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How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis

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ABSTRACT

This paper presents the application of Cognitive Work Analysis to the description of the functions, situations, activities, decisions, strategies, and competencies of a Trafalgar class submarine when performing the function of returning to periscope depth. All five phases of Cognitive Work Analysis are presented, namely: Work Domain Analysis, Control Task Analysis, Strategies Analysis, Social Organisation and Cooperation Analysis, and Worker Competencies Analysis. Complex socio-technical systems are difficult to analyse but Cognitive Work Analysis offers an integrated way of analysing complex systems with the core of functional means-ends analysis underlying all of the other representations. The joined-up analysis offers a coherent framework for understanding how socio-technical systems work. Data were collected through observation and interviews at different sites across the UK. The resultant representations present a statement of how the work domain and current activities are configured in this complex socio-technical system. This is intended to provide a baseline, from which all future conceptions of the domain may be compared. The strength of the analysis is in the multiple representations from which the constraints acting on the work may be analysed. Future research needs to challenge the assumptions behind these constraints in order to develop new ways of working.

1. Introduction

The discipline of Ergonomics has always been concerned with the theory, methodology and analysis of systems (Waterson and Eason, 2009; Dul et al., 2012) in both simple (Walker et al., 2009a) and complex (Walker et al., 2009b). Such analyses have been previously undertaken in aviation (de Carvalho et al., 2009; Harris and Stanton, 2010), healthcare (Carayon and Buckle, 2010; Jun et al., 2010), military (Walker et al., 2009b; Rafferty et al., 2010), road and rail (Stanton and Salmon, 2011) and sports (Salmon et al., 2010) domains. This paper is concerned with the analysis of a complex socio-technical system (Walker et al., 2010). Specifically, the aim of the paper is to help develop an understanding and explicit representations of how a submarine returns to periscope depth. The complexity of this system is in the problem of returning to the surface safely, whilst being dependant on passive sonar as a means of detecting surface vessels and working as a team comprising personnel the sound room, control room and ships control, as well as contributions from the rest of the ship. To analyse this system required the application of a method that would assist in identifying key features of the work and clarify the constraints. Cognitive Work Analysis (CWA) was developed to analyse complex socio-technical systems such as those found in nuclear power generation (Rasmussen, 1986). This development came from the realisation that an in-depth understanding of the interrelations of social systems and technical systems was required to fully appreciate how constraints act upon the working of system functions (such as the communications and activities in and between the sound room and control room on a nuclear submarine). These systems are made up of numerous interacting parts, both human and non-human, operating in dynamic, ambiguous and often safety critical-domains. The complexity embodied in these systems presents significant challenges for modelling and analysis and most methods are not well designed to capture the complexity of the interrelations and analyse the layers of interconnection within socio-technical systems (Jenkins et al., 2009; Vicente, 1999; Rasmussen, 1986). The semi-structured framework presented within CWA helps to guide the analyst through considerations of the various levels of constraints acting on systems and the effects that can have upon the way in which work can be carried out. The

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attraction of CWA is the flexibility of the approach and the range of domains to which is has been applied (Durugbo, 2012). It is generally accepted that CWA is divided into five main phases, each focussing on different constraint sets and presenting different perspectives on the system; the phase names are listed on the left-hand side in Fig. 1. In the centre of the figure, is an indication of the types of constraint analysis undertaken for these phases. The different forms of representation are listed on the right-hand side of Fig. 1.

The CWA process has been criticised for being complex and time consuming. In order to address these concerns, and in an attempt to provide some level of guidance and expedite the documentation process, a software tool has been developed (Jenkins et al., 2009). The software tool allows data to be passed between these phases, expediting the documentation process, and facilitating updates and changes. Thus, the tool provides structure to the analysis process and markedly expedites the documentation and presentation of the analysis results. There is the added benefit that it has standardised and proceduralised the process, although we do accept that there may be variations for those not using the tool.

Wilson (2012) identified six of the defining characteristics essential to Systems Ergonomics as: systems focus, context, interactions, holism, emergence and embedding. Any method that lays claim to be a Systems Ergonomics, such as EAST, should embody these characteristics. Table 1 indicates how EAST encapsulates these properties.

As the contents of Table 1 attest, CWA passes the 'systems' test. By analysing systems from the five phases of CWA enables the analyst to have different perspectives. CWA has a whole system focus, comprising both the social system and the technical system as well as their interactions (particularly in the SOCA phase). Emergent properties are described in terms of the strategies, decisions and activities of the system in particular situations. CWA is, perhaps, the epitome of a systems ergonomics method.

Table 1
Systems characteristics of CWA (adapted from Wilson, 2012).

Characteristic	Properties of CWA
Systems focus	Captures the whole socio-technical system in the five different perspectives and does not favour one system over the other.
Context	Analyses system behaviour at work using observations in context with input from Subject Matter Experts. System boundaries are defined by subject matter of interest as well as emerging during the course of the analysis.
Interactions	The interacting parts of the system are revealed in the in the SOCA phases in which functions are constrained by situations and actors (in SOCA-CAT), decisions and actors (in SOCA-DL) and strategies and actors (in SOCA-StrA).
Holism	The system analysis is based on the whole system, from the Abstraction Hierarchy and throughout all of the phases and representations. This is a significant strength of CWA.
Emergence	The emergent properties of the system are revealed through different phases of analysis, particularly in the Social Organisation and Cooperation Analysis phase were all of the previous phases are assigned agents. The function allocation process serves to bring the systems analysis together. The different perspectives offered by the analyses reveal the combined systems properties and their associated emergent properties.
Embedding	The method itself is embedded in the communications and systems engineering disciplines, so it offers familiarity to organisations wishing to scrutinise their socio-technical systems. It has the benefit of representing the system in diagrammatical form which supports communication with other engineers.

2. Visits, observations and interviews

The CWA software tool was used to construct the products in the presence of Subject Matter Experts. This has the benefit of showing them the process as well as the outcomes. The phases of analysis are shown in Fig. 1. It is important that phase one (construction of

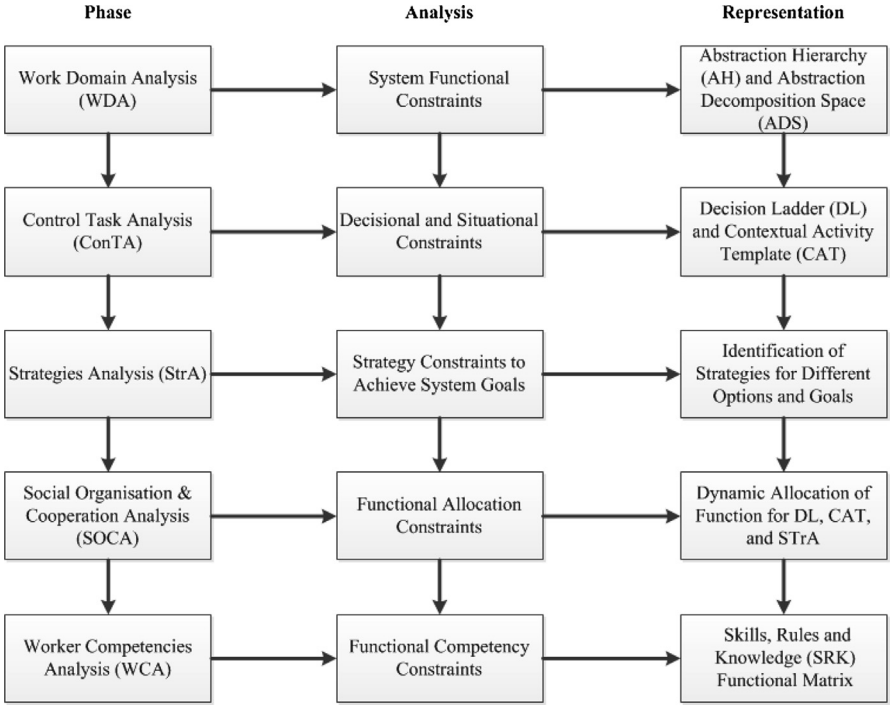

Fig. 1. The five phases of CWA adapted from Vicente (1999).