Cognitive Work Analysis and Road Safety: Potential Applications in Road Transport

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ABSTRACT

Cognitive Work Analysis (CWA) offers a comprehensive methodological framework for the design, representation, and evaluation of complex, socio-technical systems and their component technologies. This article describes research that was conducted to examine the potential for applying methods from the CWA framework within the road transport domain. The research involved a review of the CWA framework, a review of the previous CWA applications reported in the literature, the identification of potential CWA-related applications in the road transport domain, and the conduct of a series of exploratory road transport CWA applications. The findings indicate that there is great potential for applying CWA-related methods and principles in the road transport domain, in particular during the design, development and evaluation of driver training programs and the design, development and analysis of road transport-related technology and artefacts, including intelligent transport systems, vehicle cockpits and road signage, layout and furniture. An exploratory work domain analysis of the Victorian road transport system is presented. It is concluded that the application of CWA within the road transport domain is an appropriate concept to pursue, and that the CWA applications identified could potentially contribute to the enhancement of road user behaviour and safety within the Australian road transport system.

Keywords: Cognitive Work Analysis, road transport system, road safety.

INTRODUCTION

The principles of Ecological Interface Design (EID) are used to inform the user-centred design of interfaces, systems and procedures. An ecological design refers to an artefact that has been designed to reflect the constraints of the work environment in a way that is perceptually available to the people who use it (Burns & Hajdukiewicz, 2004). That is, users will be able to take effective action with the interface and understand how those actions will move them towards the achievement of their goals (Burns & Hajdukiewicz, 2004). One EID-related approach that is currently receiving increased attention is the Cognitive Work Analysis framework (CWA; Vicente, 1999). CWA offers a comprehensive methodological framework for the design, development, representation and analysis of complex socio-technical systems. CWA was originally developed at the Risø National Laboratory in Denmark (Rasmussen, Pejtersen and Goodstein, 1994) and unlike traditional cognitive task analysis approaches, which are used to describe the cognitive aspects of activity within a particular system, is used to provide an in-depth analysis of the various constraints that shape activity within the system. CWA focuses upon the properties of the work domain, tasks, artifacts and agents that constrain activity within a particular system. According to Sanderson (2003):

> *"(CWA) is an approach to analysing, modeling, designing and evaluating complex systems. CWA does not focus on how human-system interaction should proceed (normative modeling) or how human-system interaction currently works (descriptive modeling). 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 modeling)." (Sanderson, 2003)*

This article describes a program of research that was conducted to examine the potential for applying methods from the CWA framework within the road transport domain. The research involved a review of the CWA framework, a review of the previous CWA applications reported in the literature, the identification of potential CWA-related applications in the road transport domain, and the conduct of a series of exploratory road transport CWA applications.

COGNITIVE WORK ANALYSIS

The CWA framework comprises five different but inter-related phases: work domain analysis; control task analysis; strategies analysis; social organization and co-operation analysis; and worker competencies analysis. A brief description of each phase is provided below:

1. Work Domain Analysis (WDA). The first CWA phase involves modeling the system in which the activity takes place. A WDA is used to identify the functional purpose and structure of the work domain in terms of the overall system goals, the processes adopted and the artifacts used within the system. In modeling a system in this way, the system constraints that modify activity within are specified.
2. Control Task Analysis. The second CWA phase involves the identification of the tasks that need to be performed within the system under analysis. A control task analysis is used to determine what tasks are undertaken, regardless of how they are undertook or who undertakes them.
3. Strategies Analysis. The third phase of a CWA involves the identification of the strategies that the agents involved might employ when conducting the control tasks identified during the control task analysis phase.
4. Social Organisation and Co-operation Analysis. The fourth CWA phase involves identifying exactly how the control tasks are distributed between agents and artifacts within the system.
5. Worker Competencies Analysis. The fifth phase involves identifying the cognitive skills that agents employ during control task performance. Worker competencies analysis uses Rasmussen's Skill, Rule, Knowledge (SRK) framework in order to classify the cognitive activities employed by agents during control task performance.

The CWA procedure uses a number of loosely defined methodologies, including abstraction hierarchy, decision ladders, information flow maps and the (SRK) framework. The different phases of CWA and the associated methods used are presented in table 1.

Table 1. CWA phases and methods used

CWA Phase	Purpose	Methods Used
Work Domain Analysis	To identify and describe the functional purpose and structure of the work domain under analysis	Abstraction Decomposition Space (ADS)
Control Task Analysis	To identify and describe the tasks required during activity in the system under analysis	Decision Ladders
Strategies Analysis	To identify the strategies that the agents involved may employ during task performance	Information Flow Maps
Social Organisation and Strategies Analysis	To identify exactly how the control tasks are distributed between agents and artefacts within the system	Abstraction Decomposition Space Decision Ladders Information Flow Maps
Worker Competencies Analysis	To identify the cognitive skills that agents employ during task performance	Skill, Rule, Knowledge (SRK) framework

CWA APPLICATIONS

As a result of the literature review, CWA applications were identified in the following domains: aviation (e.g. Naikar & Sanderson, 2001), process control (e.g. Vicente, 1999) nuclear power (e.g. Olsson and Lee, 1994), Naval (e.g. Bisantz, Roth, Brickman, Gosbee, Hettinger & McKinney, 2003), military command and control (e.g. Salmon, Stanton, Walker & Green, 2004), road transport (e.g. Stoner, Wiese and Lee, 2003) health care (e.g. Miller, 2004), air traffic control (e.g. Ahlstrom, 2005) and manufacturing (e.g. Higgins, 1998). Additionally, the literature review indicated that the methods within the CWA framework have been used for a number of different purposes, including:

- work domain modeling;
- system design;
- training needs analysis, training program evaluation and design;
- interface design and evaluation;
- information requirements specification;
- tender evaluation;
- team design; and
- error management strategy design.

A number of general conclusions regarding the potential application of CWA in the road transport domain were made. A summary is presented below:

- the different CWA phases and methods can be applied throughout the design life cycle;
- its flexible nature is such that it can be used for a variety of purposes, ranging from training design and evaluation to information requirements specification;
- the CWA methods are generic and can be applied in any domain;

- the WDA component is the most commonly used CWA phase. Consequently, the abstraction decomposition space is by far the most developed of the CWA methods and has the most published literature associated with it;
- the social-organisation and co-operation analysis and worker competencies analysis components have received only limited attention and consequently there is very little published literature regarding the application of these phases;
- analysis requirements dictate which of the CWA phases and methods are applied in a particular analysis effort. For example, for system modeling purposes, only the work domain analysis component may be required;
- due to the comprehensive nature of the CWA framework, CWA efforts typically require substantial resources and produce large and complex outputs;
- CWA analyses efforts typically involve the use of a multi-disciplinary team of analysts;
- CWA inputs include interviews with appropriate subject matter experts, relevant documentation (e.g. training manuals, rules and regulations, standard operating procedures etc), observational study, verbal protocol analysis data, and task analyses; and
- CWA is a complex approach and practitioners wishing to use it may require considerable training in the various methods involved;

CWA AND ROAD TRANSPORT

The next phase of this research involved identifying and investigating potential CWA applications in the road transport domain. Initially, the five phases of the CWA framework were defined in relation to the road transport domain (see table 2). The previous application areas identified above were then discussed with regard to their potential application within road transport. A brief summary of the most pertinent CWA road transport-related applications is presented below.

Table 2. Road transport CWA phases

CWA phase	Description in relation to the road transport domain
Work domain analysis	Provides information about the purpose and functions of the road transport system and identifies what information about the environment needs to be displayed to different road users.
Control task analysis	Provides information about what tasks need to be completed in order to safely and efficiently perform activity (e.g. drive) within the road transport system
Strategy analysis	Provides information about different strategies for carrying out the tasks
Social organisation analysis	Provides information about how activity within the road transport domain is co-ordinated across multiple actors
Worker competencies analysis	Provides information about the human information processing competencies required for activity within the road transport system (e.g. driving, walking, cycling etc)

Work Domain Modeling

The WDA component of CWA has been primarily used to model systems in a number of different domains. WDA is conducted at the functional, rather than behavioural level, and describes the boundaries that shape behaviour within a particular system, rather than the activity that actually takes place. The main features of a WDA are that it defines the reasons for behaviour within the system (functional properties) and it also defines the resources available for behaviour (physical properties). As WDAs are event independent, a road transport WDA would be relevant to a variety of different situations. One of the key outputs of modeling the road transport system in this way would be a description of the types of information that each road user group requires in order to achieve their goals. This has a number of uses, particularly in the design and evaluation of road transport-related technology. Modeling the road transport system using WDA has a number of additional benefits, including that it would:

- provide a simplistic model of the complex road transport system;
- describe the various constraints that impact road user behaviour in Australia;
- define the resources currently available for performing activity within the road transport system;
- describe the different types and sources of information that are used by different road user groups when performing activity;
- define the different stakeholders within the Australian road transport system.

Using WDA to model the road transport system from the point of view of the different stakeholders (e.g. drivers, authorities, police, pedestrians, vehicle manufacturers etc) within the system would also be useful. This would allow the identification of competing and conflicting purposes, values and priorities within the road system. For example, it may be that road transport infrastructure designers and road users have conflicting purposes, values and priorities, which may impact activity and safety within the road transport system. To demonstrate with a simple example, it may be that designers have the functional priority of designing a particular road system so that it can cater for more traffic and at higher speeds, whilst one of the road user functional priorities may be to travel safely and efficiently between a starting point and a desired end-point. The conflict in this case would be the designers trying to cater for a greater volume of traffic traveling at a quicker speed and the road users requiring safe and efficient travel. Such conflicts impact the design process, and so the outputs of road transport system WDA could be used to inform the future design of road transport systems. In addition, more useful conflicting purposes, values and priorities with regards to road safety might be highlighted between different road transport authorities and groups, and also between the relevant road transport authorities and different road user groups. Such information could be particularly useful for the design of road transport policies, strategies and technology.

Training

The CWA framework is particularly suited to training needs analysis, training program design and training program evaluation. The work domain analysis, control task analysis, strategies analysis and worker competencies analysis could be used to identify driver training needs and training functions, which in turn could be used to develop novel driver training programs. According to Naikar, Lintern & Sanderson (2002), CWA can inform training design in powerful ways that focus more on satisfying the functional purposes of a work domain by adapting behaviour rather than by evoking procedures. Naikar & Sanderson (1999) used the WDA component of CWA to conduct a training needs analysis for F/A-18 pilots. According to Naikar & Sanderson (1999), the functional structure of the work domain (as described by the work domain analysis) can be used as the basis for defining training needs, as each level of the abstraction hierarchy identifies particular training needs. It was therefore concluded that CWA could be used to conduct a training needs analysis within the road transport domain. This could be used to determine whether or not contemporary driver training programs are providing sufficient levels of appropriate

training and in the correct manner to drivers within Australia. CWA could also potentially be used in the evaluation of existing driver training programs. At present, there is a lack of structured methods available to support the evaluation of existing driver training programs, and it appears that CWA is an appropriate methodology to use for this purpose, since it can be used to define the training needs for a particular system.
It was therefore concluded that the CWA framework be used in the future for assessing and evaluating driver training programs.

Design
In the past CWA has been most commonly used in the design and evaluation of novel interfaces, artefacts and complex systems. For example, Ahlstrom (2005) describes the use of the CWA framework in the development and design of weather display concepts. Bisantz et al (2003) describe the use of CWA in the design of a next generation US Navy Surface combatant. Vicente (1999) describes the application of CWA to the Dual Reservoir System Simulation (DURESS II), which involved the development of interfaces that support human operators faced with unanticipated variability (Sanderson 2003). One particularly useful aspect of the framework is that it can be used to inform the design of so-called 'first-of-a-kind' systems. It was therefore concluded that CWA could potentially be used in the design and development of novel artifacts and interfaces within the road transport domain, including ITS technologies, in-car interfaces, vehicle cockpits, road signage and furniture and road infrastructure and layout. There are a plethora of potential design and evaluation-related applications that the CWA methods could be used for, a summary of which is given below:

- design of novel driver interfaces;
- evaluation of existing driver interfaces;
- design of novel vehicle cockpits;
- evaluation of existing vehicle cockpits;
- road sign design (e.g. variable messaging systems);
- evaluation of existing road signs;
- intelligent transport system (ITS) design;
- evaluation of existing ITS's;
- road furniture design;
- road infrastructure design (e.g. road layouts etc);
- evaluation of existing road furniture;
- assessing the potential impact of alternative design solutions on the road transport domain; and
- tender evaluation.

Information Requirements Specification
What information is presented to end-users and in what form the information is presented are important features to consider during the design process. Presenting the wrong information in the wrong manner can have a detrimental effect upon task performance as it can potentially increase user mental workload, attentional demands, and decrease or inhibit situation awareness. To ensure that a particular system or interface presents the appropriate information in the correct manner to its users, information requirements analysis is typically used. There are a number of ways to conduct an information requirements analysis, including through the use of interviews with SMEs and also the development of task analyses for the system or artefact in question. CWA appears to be particularly suited for information requirements analysis. The methods within the CWA framework have been

used in the past for information requirements specification purposes in a number of different domains. A WDA can be used to model the system in terms of the information required to support activity at each different level of representation of the system, or each of the different ways in which users can think about the system. In modelling the system in this way, a comprehensive breakdown of the information required by agents performing activity within the system is presented. This allows designers to exhaustively define the information requirements for a particular interface or system. Potentially, each of the cells within an ADS can define a set of information requirements for a particular device or system. For example, Salmon et al (2004) used the ADS in this way to specify the information requirements for a command and control knowledge wall display. Stoner et al (2003) used the ADS to identify the types of information that driver support systems should be presenting to drivers. Ahlstrom (2005) also describes the use of the ADS for determining the types of information that air traffic controllers require for effective performance during adverse weather conditions. CWA could be used in this way to support the design of interfaces throughout the road transport system, including vehicle cockpits (general, law enforcement etc), road signs, and also ITS technologies. The information requirements could be determined for different road user groups, and also for different technological artifacts within the road transport domain. It might be that drivers are currently overloaded with information from both the vehicle and the road infrastructure, and that some of this information is useless in relation to the driving task and individual driver goals. It might also be, on the other hand, that drivers currently are not receiving adequate informational support during the driving task, and that they require further information when driving. A WDA could potentially define the information content that drivers and other road user require, which component of the system (e.g. vehicle, road infrastructure, road furniture, road signage, ITS) should be presenting the information to them, and in what form the information is best presented so that it is compatible with their capabilities. A WDA could be used to determine the optimal information that each road user group (e.g. drivers, pedestrians etc) requires.

Further Applications

A number of further CWA applications were identified, but it is beyond the scope of this report to describe them fully. A brief summary of selected applications is presented below:

- allocation of functions analysis. The CWA framework could potentially be used for allocation of functions analysis purposes within the road transport system. In particular, the work domain, control task, strategies and social organization and co-operation analysis components could potentially be used to determine the optimal distribution of driving tasks between the driver, the vehicle and passengers i.e. which aspects of driving task should be allocated to the driver, the passengers or to automation or in-vehicle technology.
- Problem solving trajectories. Studies conducted by Rasmussen (1979; cited in Vicente, 1999) demonstrate that experienced workers spontaneously switch between different models of the work system in order to match their task demands. Similar applications in the road transport domain could be of use. For example, novice, expert and elderly driver verbal protocol analysis data could be mapped onto a work domain analysis of the driving domain to indicate how they ‘think’ about the work system during driving. It may be that different drivers adopt different problem solving trajectories when driving or think about the driving task and system in different ways. This has a number of implications, including for the design of technology and artifacts within the road transport system in terms of how designs cater for the different ways in which drivers

approach and think about the driving task. A particular device may support one driver's way of thinking about the driving task, but it may inhibit another drivers approach to the driving task. Such a study would also yield particularly interesting results which could potentially explain the differences in behaviour of different driver groups (e.g. elderly, young, expert drivers). Consequently, the evaluation of designs for such systems must determine whether particular designs offer support for a variety of work patterns in a dynamic work space (Naikar & Sanderson, 2001). According to Naikar & Sanderson, using an abstraction hierarchy for the evaluation of designs allows the physical features of the design to be evaluated in terms of how they support the functions and objectives of the work domain and also the interactions among physical devices to be evaluated.

- error management strategy design. One current theme that is receiving attention within complex, sociotechnical systems is the concept of error management. It was concluded that the CWA framework could potentially be employed in the development of error detection and management strategies for different road user groups e.g. pedestrians and drivers.
- situation awareness (SA) requirements analysis. Before an assessment of SA can be made, a SA requirements analysis is required in order to determine what optimal SA comprises in the system in question. Road user SA assessments require the provision of an initial SA requirements analysis. CWA, in particular the WDA component, is appropriate for SA requirements analysis purposes, as it defines the information required for effective performance.
- CWA and intersections. Intersections are over represented in road traffic accidents, and the design of intersections is a complex theme that is currently receiving attention from the road transport community. It was concluded that CWA be used in the design and evaluation of intersections. For example, WDA could be used to determine the optimal information requirements for drivers negotiating intersections, and the control task analysis and strategies analysis could be used to determine the tasks and strategies required for existing problematic intersections sites. CWA could also be used to evaluate current intersection designs and develop novel intersection design concepts. In particular the information and support provided to road users at intersections could be analysed, and novel suggestions could be proposed.

EXPLORATORY ROAD TRANSPORT ANALYSES

To demonstrate the potential of CWA as a design and evaluation tool for use in road transport, a series of simplistic road transport CWA analyses were conducted. Due to the limited resources available, only an initial WDA of the Victorian road transport system, a social-organisation and co-operation analysis of the Victorian road transport system, and a WDA for ITS technologies was conducted. It is beyond the scope of this article to fully present the analyses, however, a brief overview of the Victorian road transport WDA is presented in table 3. The aim of the WDA was to develop a simplistic model the Victorian road transport system. The WDA analysis involved the development of an ADS based upon the subjective judgment of the authors, and a variety of inputs, including the VicRoads website, Transport Accident Commission (TAC) Website, and various road transport rules and regulations related information. Due to the limited resources available, the use of information collection procedures such as road user interviews, walkthroughs and questionnaires was not possible.

The ADS presented in table 3 provides a simplistic model of the Victorian road transport system. The ADS uses five levels of abstraction, ranging from the most abstract level of purposes to the most concrete level of form (Vicente, 1999). A description of each of the five abstraction hierarchy levels is given below.

- *Functional purpose*: - The overall meaning of the system and its purpose in the world,
- e.g. system goals at a high level.
- *Abstract function*: - General and symbolic level of the system, e.g. descriptions in mass or energy terms to convey flow through the system.
- *Generalised function*: - Generalised processes of the system that reflects behavioural structure, e.g. diagram of information flow and feedback loops
- *Physical function*: - Specific processes related to sets of interacting components, e.g. specific sub-systems, such as electrical or mechanical.
- *Physical form*: - Static, spatial, description of specific objects in the system in purely physical terms, e.g. a picture or mimic of the components.

At the total system level, the WDA indicated that the overall purpose of the road transport system was to provide, “safe, efficient, enjoyable, and comfortable transportation of people and goods”, or, “safe, efficient, enjoyable and comfortable mobility”. Abstract functions (e.g. criteria used to measure the systems progress towards its functional purposes) include crash statistics and databases, road toll statistics, travel times, road user satisfaction, road user risk, comfort, safety and pleasure and insurance crash data. The physical function was defined as the transportation of people and goods from a start point to a desired end point, traffic dynamics and the capability and functionality of the road system. Finally, at the total system level the physical forms (the physical objects in the system that afford the physical functions) identified were: vehicles (including cars, trucks, bicycles, lorries etc); road users; road furniture; road signage; road layout; environmental features; and meteorological features.

At the sub-system level (e.g. road system and infrastructure level), the functional purposes, “provide the environment required for safe, efficient, enjoyable and comfortable transportation of people and goods”, and, “facilitation of safe, efficient, enjoyable and comfortable transportation of people and goods” were specified. External constraints at this level included physical and spatial constraints such as road layout and road traffic rules and regulations. The generalised functions (e.g. general functions required for achieving the functional purposes) identified included, “safe and efficient driving” and “adherence to road traffic rules, regulations, laws and legislation”. The physical functions identified at this level included directing road users, informing road users, controlling road user behaviour, restricting and affording road user movement and providing efficient, appropriate layout, labelling and design of the road system. The physical forms identified at this level included road type (e.g. freeway, arterial etc), road markings, layout, signage, furniture, composition, measurements, surface features, additional roadside objects and road infrastructure topography.

The third and final level of decomposition was the component, consisting of road users and vehicles. The functional purposes identified at this level included for vehicles, “to provide the means for safe, simplistic, comfortable, efficient and enjoyable transportation” and for road users, “to manoeuvre safely and efficiently from starting point to desired destination”. The external constraints for vehicles included safety requirements and regulations, vehicle design guidelines and standards, and vehicle safety standards, vehicle roadworthiness. The abstract functions identified included vehicle safety testing, performance testing and driver satisfaction. The external constraints for road users included crash, fatality and injury statistics, road user satisfaction, driver licensing and testing, travel times and road safety campaigns. The generalised function level was divided into three components: vehicles, drivers and pedestrians. Vehicle generalised functions included the physical dynamics (e.g. movement, velocity, manoeuvrability, speed etc), safety, comfort and maintenance of the vehicle. Driver generalised functions included vehicle control input, safe, compliant and efficient driver behaviour, adherence or compliance to road traffic rules, and destinations, planned routes and alternative routes. Pedestrian generalised function included safe, compliant and efficient pedestrian behaviour, adherence or compliance to road traffic rules, planned routes and alternative routes, and physical movement from starting point to desired destination. At the physical function level, vehicle functionality, capability, limitations and status and transportation of driver and passengers from start point to desired end destination were identified as the vehicle related physical functions. Driver physical functions included control or drive the vehicle, moving the vehicle from a start point to desired destination and driver functionality, capability and limitations. Pedestrian physical functions included walking and pedestrian functionality, capability and limitations. The physical form level included the physical components that make up road transport vehicles, including vehicle model and colour, vehicle control components (e.g. steering wheel, accelerator, brake etc), ITS, safety devices, other in-car components (e.g. radio etc) external vehicle components (e.g. windscreen wipers etc), drivers and passengers.

The exploratory analysis has a number of pertinent implications for the future design and development of the road transport system, infrastructure, vehicles and technologies. Due to the size limits imposed on this article, they cannot be discussed in full here. However, a summary of selected conclusions is presented. The WDA of the Victorian road transport system provides a simplistic model of the complex road transport system in Victoria, and defines the resources available for activity, the constraints imposed on activity within the system, the different stakeholders that are part of the system and also the functional properties and purposes of the road transport system in terms of the overall system goals, the processes adopted and the artifacts used within the system.

Table 3. Australian Road Transport System work domain analysis

	Total System *Road Transport System*	**Sub-System** *Road Infrastructure*	**Component** *e.g. Drivers, Vehicles and pedestrians*
Functional Purpose	*Purposes* • Safe, efficient, enjoyable, comfortable transportation of people and goods; • Safe, efficient, enjoyable, comfortable mobility *External constraints* • Road traffic rules, regulation, laws and legislation e.g. Road safety (Road Rules) Regulations 1999, Road management (Works and Infrastructure) Regulations 2005, Road management Act 2004; • Road traffic policies, directives & strategies e.g. Vic Roads Arrive Alive strategy, Starting out Safely; • Road system guidelines & standards • Road safety campaigns e.g. TAC 'Slow down or face the Trauma'	*Purposes* • Provide the environment required for Safe, efficient, enjoyable, comfortable transportation of people and goods; • Facilitation of Safe, efficient, enjoyable, comfortable transportation of people and goods *External constraints* • Physical/Spatial constraints; • Road traffic rules, regulation, laws and legislation e.g. Road safety (Road Rules) Regulations 1999, Road management (Works and Infrastructure) Regulations 2005, Road management Act 2004; • Road traffic policies, directives e.g. Vic Roads Arrive Alive strategy, Starting out Safely; • Road system guidelines & standards • Road safety campaign e.g. TAC 'Slow down or face the Trauma'	*Purposes* • Vehicles: To provide the means for safe, simplistic, comfortable, efficient and enjoyable travel; • Drivers, passengers & pedestrians: To manoeuvre safely and efficiently from staring point to desired destination • Road user goals; *External Constraints* • Safety requirements & regulations; • Vehicle design guidelines and standards; • Vehicle safety standards; • Vehicle roadworthiness; • Road traffic rules, regulation, laws and legislation; • Driver licensing; • Road safety campaigns & strategies targeted at drivers & pedestrians e.g. arrive alive;
Abstract Function	*Criteria* • CrashStats – Victorian accident statistics and mapping program; • TAC Road Toll statistics, Serious injury statistics, statistics by issue e.g. drink driving, fatigue, seatbelt usage etc; • TAC crash database; • Travel times; • Road user satisfaction measures; • Minimise road user risk; • Maximise safety, comfort & pleasure; • Insurance crash data	*Criteria* • CrashStats – Victorian accident statistics and mapping program; • TAC Road Toll statistics, Serious injury statistics, statistics by issue e.g. drink driving, fatigue, seatbelt usage etc; • TAC crash database; • Travel times; • Road user satisfaction measures; • Minimise road user risk; • Maximise safety, comfort & pleasure; • Blackspot reporting systems, RACV safer roads save lives • Monitoring of road conditions	*Vehicles* • Safety testing e.g. crash worthiness; • Vehicle Roadworthiness testing & certification; • Performance testing; • Driver satisfaction measures; *Drivers and Pedestrians* • Crash, fatality and injury statistics • Road user satisfaction measures; • Driver licensing & testing; • Travel times; • Road safety campaigns & strategies targeted at drivers & pedestrians e.g. arrive alive;
Generalised Function	• Safe and Efficient Traffic & road user flow; • Effective law enforcement; • Safe Road user behaviour; • Adherence to road traffic rules, regulation, laws and legislation; • Inspection, maintenance and repair of road system; • Redesign & Upgrading of road system	• Safe and efficient Driving; • Safe and efficient Walking; • Safe and efficient Cycling; • Road traffic law enforcement; • Adherence to road traffic rules, regulation, laws and legislation;	*Vehicles* • Physical dynamics e.g. movement, velocity, manoeuvrability, speed, stopping etc; • Safety; • Comfort; • Vehicle maintenance; *Drivers* • Vehicle Control input; • Safe & efficient driver behaviour & driving; • Adherence to road traffic rules, regulation, laws and legislation; • Destinations, planned route, alternative routes *Pedestrians* • Safe & efficient pedestrian behaviour; • Adherence to road traffic rules, regulation, laws and legislation; • Physical movement from A to B;
Physical Function	• Transporting people and goods from start point to desired end point; • Traffic dynamics; • Road system capability/functionality	• Direct road users; • Inform road users; • Control road user behaviour; • Restrict/Afford road user movement; • Efficient & appropriate layout, labelling & design;	*Vehicles* • Vehicle functionality/capability/limitations & status; • Transport driver and passengers from start point to desired destination; *Drivers* • Control vehicle/Drive; • Moving vehicle from start point to desired end point; • Driver functionality/capability/limitations Pedestrians • Walk • Pedestrian functionality/capability/limitations
Physical Form	• Vehicles • Roads Road users • Road furniture • Road signage • Road layouts • Environmental features; • Meteorological features e.g. weather conditions;	• Road type e.g. Freeways, Freeway Tollways, Arterial roads, Municipal roads; • Road markings e.g. lane markings, intersection markings; • Road layouts e.g. intersections, roundabouts, etc; • Road signage e.g. directional road signs, variable message signs, advertising boards etc; • Road furniture e.g. crash barriers, traffic lights, tollways etc; • Road composition e.g. asphalt • Road measurements e.g. lane width, runoff space etc; • Road surface features e.g. condition, sealed shoulders • Additional roadside objects e.g. postboxes, bus stops etc; • Road infrastructure topography	• Vehicle manufacturer, model and colour; • Vehicle control components e.g. steering wheel, dashboard displays (speedo, rev counter etc), gear lever, accelerator, brake pedal, mirrors (rearview and side) etc; • Intelligent Transport Systems e.g. route navigation, collision warning systems etc; • Other in-car components e.g. radio, Hands free mobile phone, clock etc; • Safety devices e.g. airbags, crumple zones, seatbelts etc. • External components e.g. windscreen wipers, lights, Side mirrors; Wheels & Tyres; Engine & engine components; • External form e.g. shape, dimensions, material composition etc; • Cockpit layout; control layout/arrangement; • Drivers e.g. car, truck, van, bus drivers etc. • Passengers; • Pedestrians

In terms of using CWA in a road transport context, the analysis demonstrates that the CWA approach is useful as a design and analysis tool within the road transport domain. One of the main benefits of the CWA approach over traditional task analysis approaches is that it defines the functions, purposes and properties of the system, rather than the component tasks involved in activity in the system. This allows the design of technology, strategies and training to support a range of different scenarios, rather than specific ones. Additionally, the WDA caters for all of the different stakeholders who reside within the road transport system, whilst traditional task analysis techniques would only cater for the tasks required for one particular stakeholder group e.g. drivers. To cover all of the stakeholders, separate task analyses would have to be conducted for each stakeholder group.

The WDA can also be used to identify current flaws within the Victorian road transport system. For example, the analysis indicates that there are a number of functions and purposes of the road transport system that are not currently supported by road infrastructure, vehicle design and training. For example, the sub-system physical functions of *control road user behaviour* and *restrict road user behaviour* are currently not efficiently supported in the Victorian road transport system. Whilst compliant road user behaviour is generally well supported, there is currently a lack of the means with which to enforce compliant road user behaviour. Although attempts have been made to do so, such as the use of speed cameras, it is clear that non-compliant behaviour is not currently restricted well enough. Thus the WDA indicates that the development of appropriate road infrastructure and in-vehicle technologies to enforce compliant behaviour is one area that requires further investigation in the future. This might involve the development and implementation of compliance enforcing ITS such as intelligent speed adaptation technologies.

In addition, the analysis also indicates that the road transport system currently does not provide sufficient informational support to the driver in terms of supporting road user goals. The current road user risk level is currently not explicitly stated and performance criteria and measures are not clearly communicated to road users. Additionally, road users are not given adequate information in relation to their goals whilst undertaking activity within the system. Without systems such as route guidance and navigational systems, drivers currently do not have an accurate representation of the actions that they need to take, their current status in relation to their goals, and also the time it will take to get to their desired destination in the current conditions.

The analysis also provides an indication of the different stakeholders currently residing within the system and also of their respective roles within the system. The stakeholders identified included road transport authorities and governing bodies, road infrastructure, road transport law enforcement agencies, drivers and vehicle manufacturers. The analysis indicated that the relevant road transport authorities and governing bodies (e.g. Dept. of Transport & Regional Services, National Transport Commission, AustRoads, VicRoads etc) have the majority of the responsibility for the different total system levels and also the sub-system (road infrastructure levels). Drivers and other road users have the responsibility of the generalised functions at the sub-system and component level, including safe and efficient driving, walking and cycling and adherence to road traffic rules and regulations. Road infrastructure responsibilities lie at the physical function and physical form levels of the sub-system decomposition level and include directing road users, informing road users, controlling road user behaviour, restricting and affording road user movement and providing efficient and appropriate road system layout, labelling and design. The vehicle manufacturers responsibilities were identified at the component levels, including vehicle safety testing, vehicle capability and functionality and vehicle model, and the various components that comprise the vehicle.

CONCLUSION

The main aim of this research was to examine the potential application of the CWA framework within the road transport domain. On the basis of a review of previous CWA applications in other domains, it is concluded that there are a number of potential CWA applications in the road transport domain that could potentially aid the design and evaluation of road transport-related technologies, training programs and systems, which in turn could significantly impact road user behaviour and road safety. Further, a number of additional applications were identified, including allocation of functions analysis, error management strategy design, the design and analysis of intersections, SA requirements analysis, guideline evaluation and intersection evaluation and design, tender evaluation and problem solving trajectory evaluation. The final phase of this research involved the conduct of a series of exploratory CWA analyses in a road transport context. A simplistic WDA of the Victorian road transport system was conducted, using input from road transport and human factors SMEs and publicly available road transport related information (e.g. road transport Acts, directives and strategies) from VicRoads and TAC websites. The WDA output represents a simplistic model of the complex Victorian road transport system. In addition to the WDA of the road transport system, a social organisation and co-operation analysis of the road transport system, and a WDA for ITS technologies were also conducted. It was concluded that the application of CWA within the road transport domain is an appropriate concept to pursue. It is the opinion of the authors that CWA could be used within the road transport system for a variety of purposes, and that these road transport applications could potentially enhance road user behaviour and road safety through a number of avenues.

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