# Development of a Framework to Establish the Safety Benefits of Intelligent Transport Systems: The Use of Cognitive Work Analysis

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## Biography

Janet Anderson is a psychologist specialising in human factors and has recently submitted her PhD investigating the use of Cognitive Work Analysis to design auditory displays for patient monitoring in the operating theatre. She also has an interest in road safety research and in applying Cognitive Work Analysis to this domain. She is currently a researcher at the Monash University Accident Research Centre.

## Abstract

Cognitive Work Analysis is a system for analysing complex work domains. The results of the analysis can be used to design selection and training programs, design displays and interfaces and evaluate designs. In this paper the potential benefits of applying CWA to the problem of road safety are examined, particularly in relation to the introduction of ITS to vehicles. Finally, the development of a framework to explore the safety benefits of ITS by the use of CWA will be outlined.

## 1. COGNITIVE WORK ANALYSIS – AN INTRODUCTION

Cognitive Work Analysis (CWA) is a method for analysing the requirements for the design of complex socio-technical systems, with an emphasis on system safety. CWA developed from the work of the Danish Riso National Laboratory on the design of safe interfaces to control complex systems such as nuclear power plants (Sanderson, 2003). It arose from an understanding that complex systems often behave in ways that were unanticipated by system designers, and operators are therefore required to reason about the causes of unforeseen system states and correct them (Sanderson, 2003).

CWA is an approach that is recommended for open, as opposed to closed systems. A closed system is one in which operations are predictable and there are usually a limited number of options for successful completion of a task (e.g. creating a document using word processing software). In contrast, an open system is one that is subject to influences and disturbances that cannot always be foreseen. Because of the variability inherent in open systems it is not possible to specify in advance all the possibilities for action. Adaptation to the variability occurs in real time as operators manage the changing conditions. There are therefore many ways to fulfil task goals rather than a few specific courses of action that can be specified in advance (Vicente, 1999).

The task of driving a car safely and navigating a route successfully clearly takes place in an open system where variability can arise from a number of different sources. Variability can arise from environmental conditions, the performance of the engineered vehicle, the behaviour of other actors in the environment (pedestrians and drivers), traffic conditions, road conditions (closures, repairs), and navigation (following a route). Consequently, the application of CWA to driving, with the aim of improving driver safety, could be beneficial.

CWA has previously been applied to many domains, all of which have unique features and differences, often requiring modifications and extensions to the form of the analysis itself (see Vicente 2002 for a review). For example, it has been used to develop displays for nuclear power plants (Reising, Sanderson, Jones, Moray and Rasmussen, 1998), a chemical engineering process (Olsson and Lee, 1994), military aviation (Dinadis and Vicente, 1999), software engineering (Leveson, 2000), and intensive care units (Sharp and Helmicki, 1998).

The technique aims to identify how reasoning about unexpected system states can be supported so that operators can take the appropriate corrective action. It does this by modelling the constraints within which operators must function (Vicente, 1999). CWA concentrates on analysing the functional structure of the work domain because the structure of the work domain constrains the actions that can be taken by an operator. If that structure can be represented to the operator the possibilities for action will be clear. A constraint-based approach does not specify procedures. Rather, it concentrates on the requirements that need to be satisfied for effective task completion (Vicente, 1999).

## 2. CWA PHASES OF ANALYSIS

CWA consists of five phases of analysis that focus on different types of constraints on operator behaviour. A description of the five phases is contained in Table 1.

**Table 1: The five stages of CWA**

| CWA phase | Description |
|---|---|
| Work Domain Analysis (WDA) | Provides information about the purpose and functions of the work domain and identifies what information needs to be displayed to the operator |
| Control Task Analysis (CTA) | Provides information about what tasks need to be completed in the work domain |
| Strategy Analysis (SA) | Provides information about different strategies for carrying out tasks |
| Social Organisational Analysis (SOA) | Provides information about how work is shared and co-ordinated across multiple actors in a complex organisation |
| Worker Competencies Analysis (WCA) | Provides information about the competencies needed for a task based on the skills, rules, knowledge taxonomy |

We argue that all five phases of CWA have a contribution to make to understanding driver behaviour and how to support drivers in driving safely. We argue that such understanding and support cannot be separated from a systematic analysis of the constraints in which they operate.

## 3. CHALLENGES

Although CWA has been applied to a number of different domains, it has not to the knowledge of the authors been systematically applied to driving and road safety. The domain has some unique characteristics that would pose a challenge to carrying out these analyses, possibly requiring the form of the analysis to be modified. There are three major challenges.

First, the driving task involves controlling a physical process (engine control, speed control, braking) and controlling intentional actions (navigating a route in the presence of other vehicles that have unpredictable trajectories). When the actions of the driver are not constrained by physical processes, but are initiated by intentions, it becomes more difficult to successfully model the constraints of the process. There are, however, examples in the literature of its successful application to intentional domains (see for example, the Book House project, described by Vicente, 1999).

Second, the time available for driver decision-making and reaction in critical situations is usually very short. This is in contrast to other domains where there is usually a longer time available for problem solving. The need for quick reactions means that the advantages of supporting driver flexibility might need to be weighed against the need to constrain the options for driver behaviour simply because there is not enough time for the driver to process the information available in the environment and generate action alternatives.

Third, there is a high demand on visual attention in driving, and it is not feasible to continue introducing visual displays into car cockpits. Presenting information to different sensory modalities is a possible solution, but co-ordinating the interaction of information in different modalities will become important. The analysis techniques discussed here may need to be developed to allow the mapping of information across modalities to be co-ordinated. Such a framework has already been suggested by Sanderson, Anderson and Watson (2000) and could be further developed in this domain.

In the following sections we identify how the different phases of CWA could be applied to improving safety and human-system integration in the driving domain.

## 4. SELECTION AND TRAINING

Selection and training of drivers occurs through the licensing system. CWA provides a method for formalising the skills that drivers must demonstrate in order to be licensed. Traditional approaches to driver selection and training have emphasised the practice of procedural actions and knowledge, often at the expense of problem solving. In routine situations training in routine procedures and behaviours can be effective. However, when drivers are confronted with an unanticipated situation the actions they take cannot be specified in advance and they need to adapt their behaviour to cope with the situation (Naikar and Sanderson, 1999). The constraints based approach taken by CWA ensures that dealing with unanticipated variability is incorporated into training systems and provides an important adjunct to other instructional methods which have recently been developed for this purpose (e.g. Regan, Triggs & Wallace, 1999)

CWA has previously been used to identify training needs for the Australian Defence Force's F/A-18 fighter aircraft. Naikar and Sanderson (1999) showed that the functional structure of the work domain could be used to structure training programs. They used the work domain analysis to derive the objectives of training, the measures of performance, the components of basic training and the components of training in physical functionality. The control task analysis phase could also be used to generate training scenarios.

## 5. DEVELOPMENT OF DESIGN REQUIREMENTS

Analysing design requirements is a more complex use of CWA. An analysis of driving could be carried out from different perspectives. Dividing a CWA analysis into subsets is a strategy that has been used to successfully deal with the complexity of analysing large systems and the difficulty of defining a clear boundary for the analysis (Burns, Bryant, et al, 2000). A high level analysis of the driving environment would analyse the design requirements for the road system, traffic engineering, traffic management strategies and regulatory frameworks, all of which impact on driver safety.

An analysis from the individual driver's perspective could address the requirements for the design of safe vehicles. A work domain analysis, combined with a control task analysis, strategies analysis and social analysis could examine the issue of allocation of function within the car cockpit. The allocation of functions to humans and automation could be addressed, as well as the allocation of functions to drivers and passengers. For example, there is converging evidence that passengers play a critical role in moderating the crash risk of young drivers and, through them, their own crash risk, and it has been suggested that their potential role as "co-pilots" has not been realised (Regan and Mitsopoulos, 2001).

The evaluation of design proposals using a CWA framework is also possible. Naikar and Sanderson (2001) used work domain analysis to evaluate tenders for the design of Australia's new Airborne Early Warning and Control platform. They used WDA to evaluate the tenders against the high level purposes of the system (derived from the WDA), which are viewed as of equal importance to the technical specifications. At a later stage they used work domain analysis, control task analysis and social organisational analysis to develop a recommendation for the optimal team structure and allocation of team functions for the new platform (Sanderson, 2003). In the road safety domain, the CWA framework could be used as part of the road safety auditing process to ensure that the design of the road system is ergonomically compatible with driver processing capacities and limitations.

## 6. DISPLAY DESIGN

For display design two phases of CWA are usually used: work domain analysis and worker competency analysis (Vicente, 2002). Work Domain Analysis is the first stage of cognitive work analysis. It analyses the purpose, values, functions and components in the work domain, and the relationships between them and the constraints governing them (Vicente, 1999). Analysing the work domain involves constructing a hierarchy that represents the system at five levels of abstraction: functional purpose, abstract function, generalized function, physical function and physical form. A work domain analysis of driving would include both formal information, such as traffic signs and signals, and informal information, such as traffic density, speed and movements. At this stage of analysis the information that needs to be incorporated in a display is identified.

Worker Competency Analysis uses the taxonomy of three levels of worker competencies, the skills, rules, knowledge taxonomy, to analyse how information should be represented. Skill based behaviour is controlled by perceptual motor skills, rule based behaviour involves the retrieval of rules from memory, and knowledge based behaviour is analytical problem solving and reasoning. While the display should aim to support all of these competencies, however knowledge based reasoning is laborious and error prone. For this reason lower levels of control (i.e. skill based and rule based behaviour) are preferred (Vicente, 1999).

One of the emerging human factors issues in road safety research is whether information should be displayed to drivers inside the vehicle or outside it. In future the division between the vehicle interior and exterior will be blurred by the ability to present traffic signs and signals to drivers inside the car. This development has great potential to burden drivers with too much information and one of the benefits of a work domain analysis and worker competency analysis might be to resolve the issue of where information should be displayed. In the following section we examine the problems inherent in the introduction of Intelligent Transport Systems (ITS) to vehicle cockpits and suggest ways that CWA might help to ameliorate them.

## 7. INTELLIGENT TRANSPORT SYSTEMS

ITS have the potential to improve driving safety and efficiency by providing support to the driver in a variety of ways. For example, these systems can provide route navigation information, speed and distance warnings, collision warnings, fatigue monitoring, and traffic condition information. However, unless they are ergonomically designed, these devices also have the potential to increase the amount of information that the driver has to detect, process and act upon (Regan et al., 2001). If they are not, there is likely to be an increase in the cognitive, visual, auditory and even physical demands of the driving task. In addition, these devices could distract a driver's attention from important information in the road environment.

The rapid growth of ITS has often seen these devices being developed and introduced as the technology becomes available, without systematically evaluating from a driver centred perspective how these devices would be integrated into the car cockpit, how they might interact with each other and how the driver could interact with them. For example, it is important to consider what information would be most useful to drivers, how it should be presented to them (perceptual modality, timing, and interface form) and how devices might direct and control the driver's attention.

A work domain analysis would identify what information is needed by drivers and could potentially reduce the demands on drivers by eliminating unnecessary displays. A worker competency analysis would help to determine the optimal form of displays, given the high demands on drivers' attention. For example, multi-modal displays that take advantage of auditory and haptic perception are likely to be useful to reduce the load on visual attention.

## 8. RESEARCH PROGRAM

The MUARC team will shortly be engaging in research to develop a framework to assess the safety benefits of ITS by using CWA and other data. The overall aim of the research program is to help improve safety and efficiency in the road environment by designing ITS to better support the driving task. To achieve this, the MUARC team will undertake a full cognitive work analysis of driving, in particular focussing on how CWA might lead to better design and implementation of ITS. The authors hope that the use of this new and exciting methodology, which has been applied in other safety critical applications, will be a productive new direction for a variety of research, development, implementation and evaluation projects in the field of road safety.

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**Keywords**

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