comd Intent)	DTC / UDM Data Suitability			
		Self Preservation				
		Flexibility (adaptability)				
Values & priority measures	Adherence to Rules of Engagement (ROE)					
	Minimise Unnecessary Casualties					
Purpose-related functions			DAS Programming			
	Payload Required	Direct Fire Battle Plan		Route / Battle Position Planning	Timing Calculation	
	Tactics Techniques and Procedures (TTPs)	Understand Critical Information for Combat		Friendly Deconfliction	Calculation of: Min Safe Height; Reversionary Alt; Safety Alt	
	Weapons Effects Planning	Comms Configuration (Outside remit)		Threat Detection	Minimum Mission Equipment	
Object-related processes		Target / OPFOR Capabilities	Understanding of Friendly Units Dispositions and Activity			
		Threat Identification	Performance Understanding			
		Weapons Capability Understanding	Resource Understanding			
Physical objects		Recent Satellite Imagery	ALU / NOTAM / Civilian Aircraft	IPB / EPB / Combat Estimate	Orders / ATO	Maps
		Weather Forecast & actual weather	Special Forces Activity	Signs / Sensors (radar TV / IR BFT waveform)	Payload Weights	Weapons Performance Info
		Flying Regulations (Flying / Crew Duties, etc.)	Available Airframes	Available Ground and Air Crew	Rearming / Refuelling Points	DAS Capability

Figure 8 – ADS coloured to show actors activity


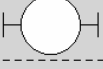

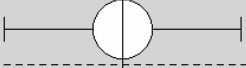
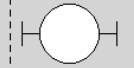
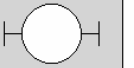



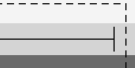


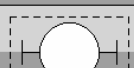

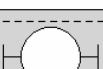
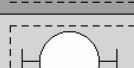
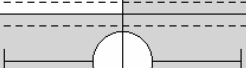



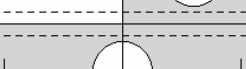







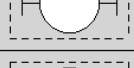
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Aircraft Weight Calculation				
Weapons Programming				
Radar Programming				
Radar Priority Scheme				
Resource Allocation				
Understand critical info for cockpit				
Minimum Mission Equipment				

Figure 9 – CAT coloured to show actors activity