MONASH University

Extension and application of cognitive work analysis to improve pedestrian safety at rail level crossings

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Abstract

Pedestrian safety at rail level crossings (RLXs) is a concern for government, the transport industry and the community. Collisions between trains and pedestrians are traditionally viewed as the result of errors or violations committed by pedestrians. However, as RLXs are complex sociotechnical systems, collisions are better understood as emergent properties of interactions amongst and between human and technical components within the system. Cognitive work analysis (CWA) is a powerful analytical framework that offers a sophisticated understanding of the functioning of RLXs as relevant to pedestrian safety, through identifying the constraints on pedestrian behaviour in this context. It does not, however, provide its users with guidance about how the findings of the analysis can be used to improve sociotechnical system functioning.

Accordingly, the aim of this research was the development and evaluation of a CWA-based approach to support the design of complex sociotechnical systems, and the application of this approach to provide recommendations for RLX design to improve pedestrian safety. A secondary aim of the research was to investigate pedestrian behaviour within the RLX system using CWA. Drawing on systems theory, and more specifically, sociotechnical systems theory, the outcome of this research is a CWA design toolkit (the CWA-DT).

The development and refinement of the CWA-DT is illustrated through a proof of concept application in the domain of public transport ticketing. Positive evaluation results were obtained and necessary refinements to the toolkit were implemented in the second version. A full evaluation of the toolkit was then undertaken within the complex, safety critical domain of RLXs. This evaluation found that while the CWA-DT could be considered a useful method, its application did not lead to the creation of design concepts that fully aligned with sociotechnical systems theory. The application did, however, lead to designs that were rated by human factors experts as more effective than the existing system design. These findings suggest that the sociotechnical systems theory approach may not provide an appropriate design philosophy in a public safety context. However, merging ideas and concepts from sociotechnical systems theory with existing paradigms such as safety management can lead to innovation and has the potential to improve safety performance.

Declaration

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes four original papers published in peer reviewed journals and two unpublished publications that are under review. The core theme of the thesis is the development of a cognitive work analysis-based design approach and its application to improve pedestrian safety at rail level crossings. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the candidate, working within the Monash Injury Research Institute under the supervision of Adjunct Professor Michael Lenné and Professor Paul Salmon of the University of the Sunshine Coast.

The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

In the case of chapters 2, 4, 5, 7, 9 and 10 my contribution to the work involved the following:

Thesis chapter	Publication title	Publication status	Nature and extent of candidate's contribution
2	Sounding the warning bells: The need for a systems approach to understanding behaviour at rail level crossings	Published	Primary author. Conceived the idea to conduct a structured literature review, determined the methodology for the review and criteria, conducted the literature search, analysed the results and was responsible for the initial drafting of the paper and the subsequent editing.
4	Cognitive work analysis and design: Current practice and future practitioner requirements	Published	Primary author. Co-conceived the idea for the study. Developed and distributed the questionnaire, collated and analysed results. Responsible for the initial drafting and subsequent editing of the paper.
5	Designing sociotechnical systems with cognitive work analysis: Putting theory back into practice	Published	Primary author. Conceived the idea for the analysis, conducted the analysis, responsible for the initial drafting and subsequent editing of the paper.
7	Designing a ticket to ride with cognitive work analysis	Published online	Primary author responsible for the concept, design, data collection activities and the CWA analysis. Developed the CWA-DT and planned and conducted the design workshops. Responsible for initial drafting of the paper and subsequent editing.
9	Walking the Line: Understanding pedestrian behaviour and risk at rail level crossings with cognitive work analysis	Under review	Primary author responsible for the concept, design, data collection activities, the CWA analysis and interpretation. Responsible for initial drafting of the paper and subsequent editing.
10	When paradigms collide at the road-rail interface: Evaluation of a sociotechnical systems theory design toolkit for cognitive work analysis	Under review	Primary author responsible for the design of the study. Facilitated the design workshops and expert panel workshop. Responsible for analysing and interpreting the results of the study and the initial drafting and subsequent editing of the paper.

I have not renumbered sections of submitted or published papers in order to generate a consistent presentation within the thesis.

Student signature: [redacted] **Date:** 2 July 2015

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the student and co-authors' contributions to this work.

Main Supervisor signature: [redacted] **Date:** 2 July 2015

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Thank you to the staff and students at the Monash Injury Research Institute (MIRI) for all of the formal and informal support you have offered me. I felt welcome from the day I started and have thoroughly enjoyed my time as a MIRI student. Special thanks to Casey Rampollard for her amazing ability to get anything done.

To Paul and my new team at the Centre for Human Factors and Sociotechnical Systems, I appreciate the support you have given me to complete this thesis and I look forward to working with you to complete the overall program of rail level crossing research and to explore new applications and innovations in human factors methods and sociotechnical systems theory.

I could not have completed this research without the assistance of the many research participants who shared with me their knowledge, their opinions, their experiences, their data and their design ideas. I am continually amazed at the generosity of people who participate in research and I hope that our combined efforts will lead to genuine improvements to safety.

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This thesis is dedicated to those who have lost their lives at rail level crossings and all those affected by these tragic events

Contents

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Acronyms

ADS	Abstraction-decomposition space
AH	Abstraction hierarchy
CAT	Contextual activity template
ConTA	Control task analysis
CWA	Cognitive work analysis
CWA-DT	Cognitive work analysis design toolkit
EAST	Event Analysis of Systemic Teamwork
EID	Ecological interface design
FRAM	Functional Resonance Analysis Method
HFE	Human factors and ergonomics
RLX	Rail level crossing
SAD	Strategies analysis diagram
SME	Subject matter expert
SOCA	Social organisation and cooperation analysis
SRK	Skills, rules and knowledge
STAMP	Systems-Theoretic Accident Model and Processes
StrA	Strategies analysis
WCA	Worker competencies analysis
WDA	Work domain analysis

Publications arising from this thesis

Peer reviewed journal articles

Read, G. J. M., Salmon, P. M. & Lenné, M. G. (2013). Sounding the warning bells: The need for a systems approach to understanding behaviour at rail level crossings. *Applied Ergonomics, 44*, 764-774. (Chapter 2)

Read, G. J. M., Salmon, P. M., Lenné, M. G. (2015). Cognitive work analysis and design: Current practice and future practitioner requirements. *Theoretical Issues in Ergonomics Science, 16*, 154-173. (Chapter 4)

Read, G. J. M., Salmon, P. M., Lenné, M. G. & Stanton, N.A. (2015). Designing sociotechnical systems with cognitive work analysis: Putting theory back into practice. *Ergonomics, 58,* 822-851. (Chapter 5)

Read, G. J. M., Salmon, P. M., Lenné, M. G. & Jenkins, D. (2015). Designing a ticket to ride with cognitive work analysis. *Ergonomics*. Advance online publication. (Chapter 7)

Read, G. J. M, Salmon, P. M., Lenné, M. G. & Stanton, N. A. (Under review). Walking the line: Understanding pedestrian behaviour and risk at rail level crossings with cognitive work analysis. *Applied Ergonomics*. (Chapter 9)

Read, G. J. M., Salmon, P. M. & Lenné, M. G. (Under review). Evaluating a design toolkit for Cognitive Work Analysis. *Ergonomics*. (Chapter 10)

Other research outputs

Read, G. J. M., Salmon, P. M., & Lenné, M. G. (2012). From work analysis to work design: A review of cognitive work analysis design applications. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Boston, USA.

Read, G. J. M., Salmon, P. M., & Lenné, M. G. (2013). Development of a systems-based human factors design approach for road safety applications. *Proceedings of EPCE/HCII 2013*, Las Vegas, USA.

Read, G. J. M., Salmon, P. M., & Lenné, M. G. (Under review). The application of a systems-based design toolkit to improve situation awareness and safety at road intersections. *Proceedings of the 6th International Conference on Applied Human Factors and Ergonomics*, Las Vegas, USA.

Read, G. J. M., Salmon, P. M., & Lenné, M. G. (Under review). Using cognitive work analysis and the sociotechnical systems approach to improve pedestrian safety at rail level crossings. *Proceedings 19th Triennial Congress of the IEA*, Melbourne, Australia.

Read, G. J. M., Salmon, P. M., Lenné, M. G. & Grey, E. M. (2014). Evaluating design hypotheses for rail level crossings: An observational study of pedestrian and cyclist behaviour.

Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics, Kraków, Poland.

Read, G. J. M., Salmon, P. M., Lenné, M. G. & Jenkins, D. P. (2014). Extracting design information from the outputs of systems analysis: A case study in public transport ticketing. *Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics*, Kraków, Poland.

Salmon, P. M., Lenné, M. G., Read, G. J. M., Mulvihill, C., Young, K., Cornelissen, M., Walker, G. H., Stanton, N. A. (In press). More than meets the eye: using cognitive work analysis to identify design requirements for safer rail level crossing systems. *Applied Ergonomics*.

Salmon, P. M., Read, G. J. M., Stanton, N. A. & Lenné, M. G. (2013). The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. *Accident Analysis and Prevention, 50*, 1278-88.

Part One

Review of theoretical and methodological literature, and current practice

1 Introduction

"…it is not enough to simply analyse a situation from a socio-technical perspective and then explain this to engineers" (Baxter & Sommerville, 2011, p 4)

As a discipline, Human Factors and Ergonomics (HFE) is concerned with the analysis and design of sociotechnical systems to improve human wellbeing and overall system performance (IEA, 2015). Analysis is undertaken so that the current or potential role of humans within a system can be understood and the findings of the analysis are provided as recommendations for design. Systems thinking and the systems approach has become a central tenet of the discipline (Norros, 2014) and cognitive work analysis (CWA; Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999) is a key analysis framework that has gained traction in this area. However, questions have been raised about its capacity to contribute directly to design (e.g. Jenkins, Stanton, Salmon & Walker, 2010; Lintern, 2005; Mendonza, Angelelli & Lindgren, 2011). Further, although HFE has traditionally been the study of work (Karwowski, 2005), in recent times the discipline has expanded its reach beyond workers operating within organisations to any sociotechnical system in which there is a need to enhance performance and / or safety, such as private transportation.

The research described in this thesis seeks to address the issues associated with CWA use in design in an application domain which has recently begun to be explored using systems-based approaches, in line with the general shift in HFE methods. The application domain chosen was the use of rail level crossings (RLXs; alternatively known as grade crossings or rail-road crossings) by pedestrians. The domain was selected due to the intractable nature of this public safety problem in Melbourne, Australia, where the research was undertaken.

The research involves the development and evaluation of a CWA-based approach to support the design of complex sociotechnical systems, and the application of this approach to provide recommendations to improve the design of RLXs for pedestrian safety. The approach is underpinned by sociotechnical systems theory, defined as the body of literature and practice that arose from the classical work of the Tavistock Institute which had a focus on the analysis and design of organisations and their structure (Badham, Clegg & Wall, 2006). This thesis proposes that a useful design approach based on CWA and sociotechnical systems theory can be developed and applied to provide design recommendations that have the potential to improve pedestrian safety at RLXs.

This introductory chapter will provide an overview of the key theoretical concepts and constructs that underpin this thesis. It will present the rationale for positioning this work within the HFE discipline and for the selection of the sociotechnical systems theory approach and CWA as a basis for design in this context. It will also introduce the problem of pedestrian safety at RLXs and describe the research questions to be answered within this thesis. Finally, this chapter provides a description of the methodological approaches applied within the research and provides an overview of the remaining sections of the thesis.

1.1 HFE as a design discipline

The status of HFE as a design-driven discipline has recently been reinforced (Dul et al, 2012; Norros, 2014). HFE aims to understand the nature of interactions between people and systems and to use this understanding in design (Karwowski, 2005). Figure 1.1 shows the general dimensions of the HFE discipline, adapted from those identified by Karwowski (2005), and the relationships between them. Importantly, it highlights that within HFE, philosophy and theory have an interdependent interaction with the other aspects of the discipline, and with one another. For example, philosophy underlies design processes, design outcomes (e.g. the design of technology and environments), as well as the design of management systems and overall HFE practice and education. Further, these aspects, such as practice, have a feedback loop which leads to changes in other aspects such as the prevailing philosophy and theory of the discipline over time.

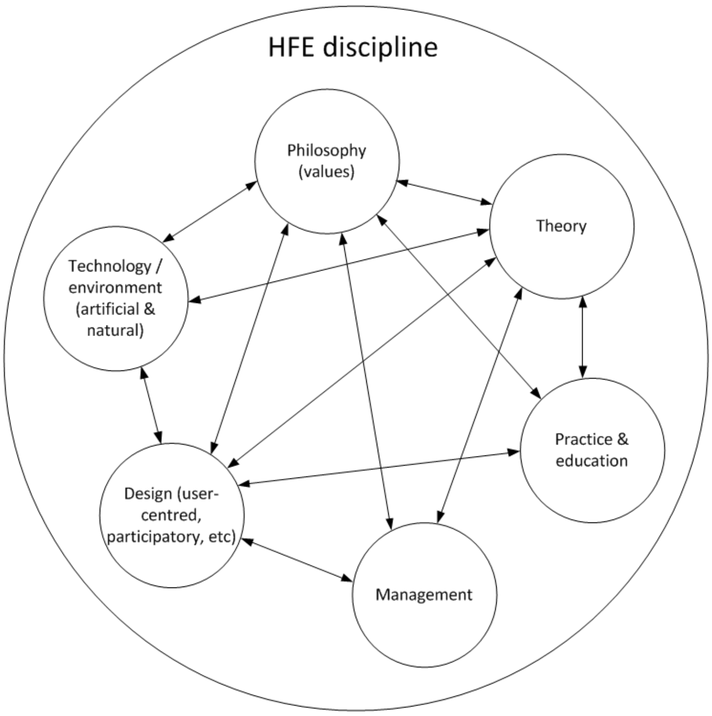

Figure 1.1. Aspects of the HFE discipline (adapted from Karwowski, 2005).

It should be acknowledged that the aspects described in Figure 1.1 do not exist only within HFE, but are used within HFE for the purpose of analysing and designing systems to improve wellbeing and system performance. There is considerable input and collaboration between HFE and the disciplines of engineering, design, psychology, sociology and business (amongst others) making it a truly interdisciplinary area, enhanced by the adoption of systems-theoretical methods and approaches.

1.2 Systems theory and systems-based approaches to safety

The discipline's uptake of systems thinking has also drawn upon the biological and physical sciences. For example, Von Bertalanffy's (1950) principles of open systems as applied to living organisms has been a key influence. Skyttner (2001) has drawn together the properties of general systems theory for open systems, based on the work of Von Bertalanffy as well as numerous other systems theorists. He suggests the following characteristics of open systems:

- Interrelationship and interdependence of components and their attributes: the parts of the system are interconnected rather than disparate.
- Holism: the system exhibits emergent properties that cannot be identified from analysing the components; the whole is more than the sum of its parts.
- Goal seeking: the system has a goal or final end state.
- Transformation processes: the system transforms inputs into outputs in order to attain its goal/s.
- Inputs and outputs: inputs are taken from the environment and transformed, outputs are returned to the environment.
- Entropy: systems tend toward disorder or randomness without intervention.
- Regulation: the interrelated components constituting the system must be regulated for goals to be obtained. Regulation can be achieved through control and feedback loops.
- Hierarchy: systems comprise sub-systems nested within one another in a hierarchical structure.
- Differentiation: specialised units performed specialised functions within a system.
- Equifinality: from the same initial conditions, systems have different alternative ways of achieving the same goal.
- Multifinality: from the same initial conditions, systems can obtain different goals and objectives.

These system properties provide the basis for the notion of adaptive capacity. Specifically, those systems most able to continue to achieve goals and avoid entropy would be those who can adapt to external environmental conditions (i.e. to changes to inputs and outputs), by using alternative means (through having the property of equifinality). Matters such as how regulatory mechanisms within the system operate and the amount of differentiation available within the system can affect its capacity to adapt and to achieve its goals.

In relation to safety, general systems theory views this as an emergent property of the interactions between system components. That is to say, safety cannot be analysed by understanding the components of the system without consideration of the whole. Further, systems theory suggests that understanding safety requires an understanding of the variability of behaviour and performance within regulatory structures. It also requires an understanding of how the hierarchy present within the system affects system functioning, particularly the extent to which consistency and coherence is maintained across hierarchical levels. Finally, researching safety from a systems perspective requires acknowledgement that systems are dynamic, not static. Open systems are in a continual state of change as inputs are transformed to outputs, with the system tending towards a state of entropy over time. The four characteristics of emergence, performance variability, hierarchy and dynamicism can be considered the most relevant characteristics for understanding safety from a systems perspective.

1.3 Systems-based approaches within HFE

While many methods and approaches have been developed to uncover and describe the functioning of complex sociotechnical systems (e.g. STAMP, Leveson, 2004; FRAM, Hollnagel, 2012), the CWA framework of methods supports the analysis of complex sociotechnical systems with the specific aim of improving system design (Vicente, 1999). CWA was developed at the RISØ National Laboratory in Denmark within a wider cognitive engineering research program which aimed to support the development of safe electricity from nuclear power. The researchers found that even where reactors could be designed to exhibit close to perfect technological reliability, accidents could still occur. To understand this, they conducted a review of reports into incidents in the nuclear and aviation domains. The findings showed that the majority of incidents were associated with human error and that in the vast majority of incidents, the operators would have made an appropriate decision had the actual system state been known to them. There are interesting parallels to this in the pedestrian RLX context. Historically, safety at RLXs has been sought through the implementation of warnings and barriers that have high levels of technological reliability and meet 'fail-safe' obligations of safety critical equipment (as required by international standard IEC 61508:2010; IEC, 2010). This has not, however, eliminated crashes from occurring due to 'human error' or due to 'violation' of the warning systems. Further, the warnings provided to pedestrians and other road users at RLXs are simple and do not indicate the system state. For example, the warnings can be activated when one train is approaching, when two trains are approaching, or indeed, when the system has failed and the warnings are operating in fail-safe mode. RLX users are not supported through design to understand the system state, and are instead expected to comply with road rules which state that where warnings are activated the user must not enter the RLX.

The finding by Rasmussen and his colleagues at RISØ that workers require support to understand and respond to the system state led to the impetus of CWA; the requirement for an approach that could design for abnormal situations, unanticipated by designers, by giving operators the flexibility to adapt to the circumstances. Vicente (1999) describes the philosophy of CWA as to enable the worker to 'finish the design'.

To support this design philosophy, CWA provides a formative approach to the analysis of human activity by identifying and analysing the constraints within the system that shape behaviour (Vicente, 1999). The framework encompasses five phases of analysis. The first phase, work domain analysis (WDA), describes the environmental constraints on behaviour within the domain. Secondly, control task analysis (ConTA) considers the tasks that need to be achieved. Thirdly, strategies analysis (StrA) identifies the various strategies that can be used to fulfil the tasks. The fourth phase, social organisation and cooperation analysis (SOCA) is used to allocate functions amongst humans and technology and to identify communication and collaboration requirements. Finally, the competencies required by actors operating within the domain are identified through the final phase, worker competencies analysis (WCA; Vicente, 1999). Further detail about CWA and the five phases of analysis is provided in later sections of this thesis (see Section 3.2 and Section 6.2).

CWA has been applied to a wide range of complex systems including air traffic control (e.g. Ahlstrom, 2005), nuclear power generation (e.g. Burns et al., 2008), military command and control (e.g. Jenkins, Stanton, Walker, Salmon, & Young, 2008), road transport (e.g. Cornelissen, Salmon, McClure, & Stanton, 2013) and rail transport (e.g. Stanton et al., 2013). It continues to be a popular method for the analysis and design of sociotechnical systems and extensions to the framework have been proposed (e.g. Cornelissen, Salmon, McClure, & Stanton, 2013; Elix & Naikar, 2008; Hassel, Sanderson & Cameron, 2014; Kilgore, St-Cyr &

Jamieson, 2008). In relation to the use of CWA in design, the ecological interface design (EID) approach has been successfully used for the design of computer interfaces and decision support systems that make the constraints of the system available to its human controllers (Burns & Hajdukiewicz 2004; Vicente 2002). EID generally draws upon the first and last phases of the framework, meaning that there is opportunity for additional exploration of how all five phases can be used in design. Furthermore, there are opportunities to explore CWA's role in wider system design, beyond the design of interfaces.

1.4 A theory for the design of sociotechnical systems

While 'sociotechnical system' is a commonly used term which applies to any circumstance where humans interact with technology for a purposeful reason (Walker, Stanton, Salmon & Jenkins, 2008), sociotechnical systems theory is associated with a particular body of literature that emerged from the work of the Tavistock Institute in the 1950s. Within this thesis, the term 'sociotechnical systems theory' is used to refer to that body of literature and practice while the term 'systems approach' encompasses a broader range of approaches that have their roots in systems theory.

The sociotechnical systems theory approach has been applied to organisational design for many decades (Mumford, 2006). Strongly aligned with systems theory and underpinned by notions of industrial democracy, participatory design and humanistic values; the sociotechnical systems theory approach aims to design organisations and systems that have the capacity to adapt and respond to changes and disturbances in the environment. Key principles and values of sociotechnical design have evolved over many years of action research implementing innovations in organisations (e.g. Cherns, 1976; Clegg, 2000; Davis, 1982; Walker, Stanton, Salmon, & Jenkins, 2009). These principles intend to support the design of sociotechnical systems that exhibit adaptive capacity. Figure 1.2 provides an overview of the sociotechnical systems theory principles relating to the design process (outer band), and to the content of the designed system (middle band) that, recognising the key properties of complex systems as relevant to safety, support system design for adaptive capacity. The arrows represent the values underpinning sociotechnical systems theory that permeate both the design process and the designed system.

The sociotechnical systems approach is beneficial as it encompasses guidance for both the design process (including on-going re-design processes) as well as the content of the designed system. It can be seen as supporting both the hard (i.e. engineered) aspects of design as well as the soft (i.e. process) aspects (Checkland, 1981).

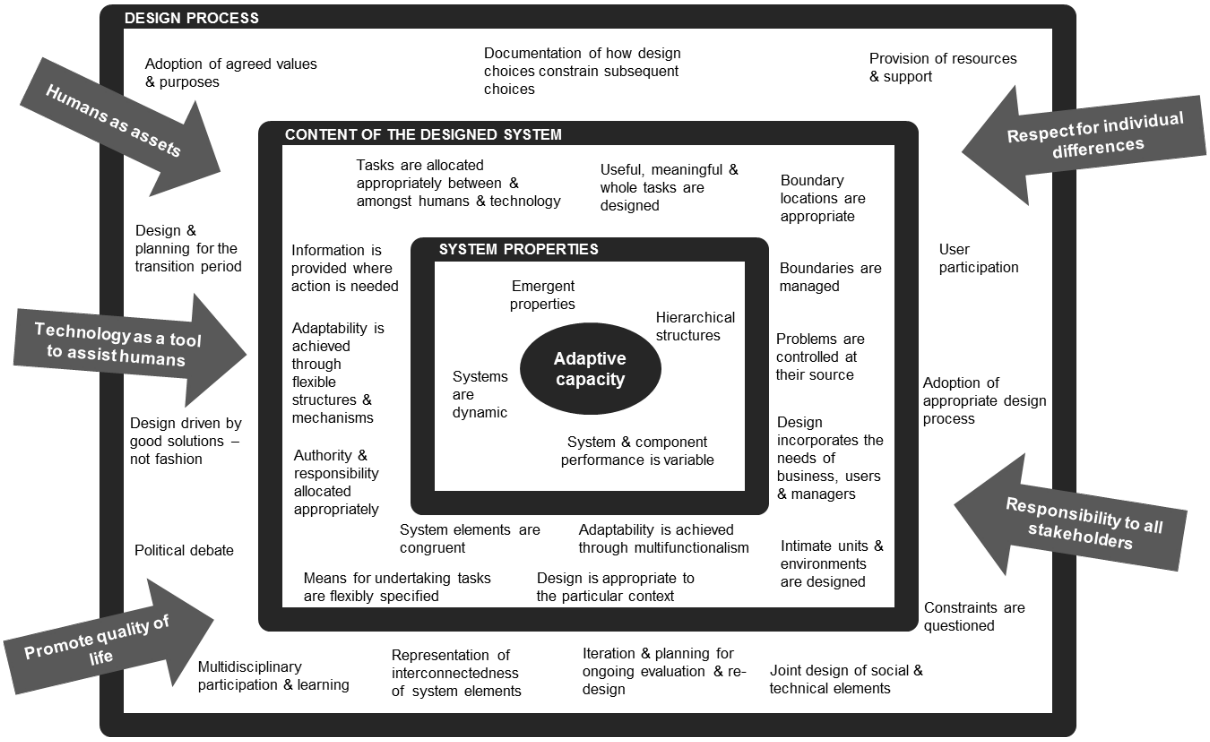

Figure 1.2. The principles and values of sociotechnical systems theory.

1.5 Appropriateness of the approaches

It is important to establish the appropriateness of CWA and the sociotechnical systems approach for design in safety-critical domains. Table 1.1 shows that the approaches have complementary but distinct contributions to design which are consistent with key aspects of general systems theory. CWA provides knowledge about the constraints of the system while the sociotechnical systems approach provides a theoretically-grounded philosophy for design.

While the content of Table 1.1 reinforces the complementary nature of the approaches, interestingly, CWA does not appear to have previously been explicitly linked to the principles of sociotechnical systems theory, at least in the recent HFE literature. While Rasmussen, in early writing on CWA, makes reference to some sociotechnical systems theory literature in regards to task distribution as an aspect of his fifth dimension of analysis titled ‘Allocation of decision roles’ (Rasmussen, 1990), there appears to be no reference to the principles of sociotechnical design discussed by seminal figures such as Eric Trist, Fred Emery, Albert Cherns or Louis Davis. While it is acknowledged that CWA may have been inspired by the Tavistock work in some way, this thesis intends to create a stronger link between the two approaches through the development and application of a design approach which incorporates CWA and the values and principles espoused by the sociotechnical systems theory approach. The design approach will be applied and tested in the RLX context.

Table 1.1. How CWA and the sociotechnical systems theory approach align with the key aspects of systems theory.

Key aspects of systems theory	**Cognitive work analysis**	**Sociotechnical systems theory approach**
Safety as an emergent property	By defining the system constraints, and detailing the interactions between components, CWA can be used to identify emergence.	Posits that outcomes are associated with the interaction of humans and technology and argues for joint optimisation of technical and human components. That is, successful performance emerges from the interaction of humans and technology.
Performance variability	CWA provides a formative approach to analysing behaviour. That is, it can identify all the ways in which behaviour can occur, given the constraints and goals that limit and influence behaviour. For example, in the StrA phase the analyst identifies all the possible ways in which tasks can be performed.	Acknowledges that humans are assets and adaptive problem solvers that can respond to changing circumstances as well as manage external disturbances and variances in the technical system. Humans are expected to display adaptive variability.
Systems as hierarchical structures	In the WDA phase, CWA identifies a hierarchy of abstraction with purposes and values from the organisational system at the top and physical objects at the bottom.	Acknowledges the social hierarchy within an organisation including management, supervisors and employees. Also promotes broad thinking regarding system stakeholders and boundaries (e.g. the impacts of design decisions on suppliers, future users, etc.).
Dynamicism	By identifying the constraints of the system CWA provides the potential to model the impact of system changes over time.	Advocates for the participation of workers because as open systems are constantly changing, it is those within the system who will need to respond to changes and to re-design the system to cope with the dynamic environment.

1.6 The application domain – RLXs

1.6.1 Background to RLX design

RLXs were never originally designed; rather, they evolved through use. Wigglesworth (2008) described how during the mid- to late-1800s rail transport in Australia saw a period of growth and was the dominant mode for moving passengers and freight. In places where people needed to cross the rails, rough, informal paths developed over time. These were used by pedestrians, people on horseback or those driving horse-drawn carriages. Both trains and horse-powered vehicles would have travelled relatively slowly providing time to recognise a train approaching and stop accordingly, and the road traffic certainly posed no risk to trains. It was not until the age of the motor car that the safety risks at RLXs became a public safety consideration in Australia and internationally. Even then, the design of protection measures have tended to evolve rather than represent the outcome of a considered analysis following a change in the context of use. For example, the flashing red lights provided at RLXs to warn of an approaching train were designed to resemble a red lantern being swung from side to side, as this is how signalmen or station masters warned of trains approaching prior to the introduction of electric track circuits (Green, 2002). Similarly, modern train horns were designed to emulate the sound of steam train whistles (Transportation Safety Board of Canada, 1996), rather than purposefully designed to provide an optimal auditory warning stimulus that produces an appropriate response from those who may be in the path of the train. Manually operated gates were traditionally used to block road vehicles when the train was approaching and to stop horses or livestock wandering onto the tracks when open to the road. These evolved into the automatic boom barriers that are now commonly installed at RLXs worldwide (Wigglesworth, 1978).

1.6.2 Pedestrian safety at RLXs

Collisions at RLXs involving pedestrians are a significant public safety concern in Australia and internationally. The most recent statistics available show that in the 10 year period between 2002 and 2011, 92 pedestrians were struck by trains at RLXs in Australia (Australian Transport Safety Bureau, 2012). The majority of these collisions (51) occurred in the state of Victoria, with other states and territories experiencing between zero and 16 collisions over the same time period. In Victoria, collisions between trains and pedestrians at RLXs resulted in 17 fatalities and six serious injuries in the five year period between 2009 and 2013 (Transport Safety Victoria, 2014).

The circumstances of one case, occurring in 2004, that raised significant public and political concern, were reported as follows:

> *… the Coroner found that the deceased died from severe head injuries sustained when she unintentionally walked in front of and was hit by a north-bound express train. The Coroner also noted that the deceased opened the unlocked pedestrian emergency exit gate which had a sign on it saying "No Entry". Despite the operating bells and lights and the warning train whistle, she entered the railway line area. She seemed to remain unaware that a train was approaching as she began to walk across Line 2.*
> (Spicer, 2008, p 171).

To provide some context regarding RLX types and locations, in 2009, there were 2,817 public RLXs in the state of Victoria, Australia including 857 pedestrian-only crossings (Rail Industry

Safety and Standards Board, 2009). The majority of RLXs in Victoria are located in rural environments, with approximately 350 (road) crossings located in the Melbourne metropolitan area (Road Safety Committee, 2008). This research is focussed on road RLXs which have separated pedestrian footpath facilities and this arrangement is more likely to occur in metropolitan than rural contexts. Further, according to data collected and analysed by Victorian Government agencies, the 20 RLX sites that have experienced the most collisions and near misses between trains and pedestrians are all located in the Melbourne metropolitan area (G. Sheppard, personal communication, May 10, 2013). Acknowledging the larger safety problem, this research was undertaken in the Melbourne metropolitan area.

All road RLXs in the Melbourne metropolitan area have what is known as ‘active protection’ which encompasses dynamic warning devices that alert road users (including pedestrians) of train approach. The warning devices include twin flashing lights, half boom barriers and audible bells (also known as an alarm). The majority of pedestrian footpaths provided at RLXs incorporate automatic gates that close across the footpath when the warnings are activated. Additional gates are also provided to enable pedestrians, caught on the RLX when the automatic gates close, to exit the crossing. These are known as emergency escape gates and on the entry side they have signage advising ‘no entry’. Photographs of example RLXs are provided in Figure 3 to illustrate these features. As noted in Section 1.3, technology at RLXs is designed to be ‘fail-safe’ meaning that if a failure is detected the warnings will activate as if a train is approaching. It is very rare for RLX warnings (including pedestrian gates) to fail in an unsafe manner (i.e. for the gates to remain open when a train is approaching).

Figure 1.3. Photographs of example RLXs with pedestrian facilities.

Crashes at RLXs are generally considered to be caused by the behaviour of road users, given that by law road users must give way to trains (Australian Transport Safety Bureau, 2008). Therefore, the focus of research has tended to be on understanding the errors and violations made by RLX users, including pedestrians (e.g. Freeman & Rakotonirainy, 2015). While there has been limited research investigating pedestrian behaviour at RLXs (Freeman, Rakotonirainy, Stefanova & McMaster, 2013), some of the factors suggested within the literature as influencing pedestrian behaviour have included the presence of barriers or gates (Metaxatos & Sririj, 2013), having a poor viewpoint and being unable to see a train approaching (Human Engineering, 2008), time pressure (Clancy, 2007), distraction (Clancy, 2007), expectations (Stefanova, Burkhardt, Filtness, Wullems, Rakotonirainy & Delhomme, 2015) and lack of previous experience of enforcement of road rules (e.g. receiving a fine; Stefanova, Burkhardt, Filtness, Wullems, Rakotonirainy & Delhomme, 2015).

1.6.3 The current approach to improving safety at RLXs

In terms of the policy context within which RLXs reside, the issue of RLX safety has been the subject of Australian parliamentary committee inquiries (e.g. Neville, 2004; Road Safety Committee, 2008), as well as special coronial inquests and reports (e.g. Hendtlass, 2013; Johnstone, 2002). Further reflecting the concern of governments regarding RLX safety, a National Level Crossing Safety Strategy (Rail Level Crossing Group, 2009) has been developed to guide policy and action in this area. The strategy aims “to reduce the likelihood of crashes and near misses at Australian railway level crossings” (p. 5). Positioned under the wider government strategic goal of “a safe land transport system that meets Australia's mobility, social and economic objectives with maximum safety for its users” (p. 4), the strategy outlines six key areas of focus to achieve the aim of reducing the likelihood of crashes and near misses. These areas are:

- Safe system: adoption of the ‘safe systems’ approach.
- Governance: nationally consistent and coordinated arrangements between Australian jurisdictions.
- Risk management: effective risk management processes.
- Technology: the continued identification and evaluation of new, cost-effective engineering and technological measures that alert or guide road users.
- Education and enforcement: the use of education and enforcement with the aim of ensuring road users ‘always comply with level crossing controls’.

- Data improvement and knowledge management: better data capture to provide an understanding of the characteristics surrounding RLX incidents.

While the priority areas appear similar to those selected for other public safety issues, they suggest that the current approach to improving RLX safety contrasts with systems theory-based approaches. For example, the safe systems approach, although acknowledging that accidents are a result of emergence (i.e. from interactions between a road user, their vehicle and the road environment), may not align with key tenets of systems theory such as acceptance of performance variability (Larsson, Dekker & Tingvall, 2010). In addition, the way in which the safe systems approach is implemented tends to become reductionist (Salmon, McClure & Stanton, 2012) with a focus on improving each of the areas independently through, for example, initiatives to improve road design or to influence road user behaviour in isolation from one another.

Further, the emphasis in the strategy on risk management suggests that the hierarchy of control would be applied in the identification and implementation of risk controls to manage road user behaviour. The hierarchy of control is ubiquitous in safety management and ranks the effectiveness of risk controls in the following order, from most effective to least effective:

- Elimination: removal of the hazard.
- Substitution: replacement of the hazard with something less dangerous.
- Engineering: addition of barriers or guards.
- Administrative controls: use of policies, procedures, rules or training to influence behaviour.
- Personal protective equipment: items worn by individuals to protect them from physical harm (e.g. hardhats, gloves).

The hierarchy is concerned with the control of hazards, however, its implementation in the RLX context appears to be more about the control of RLX users, including pedestrians. Specifically, because pedestrians must stop for the train, barriers could be seen as protecting the railway from pedestrian intrusion, rather than protecting pedestrians from the hazard posed by the train. Coupled with the fifth area of priority stated in the strategy, education and enforcement, there is a strong focus on ensuring rule compliance with the prevailing mindset being the RLX would be safe if only road users would follow the rules. This Taylorist approach advocates a single correct way for pedestrians to use an RLX where optimally, pedestrians would perform consistently, crossing in the same manner each time. Taking a systems theoretical perspective, this approach is inappropriate as RLXs are open, dynamic systems which must deal with unanticipated events and emergence (e.g. Vicente, 1999). Further, from a quality of life viewpoint, a world in which pedestrians are expected to act without variation or choice in their behaviour would be dissatisfying and would lead to poor levels of wellbeing in the community.

Finally, the inclusion of technology as a priority within the strategy is interesting when compared with the sociotechnical systems theory approach. A number of sociotechnical researchers have noted the trend toward technology implementation as the norm, based on underlying assumptions about humans as being error-prone, unreliable and needing to be controlled (e.g. Cherns, 1976; Clegg, 2000). Although issues with automation such as skill degradation and human limitations for tasks requiring vigilance and passive monitoring are well established (e.g. Bainbridge, 1983), calls for automation and removing human decision making are still made. In contrast, the aim of the sociotechnical systems theory approach is to obtain an optimal balance of tasks between and amongst humans and technology to achieve joint optimisation (Cherns, 1976).

For historical reasons associated with legal liability in the case of collisions at RLXs, the existing design is technology driven with high levels of redundancy built into technical systems on the assumption that the system is safe as long as warnings are provided. However, as noted previously, the warnings can be ambiguous, providing the same information for multiple system states (i.e. train coming, failure modes, etc.). The existing technology may therefore be failing to appropriately meet its communicative intent (Bade, 2011). In summary, the existing strategy, while hinting towards a systems approach, does not necessarily support RLX design and management in line with open systems principles and the sociotechnical systems theory approach.

In relation to policy and strategy more broadly, the priority has been the prevention of vehicle-train collisions and, in particular, collisions involving heavy good vehicles due to the potential for multiple fatalities in such scenarios. For example, a collision between a loaded semi-trailer and train at Kerang, Victoria in 2007 resulted in the deaths of 11 train passengers (Office of the Chief Investigator, 2007; Salmon, Read, Stanton & Lenné, 2013). Relatively less attention has been given to the prevention of collisions between trains and pedestrians even though examples of multiple pedestrian deaths occurring in a single collision event are not unknown. In one case in the United Kingdom, two schoolgirls were struck by a train and killed in 2005 at Elsenham station near Cambridge (Rail Accident Investigation Branch, 2006). With growing train patronage (Public Transport Victoria, 2012) and with footpaths and warning times not necessarily designed for large numbers of commuters (Metaxatos & Sririj, 2013), the risk of multiple fatality incidents involving pedestrians may increase in the future.

In contrast to existing policy and practice in RLX design, the research described in this thesis will investigate pedestrian safety at RLXs through a systems thinking lens, using CWA to explore the constraints of the system and sociotechnical systems theory to provide recommendations for design solutions. While pedestrian-train collisions that occur on railway tracks in locations other than at RLXs, and that occur due to intentional self-harm, are important issues for the railways and for society, the scope of this research will be limited to unintentional collisions occurring at RLXs in Melbourne, Victoria, Australia.

1.7 The need for evaluation

Another key focus of this thesis is methodological evaluation. The need for evaluation of HFE methods to ensure their effectiveness has been strongly advocated (e.g. Stanton & Young, 1999). Although assessing the reliability and validity of CWA is difficult, a body of evidence is being built up for its reliability, validity and usefulness (e.g. Burns, Bisantz & Roth, 2004; Cornelissen, McClure, Salmon & Stanton, 2014; Hassall & Sanderson, 2014). This research will contribute to this area, not through a formal evaluation of CWA itself, but through the evaluation of a design extension to CWA. The findings of this evaluation are intended to provide potential users with information to assist their selection of methods.

1.8 Aims and research questions

Collisions at RLXs involving pedestrians are a significant safety concern yet the systems approach, widely advocated in modern safety science, does not appear to have influenced research, policy or practice in this area. While CWA is well-suited to understanding pedestrian behaviour at RLXs from a systems perspective, there is evidence suggesting the existence of a gap between the outputs of CWA and system design. Consequently, the overall aim of the research described in this thesis is to develop and evaluate a CWA-based approach to support the design of complex sociotechnical systems, and to apply this approach to provide recommendations to improve the design of RLXs to support pedestrian safety. A secondary aim of the research is to investigate pedestrian behaviour at RLXs using CWA.

The key research questions to be addressed in this thesis are:

1. What methodological adaptations or extensions can be made to CWA in order to support translation of analysis outputs into system design solutions?

2. What are the desirable methodological attributes for a design approach to be used to support CWA-based design?
3. Can the design approach developed be shown to be useful?
4. What are the constraints and goals that influence pedestrian behaviour at RLXs?
5. Can effective designs be produced from the design approach developed to improve safety at RLXs?
6. Is the sociotechnical systems theory approach to design appropriate for public safety contexts?

1.9 Methods and approaches

The key research activities and associated methods are shown in Figure 1.4. The figure also illustrates how the activities contribute to answering the research questions posed in this thesis.

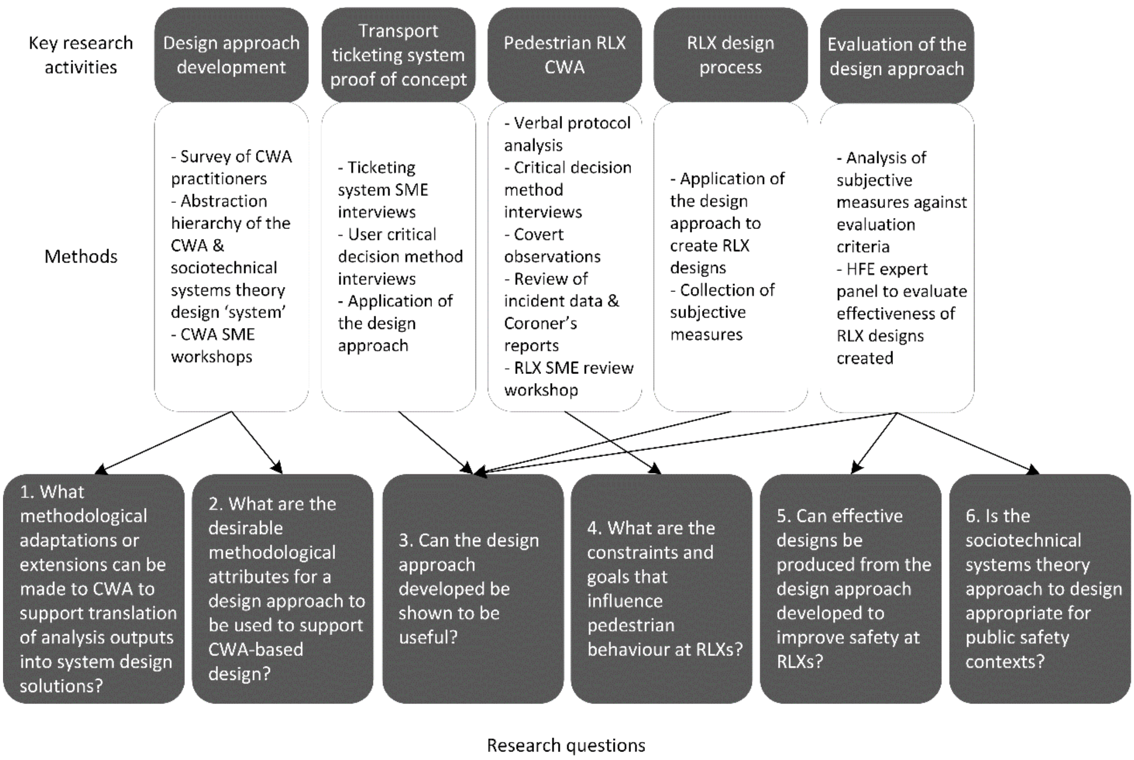

Figure 1.4. Key research activities and methods applied within the research.

The research methods were selected and executed taking account of the sociotechnical philosophy and with the aim of applying the associated values and principles where appropriate. For example, in the development of the design approach, participatory activities such as a survey of CWA practitioners and workshops provided opportunities for CWA users to provide their expertise and input on aspects of the approach. Further, the use of the abstraction hierarchy (AH) representation in the development of the design approach enabled the values of sociotechnical systems theory to be used to define the requirements and the evaluation criteria for measuring the utility and effectiveness of the approach, to retain a strong link with its underlying theory.

A participative approach was also maintained when working with RLX stakeholders and sponsors involved in the research project. For example, stakeholders were invited to review CWA outputs for their accuracy and completion. Further, stakeholders participated in design workshops and were also invited to participate in an evaluation process using the WDA outputs to review the design concepts initially proposed. This provided additional opportunities for road and rail stakeholders to gain experience with CWA with the intention to build capacity within these organisations around systems thinking and the application of systems-based approaches.

Naturalistic and qualitative research methods also played a considerable role in the research. Data collected for the purposes of constructing the CWA employed approaches such as the critical decision method (Klein, Calderwood & McGregor, 1989) and verbal protocol analysis (Bainbridge & Sanderson, 1995) following the guidance provided by Walker (2004). Additional data collection methods included structured interviews, covert user observations and subject matter expert (SME) input through various workshops.

1.10 Structure of the thesis

This thesis is structured in three parts.

Part One provides a review of the theoretical and methodological literature relevant to the research as well as a review of current practice in the use of CWA for design. It contains the following chapters:

> *Chapter 2. Literature review part 1 – Applying a systems approach to RLXs*
>
> This chapter describes the findings from a structured review of the existing literature on user behaviour and cognition at RLXs which considered the extent to which previous research has taken an approach aligned with systems theory to this problem domain.

Chapter 3. Literature review part 2 - Review of the CWA design literature

This chapter reviews CWA design applications reported in the literature and establishes the presence of a gap between analysis and design, particularly for domains governed by intentional, rather than causal constraints. It concludes that there is a lack of clarity around the translation of CWA outputs into design artefacts.

Chapter 4. Current practice using CWA for design

This chapter reports the results of a survey of CWA practitioners which aimed to gather more in-depth information about how CWA is applied within design processes. The results indicated that there is no standard approach to designing with CWA and that practitioners often craft their own approach to design. This chapter recommends that further guidance and tools be developed to assist practitioners to achieve CWA-based design.

Part Two of the thesis describes the development and refinement of the design approach developed within the thesis. It contains the following chapters:

Chapter 5. Defining the requirements for a CWA-based design approach

In this chapter it is proposed that the sociotechnical systems theory approach can provide a bridge between CWA and design. The WDA phase of CWA is used to define an ‘optimal’ design domain incorporating both CWA and the sociotechnical systems approach and to define design requirements and evaluation criteria for the design approach.

Chapter 6. Developing Version 1 of the CWA Design Toolkit

This chapter outlines the development activities undertaken to create the design approach, titled the CWA Design Toolkit (CWA-DT). It also describes the content of Version 1 of the CWA-DT.

Chapter 7. Applying the CWA-DT to design a transport ticketing system

This chapter describes a proof of concept application of the CWA-DT to the public transport ticketing domain. Initial evaluation results and recommendations for refinements to improve the toolkit are described.

Chapter 8. Refining the design approach – Version 2 of the CWA-DT

This chapter describes the refinement activities undertaken following the proof of concept application and provides details about the content of Version 2 of the CWA-DT.

Part Three of the thesis describes the application of the CWA-DT to derive recommendations for improving pedestrian safety at RLXs and provides the results of the formal evaluation of the toolkit. It contains the following chapters:

Chapter 9. Understanding pedestrian behaviour and risk at RLXs with CWA

This chapter reports the results of the application of the five phases of CWA to the RLX system with a focus on pedestrian behaviour. The analysis identifies key risks associated with pedestrian use of RLXs and provides initial recommendations for design improvements.

Chapter 10. Evaluation of the CWA-DT

This chapter describes the application of the CWA-DT to RLX design and the outcomes of its evaluation against the pre-determined criteria (identified in Chapter 5) to demonstrate its effectiveness. It provides discussion regarding the appropriateness of sociotechnical systems theory for designing in a public safety context. Further, it describes refinements to the CWA-DT undertaken based on the evaluation findings.

Chapter 11. Recommendations for improving pedestrian safety at RLXs

This chapter describes in detail the design recommendations identified for improving pedestrian safety in line with the principles of sociotechnical systems theory. Implications for RLX design practice are discussed.

Chapter 12. Discussion and conclusions

In the final chapter, the theoretical, methodological and practical implications of the research are discussed and avenues for further research are recommended.

The *Appendix* provides the final version of the CWA-DT in the form of a guidance document intended for use by CWA practitioners to assist them to use CWA for design purposes. The toolkit is not domain or project specific but is intended to be flexible such as to be useful for any CWA user wishing to use the framework for design purposes.

2 Literature review part 1 – Applying a systems approach to RLXs

Read, G. J. M., Salmon, P. M. & Lenné, M. G. (2013). Sounding the warning bells: The need for a systems approach to understanding behaviour at rail level crossings. *Applied Ergonomics, 44,* 764-774.

2.1 Introduction

The adoption of a systems approach to understanding transport systems has been strongly advocated, including for road (e.g. Larsson, Dekker & Tingvall, 2010; Salmon, McClure & Stanton, 2012) and rail transport (e.g. Wilson & Norros, 2005). Accordingly, systems-based analysis and design methodologies are required firstly, to understand current RLX functioning and how this influences safety performance, and secondly, to generate new, more effective designs. While the literature has alluded to the need for systems approaches to understanding RLXs, and policy aspires to the adoption of a safe systems approach, no previous work has explored to what extent the existing research literature has taken a systems approach. This chapter aims to provide an analysis of the RLX literature to answer this question.

The scope of the literature review included all road users as to consider pedestrians in isolation from other road users and the broader RLX context would be inappropriate given the systems perspective underpinning this thesis. Pedestrians interact with other road users at the RLX as well as with warnings and infrastructure designed for use by other road users (such as the road surface). These interactions need to be understood to provide a comprehensive appreciation of pedestrian behaviour in this context.

Declaration for Thesis Chapter 2

Declaration by candidate

In the case of Chapter 2, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Primary author. Conceived the idea to conduct a structured literature review, determined the methodology for the review and criteria, conducted the literature search, analysed the results and was responsible for the initial drafting of the paper and the subsequent editing.	85%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	Nature of contribution	Extent of contribution (%) for student co-authors only
Paul M. Salmon	Guidance on interpretation and presentation of results. Provided critical review of draft versions of the paper.	n/a
Michael G. Lenné	Guidance on interpretation and presentation of results. Provided critical review of draft versions of the paper.	n/a

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's Signature	[redacted]	**Date** 2 July 2015

Main Supervisor's Signature	[redacted]	**Date** 2 July 2015

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Sounding the warning bells: The need for a systems approach to understanding behaviour at rail level crossings

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A B S T R A C T

Collisions at rail level crossings are an international safety concern and have been the subject of considerable research effort. Modern human factors practice advocates a systems approach to investigating safety issues in complex systems. This paper describes the results of a structured review of the level crossing literature to determine the extent to which a systems approach has been applied. The measures used to determine if previous research was underpinned by a systems approach were: the type of analysis method utilised, the number of component relationships considered, the number of user groups considered, the number of system levels considered and the type of model described in the research. None of research reviewed was found to be consistent with a systems approach. It is recommended that further research utilise a systems approach to the study of the level crossing system to enable the identification of effective design improvements.

1. Introduction

In the ten year period between 2000 and 2009, 695 collisions between road vehicles and trains occurred at rail level crossings in Australia. Ninety-seven fatalities resulted from these collisions, accounting for approximately 30% of rail fatalities over that period (Independent Transport Safety Regulator, 2011). Pedestrians were struck by trains in 98 level crossing incidents over a similar time period (Australian Transport Safety Bureau, 2011). With approximately 10,497 road and pedestrian level crossings in Australia (Rail Industry Safety and Standards Board, 2009), this longstanding safety concern is not only a priority for the Australian rail industry, where it has been identified as one of the top five safety risks (Stroud, 2010), but also internationally. The United Kingdom experiences approximately 11 fatalities each year due to accidents at level crossings (Evans, 2011), while the United States government recorded 249 fatalities in the year 2011 (Federal Railroad Administration, 2012).

Collisions at level crossings result in a higher mortality rate than other types of road traffic accidents (Wigglesworth, 1976) and, due to the disparity in mass between the train and the road vehicle, the impact is usually extensive leading to traumatic scenes. A recent trend of heavy vehicle involvement in these accidents, in Australia at least, has led to risk to the train and its passengers, in addition to the road vehicle, with the potential for catastrophic outcomes (Australian Transport Safety Bureau, 2008). With growing numbers of longer and heavier freight vehicles using the road network, coupled with increased train services and speeds, this catastrophic risk may be increasing (Road Safety Committee, 2008).

Given the safety issues at level crossings and their impact on road and rail systems internationally (United Nations, 2000), there has been a substantial research effort to understand why these accidents occur and how they might be prevented. Much of this effort has focused on the behaviour of motorists with the vast majority of accident investigation reports identifying motorist error as the cause of level crossing crashes (National Transportation Safety Board, 1998). However, researchers have suggested that understanding of road user behaviour at rail level crossings remains limited (Edquist et al., 2009).

Many within the discipline of Human Factors have articulated the need for a systems approach when tackling road safety issues (e.g. Larsson et al., 2010; Salmon et al., 2012), in line with the modern approach to analysing complex safety critical systems. Modern safety science has experienced a paradigm shift away from individual, reductionist approaches to analysing and improving safety issues and now emphasises the recognition of system influences on safety and the occurrence of accidents

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(e.g. Dekker et al., 2011; Leveson, 2004; Rasmussen, 1997b; Reason, 2000).

The increased uptake of systems-based approaches to analysing safety critical domains has prompted some researchers to consider the extent to which these approaches or principles have been applied. For example, a review of patient safety literature was undertaken by Waterson (2009) to determine which publications could be judged to have adopted a systems approach. The analysis found that few studies considered all levels of the system, and suggested that the term 'systems' may be being used inappropriately. It is currently unknown to what extent the systems approach has been applied in the level crossing literature.

The aim of this paper is to review the current research approach to safety issues at rail level crossings. Firstly, two research approaches are discussed and contrasted; the individual approach and the systems approach. Next, key concepts from systems theory are outlined and are synthesised into criteria for a systems approach. These criteria build upon some of those applied by Waterson (2009). The criteria are then applied within a structured review of the rail level crossing literature. Conclusions are drawn regarding the extent to which a systems approach has been applied in the research literature in this domain.

2. The individual approach

Traditionally, research into road user behaviour has focused on individuals, their information processing capabilities and limitations and their resultant behaviour (Salmon et al., 2010b). For example, there is extensive research on the performance impacts of impairment in transport settings due to fatigue or alcohol (Baulk et al., 2008; Lenné et al., 2010; Oxley et al., 2006; Sung et al., 2005) stress (e.g. Desmond and Matthews, 2009; Hartley and El Hassani, 1994; Rowden et al., 2011), and distraction and inattention (e.g. Blanco et al., 2006; He et al., 2011; Noy et al., 2004). Researchers in this field have predominantly preferred reductionist, analytical methods such as laboratory experiments and field studies. The aim of these empirical studies is to control as many variables to enable isolation of cause and effect relationships. There may or may not be a theoretical basis for selecting the variable of interest or predicting it's affect on behaviour, with some researchers noting that, for example, road safety evaluation studies often lack a strong theoretical basis (e.g. Elvik, 2004).

Studies employing the individual approach tend to view the person as another component, similar to a piece of technology, and provide recommendations for increasing the reliability of this component. Often, little consideration is given to the context of behaviour and its influence. This approach leads to proposals for behaviour change through education and enforcement measures that increase compliance with laws. A behavioural approach to improving level crossing safety has been advocated (for example, Sochon, 2008; Wallace et al., 2006). The propensity for accident investigators to 'blame the victim' of systemic deficiencies has been noted specifically in regards to level crossing accidents (Bade, 2011; Green, 2002). This 'hunt for the broken component' mentality is now accepted in the literature to be a flawed approach to improving safety in complex systems (e.g. Dekker, 2011).

3. The systems approach

In contrast, the systems approach takes the overall system as the unit of analysis, looking beyond the individual and considering the interactions between humans and between humans and technology within a system. In cognitive systems, where functioning relies on people to perceive, think, act and collaborate with one another (Lintern, 2011), a systems approach incorporates consideration of human cognitive and/or behaviour. However, this should not limit the investigation of the system to behaviour only. From an accident prevention perspective, barriers or controls within the system may influence safety without directly affecting behaviour (for example, through affording error tolerance or mitigation of injury severity). The systems approach also encompasses factors within the broader organisational, social or political system in which processes or operations take place. According to this approach, safety is an emergent property arising from the interactions between components at all levels of the system (Leveson, 2004). This can be contrasted with the reductionist or analytical approach which looks at the components (such as humans) in isolation and views the whole as merely the sum of its parts.

The field of human factors has traditionally worked within a psychological paradigm, focussing on the physical and cognitive capabilities and limitations of humans. This knowledge about people is combined with information about the context in which they are behaving in order to understand and analyse behaviour. Qualitative methods such as task analysis (Stanton, 2006), workload analysis (e.g. Pickup et al., 2010) or human error identification (e.g. Kirwan, 1998; Stanton et al., 2009) are often used when exploring behaviour in context. Applied to safety critical systems, the focus of human factors has been understanding human behaviour, particularly human error, and how it can be managed or controlled. There can be a tendency to recommend more and more strict barriers to control and restrict behaviour, particularly in response to accidents (Dekker, 2002). However, this can create increasingly complex systems (Dekker et al., 2011; Hollnagel, 2004), or situations where people become frustrated with the lack of flexibility, and find ways to circumvent controls. Thus, a more sophisticated understanding of people's interactions with different controls, and in different contexts, is vital.

Modern human factors approaches are moving away from the psychological approach that considers humans as limited information processors. While understanding human capabilities and limitations is still important, there is greater focus on the context of behaviour and the constraints on behaviour imposed by the environment. This movement has been guided by systems theory and the advent of systems-based methods to understanding cognition such as found in the cognitive systems engineering field. There has been a move away from individual to distribution cognition (Hutchins, 1995) with cognitive processes such as situation awareness seen as distributed amongst actors in a system (human and technical), rather than being a property of an individual (Salmon et al., 2009). There has also been a shift in thinking from a focus on human error, to a consideration of performance variability acknowledging that the same processes lead to successful and unsuccessful (erroneous) behaviour. Accordingly, much can be learned from studying situations where things go right (Hollnagel, 2009). Rather than conceptualising the human as the weak link in an otherwise well designed technological system, humans are viewed as flexible and adaptive decision makers who are integral to the safe and effective functioning of the system (Lintern, 2011).

3.1. The rail level crossing system

It is essential, prior to developing criteria for a systems approach to research, to first establish the applicability of systems theory to rail level crossings. In this section we confirm the characterisation of level crossings as a complex socio-technical system, as has previously been undertaken for other high-hazard industries and domains such as nuclear power, air traffic control and space missions (Perrow, 1984). In a socio-technical system, social and technical components combine to achieve the system goals (Vicente, 1999). Operation of the level crossing system involves interactions between various road users such as motorists, cyclists, pedestrians and rail users such as train drivers and sometimes signallers. These people also interact with various technological components including vehicles (cars, bicycles, trains), equipment (gates, alarms) and infrastructure (the road, rail tracks, signage).

An analysis of the road system according to Skyttner's (2005) description of complexity concluded that roads were complex in nature due to the diverse physical elements such as road users, vehicles and infrastructure components, and the many interactions between road users and vehicles and between vehicles and the road infrastructure (Larsson et al., 2010). Further, the randomness of interactions between components within the system is evident, even with the presence of road rules. Finally, the road system is open to the environment, and is largely subject to road user behaviour, which can be highly variable (Larsson et al., 2010). The influence of the rail environment provides further complexity, both in relation to the interactions between the physical components, and in terms of the coordination required of various organisations to manage the risks to safety at these intersections.

3.2. Defining a systems approach to research

The need for the application of systems approaches has been identified across the safety critical domains, including rail (Wilson and Norris, 2005) and road transport (Larsson et al., 2010; Salmon et al., 2012; Young and Salmon, 2012; Zein and Navin, 2003). To confirm if systems approaches are actually being applied, it is necessary to operationalise the key principles and concepts from systems theory. While there may not be common agreement about what these concepts are (Waterson, 2009), some broad themes can be drawn from the literature. These themes have been identified as: safety as an emergent property, variability of system and component performance, the notion that systems are dynamic and finally, systems as hierarchical structures. It is proposed that these four features represent the essence of systems theory and they have been used as the basis for determining to what extent systems theory has been applied in level crossing research conducted to date. For each feature, a number of measures are proposed to enable analysis of whether a particular study has employed a systems approach. These features and measures are further elaborated in the following sections and are summarised in Table 1.

Criteria for a systems approach to research were derived from the measures outlined in Table 1. These criteria were that the research used a non-experimental methodology, developed or applied a formative model (rather than a descriptive or normative model), considered all relevant system components, considered all relevant users, and considered all system levels up to the socio-political environment.

3.2.1. Safety as an emergent property

According to systems theory, interactions between components produce emergent phenomena, which cannot be predicted or understood through examination of individual components in isolation (Skyttner, 2005). As Dekker (2011) explains, the parts cannot explain the whole. Both the presence of safety and the occurrence of accidents have been described as emergent properties of socio-technical systems (Dekker, 2011; Leveson, 2004). Thus, a detailed understanding of one component (such as the reliability of boom gate technology, or the personality characteristics of a single road user) cannot provide an understanding of system safety or the reasons for accidents (Leveson, 2004). All components, human and technical, need to be considered as well as the relationships between them.

A range of concepts relating to emergence have been discussed in the safety science literature. For example, the notions of holism

Table 1
Aspects of analyses indicative of a systems approach and related measures.

Features of a systems theory approach (adapted from Larsson et al., 2010)	Attributes of analyses that support this feature	Attributes of analyses that do not support this feature	Measures
Safety as an emergent property	- System is the unit of analysis - Focus is relationships between system components rather than their individual properties - Considers all components of the system and the relationships between them - Enables identification or consideration of complex, non-linear relationships - Focus is on emergent behaviour - Aim is joint optimisation	- Component is unit of analysis (e.g. road user) - Does not consider relationships between all components - Focus is establishing linear uni-directional cause and effect relationships - Aim is optimising the performance of one component or sub-system (i.e. the user)	• Type of research (*experimental or non-experimental*) • Type of model developed or applied (*normative, descriptive-normative, descriptive or formative*) • Number of system components considered in analysis • Number of users included in analysis
System and component performance is variable	- Acknowledges the variability of components in measuring and interpreting behaviour - Describes the possible range of behaviours	- Normative approach is used - Removal of 'outliers' in quantitative analyses - High level categorisations of behaviour	• Type of research (*experimental or non-experimental*) • Type of model developed or applied (*normative, descriptive-normative, descriptive or formative*)
Systems are dynamic	- Acknowledges that systems are not static, and change over time - Describes the possible range of behaviours	- Considers system only at a point in time - Normative approach is used	• Type of model developed or applied (*normative, descriptive-normative, descriptive or formative*)
Systems as hierarchical structures	- Considers components or influences at all levels of the system	- Considers only components at the physical system level	• Number of system levels included in study (*physical environment, organisational management, socio-political environment*)

(Goh et al., 2010), connectivity between elements (Waterson, 2009) and interactions (Leveson, 2011; Waterson, 2009) relate to this overarching theme.

In complex systems the relationships and interactions between components are non-linear. Small changes can have large, unexpected effects (Dekker, 2011). Further, component interactions are multi-directional and there are many-to-many relationships amongst components. The study design chosen to apply to complex systems thus requires some careful consideration. In this paper, we use the terms experimental or empirical to refer to research methods concerned with determining causal relationships, via a priori hypotheses. These studies identify independent variables and measure their effect on dependent variables, controlling for potentially confounding variables (Jacko et al., 2012). Quasi-experimental studies, such as naturalistic observation research, are sometimes employed with the aim of determining cause and effect relationships, even though such studies can generally only indicate associations or correlations. Quasi-experimental studies are commonly used to evaluate level crossing countermeasures (Edquist et al., 2009).

Empirical studies that aim to establish cause and effect relationships are inappropriate as the overarching framework for research involving complex systems because they tend to assume that these relationships are linear and uni-directional. In fact, studies employing statistical analyses may be inclined to view observed emergent phenomena as outliers or as confounding variables, rather than legitimate observations. Consider, for example, a study involving installation of rumble strips on approach to a level crossing with comparisons of motorist speed before and after installation. The experiment might conclude that with the new countermeasure in place, the mean vehicle speed decreased by 10 km/h, thus improving safety. However, this conclusion does not describe the range of speed differences (only the mean), any other behaviour changes observed (such as changes in visual search) and cannot describe any unintended, emergent consequences of the new installation. For example, some users may chose to move into the on-coming lane to avoid the rumble strips, which may be more prevalent within groups such as cyclists, motorcyclists and heavy vehicle drivers, who were not observed in the study. Looking more systemically, the introduction of rumble strips could prompt users to change their route contributing to some unforeseen safety issue in another area of the road system, in line with the concept of the 'butterfly effect' in chaos theory (Dekker, 2011).

In addition to the type of research method, the way in which human behaviour is modelled within research impacts the ability to identify emerging behaviours within a dynamic system (Rasmussen, 1997a). Different types of modelling have been described, differing according to their underlying philosophy to understanding and supporting human behaviour. The first type, normative modelling, is prescriptive and defines what should be done to achieve a goal. Vicente (1999) provides traditional task analysis techniques as examples of normative human behaviour modelling. However, it has been noted that some task analysis methods, such as hierarchical task analysis, can be applied to model the system rather than the task (Stanton, 2006). As such, the model types cannot be identified only by the technique used, but how it has been applied and how the data have been interpreted. The second type, descriptive modelling, is based on actual behaviour, either describing behaviour in terms of how it differs from norms, or without reference to a normative standard. Finally, predictive (Rasmussen, 1997a), subsequently termed formative (Vicente, 1999) models, describe the constraints and behaviour shaping features within the system, rather than focussing on behaviour. Rasmussen (1997a) and Vicente (1999) provide more detailed descriptions of these types of models and examples of their use. Of interest to the present research question is the proposition that normative and descriptive approaches are not adequate for identifying all types of emergent phenomena (Vicente, 1999). Normative models will only capture behaviours intended by system designers, and would not identify emerging, unanticipated behaviours and features within a system. Descriptive models may identify some emergent features, but this will be limited to the current state of the system. Systems are dynamic; they are constantly adapting and responding to external disturbances. The application of a formative modelling provides the best opportunity to identify emergent properties, acknowledging that this can only be done within the boundary of the system defined within the analysis, and that the nature of complex systems makes it impossible to describe them completely (Dekker, 2011).

3.2.2. Performance variability

The second feature of systems theory acknowledges the variability of component and system performance (Larsson et al., 2010). Systems theory asserts that system components and systems themselves are constantly adapting in response to local pressures (Skyttner, 2005). Thus, behaviour is not consistent, but variable. In complex socio-technical systems there are generally many degrees of freedom and people can use numerous strategies to reach a goal. All the required actions involved in implementing these strategies in specific situations cannot be specified in advance as system designers cannot foresee all disturbances and necessary adaptation within the system (Vicente, 1999). Dekker et al. (2011) have highlighted the difficulties with attempts to foresee system behaviour and to gain a complete description of the system. These difficulties and uncertainties arise from the variability within the system.

Relevant to the level crossing system, both Hollnagel (2009) and Vicente (1999) have described driving as a situation involving performance variability as the driver must constantly adjust their performance, for example in response to the actions of other road users or other dynamic elements in the road environment. Performance variability is necessary to effectively deal with disturbances and changes within the system and understanding the range of possible variability is important for understanding system functioning.

Some modelling approaches are superior to others in dealing with variability. Normative modelling approaches are insufficient to deal with performance variability as they define the 'one best way', rather than acknowledging that goals can be met through various means. Descriptive approaches will uncover the range of strategies currently in use while formative approaches, appropriately applied, should identify all possible strategies that could be exploited.

Research approaches that apply gross categorisations of behaviour within analyses are also inadequate for understanding the range of variability in a system. Experimental studies sometimes use such categorisations. In the road safety literature, categories of behaviour such as 'compliant' and 'non-compliant' represent a descriptive approach that compares actual behaviour to a normative standard. These broad categorisations, while acknowledging that variation exists, provide little insight into the varieties of behaviour and how such variations could be managed. Instead, these approaches essentially pathologise any behaviour that differs from the normative expectation, and reinforces the individual view of accidents. Further, the identification of non-compliance or violations says as much about the state of the rules as they do about behaviour. For example, it is possible for violations of the prevailing law to have no safety consequences and for compliant behaviour to be unsafe in some circumstances.

3.2.3. Systems are dynamic

Thirdly, systems are dynamic. They involve the transformation of inputs into outputs (Waterson, 2009), and consist of feedback loops (Leveson, 2011) and causal loops (Goh et al., 2010). As well as displaying variable performance at a given point in time, systems also adapt over time to changing conditions (Dekker et al., 2011). In accordance with the principle of entropy, systems migrate towards a state of increased risk (Leveson, 2011) and can drift into failure (Dekker, 2011).

Research from a systems perspective should acknowledge this dynamism, and avoid making assumptions about system behaviour that are contrary to this notion. For example, it is no longer sufficient to manage safety by only analysing past accidents and incidents (Leveson, 2011). The system will have evolved following an accident, either due to the impact of the accident, through advances in technology, or other adaptations (Dekker et al., 2011). This means that any learnings uncovered through investigation may no longer apply.

The type of model used to analyse the system can affect the extent to which it can encompass dynamic aspects of system functioning. Similar to dealing with variability, normative models are based on the assumption that systems are static and thus they cannot incorporate these dynamic aspects. Descriptive modelling approaches could incorporate dynamic elements by documenting, for example, how a system had changed over time leading to an accident (e.g. Snook, 2000). Only formative approaches, then, can potentially take account of future system states. This could be achieved through documentation of the stable constraints within the system, acknowledging that the system's behaviour can oscillate within these boundaries.

3.2.4. Hierarchical organisation

The final aspect identified is the tendency for systems to be organised in hierarchical structures (Skyttner, 2005). In order to understand the system, it is necessary to examine each relevant hierarchical level and its relationship with those above and below (Vicente, 1999). There has been longstanding acknowledgement that analyses must go beyond the immediate work environment to the influences within the management system and broader social and political environment (e.g. Larsson et al., 2010; Leveson, 2004; Rasmussen, 1997b; Reason, 1997; Waterson, 2009). The concepts of control structures (Leveson, 2011) and regulation (Goh et al., 2010) are relevant to this notion of hierarchy within systems.

Rasmussen (1997b) proposed a hierarchical model of risk management within socio-technical systems. The structure defines hierarchical levels from the work process, through various groups within the organisation and up to the level of government decision making. This model was subsequently adapted by Leveson (2004) into a control structure detailing means of control and feedback between the levels. For the purposes of this analysis, given the complex organisational arrangements in place for managing level crossing performance and safety, a simplified hierarchy is proposed. The proposed levels are:

- the physical environment (the users, vehicles, equipment and infrastructure at the level crossing itself),
- the organisational management system (aspects of management by the road authority, rail operators, commercial road transport companies, police and other organisations with influences on road users), and
- the social and political environment (activities by government, regulators, standards bodies, the media and society in general).

4. Analysis of the level crossing literature

To better understand the current state of the literature concerning behaviour at rail level crossings, a structured review was undertaken of relevant publications over a 30-year period. Within this review, the measures for the four features of systems theory discussed previously were applied to the level crossing literature. The methodology and results of the review are presented in the following sections.

4.1. Case selection

To identify relevant publications, a search was undertaken of databases, government and research organisation websites, conference proceedings and the reference lists of papers and literature reviews. The databases searched included: PsycInfo, SafetyLit, The Australian Transport Index, the Transportation Research Information Database and Google Scholar. The keywords used in the database search were: level crossing, grade crossing, rail crossing, railway crossing, active crossing and passive crossing.

Each publication identified was reviewed to determine whether or not it met the inclusion criteria. The first criterion for inclusion was chosen to limit the review to research that focuses on cognition within the system as relevant to safety to acknowledge the central role of the human in complex cognitive systems. This criterion was that the publication must include some analyses relevant to cognition and/or behaviour of level crossing users. To meet this criterion the analysis must have utilised some form of data gained from methods such as observations, accident analysis, surveys, interviews, etc. Publications may have considered aspects of the system apart from cognition and/or behaviour, but it is proposed that a systems approach in this context must consider the human as part of the system and analyse interactions between humans and other system components.

The second criterion limited the publication date to the 30-year period between January 1981 and December 2010. With systems approaches being relatively new to the road and rail safety domains, it was considered unlikely that publications prior to this date would utilise such an approach. Third and finally, the publication was required to be available in English.

The types of publications that did not satisfy the inclusion criteria included those where analyses involved no connection to behaviour or cognition (such as mathematical modelling of incident data), studies focussed on road users crossing the track at an unauthorised point (e.g. trespassing) and policy and government strategy documents. Where the same study was reported in more than one publication (for example, in a report and conference paper), the publication that provided the most details about the study was included in the review.

For publications that met the inclusion criteria the following information was documented: the type of publication, year of publication, country in which the research was conducted, the type of analysis conducted, the system relationships analysed or identified and the number of user groups considered. Further, the number of system levels analysed and the type of model described were classified. The following discussion presents the results of the review.

4.2. Publication information

In total, 124 publications met the inclusion criteria. The majority of the studies reported were conducted in the USA (59.7%), followed by Australia (16.9%), and then the United Kingdom (8.9%). Between one and six studies originated from each of Canada, the Netherlands, Japan, Sweden, New Zealand, Hungary, Finland and Israel. Thus, while this is an international problem, the greater part of the research has emerged from just one nation. The implication of this is that some findings in the literature will be difficult to generalise across countries due to unique local factors. Most of the publications that were classified were reports (39.5%) and journal articles (38.7%). Conference papers made up 17.7% of the publications with the remainder comprising two book chapters and three academic theses that were available online. The distribution of publication types indicates that a substantial segment of the literature was not subject to a stringent peer review process. Further, of the 48 journal articles only ten were published in the leading journals of the human factors and ergonomics field (for example, Accident Analysis and Prevention, Ergonomics, Human Factors, Safety Science). Notably, none of the included publications was published in Applied Ergonomics, which has a strong track record of publishing rail safety-related research (e.g. Baysari et al., 2011; Rose and Bearman, 2012; Wilson and Norris, 2005), although selected results of one report included in the review was subsequently published in this journal (Lenné et al., 2011).

4.3. Results

The following sections report the results of each of the systems measures described in Table 1. A summary of the results is provided in Table 2. For each measure shown in Table 2, the row matching the criteria for a systems approach has been italicised. Only when all five criteria have been met can a research approach be considered compatible with the systems approach.

Table 2
Summary of results for all measures.

Measure	*N*	%
Analysis method		
Experimental	94	75.81
Non-experimental	*30*	*24.19*
Number of relationships		
Zero	4	3.23
One	30	24.19
Two	42	33.87
Three	11	8.87
Four	8	6.45
Five	3	2.42
Six	10	8.06
Seven	4	3.23
Eight	1	0.81
Nine	2	1.61
Ten	1	0.81
Eleven to fifteen	5	4.03
Sixteen to twenty	3	2.42
Greater than twenty	*0*	*0.00*
Number of user groups		
One	89	71.77
Two	19	15.32
Three	9	7.26
Four	4	3.23
Five	3	2.42
Six	0	0.00
Seven	0	0.00
Eight	*0*	*0.00*
Number of system levels		
Physical	103	83.06
Physical & Organisational	17	13.71
Physical, Organisational & Socio-political	*4*	*3.23*
Model type		
Normative	2	1.61
Descriptive-normative	30	24.19
Descriptive	92	74.19
Formative	*0*	*0.00*

4.3.1. Type of research

Publications were coded as either experimental or non-experimental based on features such as whether or not hypotheses were described and whether the study design aimed to determine causal relationships by manipulating and/or controlling variables, or was more descriptive or exploratory in nature. Quasi-experimental designs were classified as experimental if the authors used the results to form conclusions or statements about cause and effect relationships. Where a combination of approaches and methods were applied, a judgement was made regarding the most dominant approach. As shown in Table 2, just under one quarter of publications were classified as non-experimental, with the majority of publications classified as experimental.

4.3.2. Number of relationships included in analysis

Each publication was reviewed to determine how many component relationships were considered in the analyses. Components were items within the system such as a user (e.g. motorist), a piece of equipment or vehicle (e.g. train), a part of the infrastructure (e.g. road), an organisational process or system (e.g. train scheduling) or an element arising from the socio-political environment (e.g. government policy). A relationship between components was coded where components were considered in relation to one another. For example, whether motorist behaviour changed when different road designs were present on approach to the level crossing. The relationships considered by the analysis may have been determined a priori, for example, outlined in hypotheses, or the relationships may have been identified as the result of the analysis, such as in exploratory research.

The range of relationships considered within each publication was between zero and twenty, as displayed in Table 2. The criterion selected for number of relationships considered (greater than 20) was chosen as it is not possible to identify with certainty the exact number of components relevant to all level crossing contexts, but it was determined by the authors that at least 20 components exist within any level crossing system. Publications were allocated zero relationships where, for example, they considered only aspects of the person such as age, gender or personality and did not relate this to any other system components. The majority of publications (70.16%) involved analysis of between zero and three relationships. Very few considered more than ten relationships within the analysis undertaken. Of these publications with more than ten relationships, most were identified through non-experimental analyses, and all considered two or more user groups.

The relationship that was classified the most frequently within the collection of literature was between motorists and active warnings (i.e. warnings designed to alert a road user to the presence of a train, such as flashing lights or boom barriers). This was coded 75 times, with the next most common (coded 53 times) being motorists and passive warnings (i.e. warnings designed to alert a road user to the presence of the crossing, such as signs and road markings). The frequency of study of these relationships relative to the range of possible relationships within the physical system is illustrated in Fig. 1. The widths of the lines in Fig. 1 represent the frequency of the relationship found in the literature. Components without connections were identified by the authors as being potentially influential on the level crossing system, but their relationship with other components was not studied

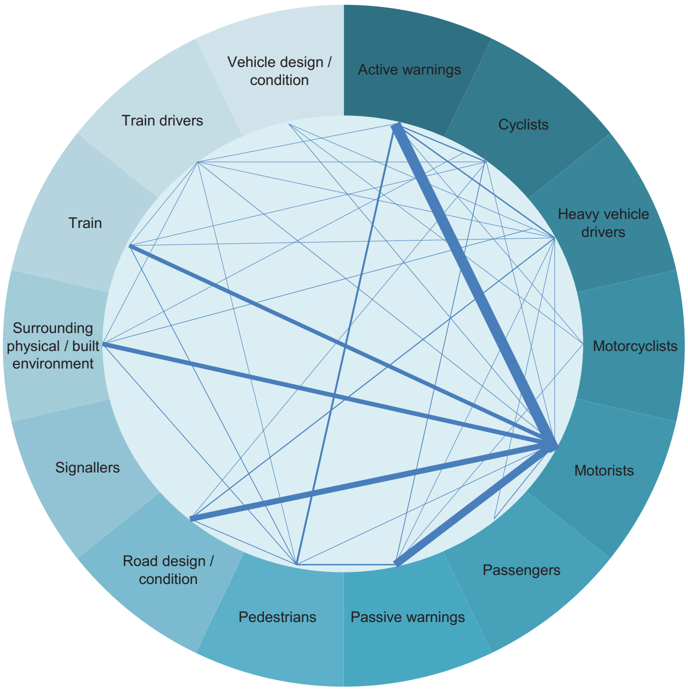

Fig. 1. Relationships between components at the physical level of the level crossing system.

within the literature. It should be noted that some relationships between users (such as how motorists behave in relation to other motorists at level crossings) were present in the literature but are not shown in the following figures.

Figs. 2 and 3 illustrate the relationships at the organisational, and then the socio-political levels of the level crossing system. The distribution of relationships amongst the hierarchical levels of the system will be discussed in Section 4.3.4 below.

4.3.3. Number of user groups considered in studies

Having classified the relationships analysed, these were reviewed to determine which user types had been considered. The users were classified into eight groups: motorists, passengers, pedestrians, cyclists, heavy vehicle drivers (including bus drivers and tractor/machinery operators), motorcyclists (including riders of mopeds and scooters), train drivers and signallers.

As outlined in Table 2, more than 70 percent of the publications included only one user in the analysis. It can be seen in Fig. 1 that these were generally motorists. Nineteen of the publications considered two user groups and the remaining considered between three and five user groups.

The criteria selected as representing a systems approach was eight user groups, based on the eight potential types of level crossing users identified. None of the analyses considered more than five user groups, and no research within the review considered signallers. It should be noted that some types of level crossings, such as pedestrian level crossings with no adjacent roadway, would not be used or affected by all of the user types. This was considered in the analysis and one publication was identified that investigated pedestrian crossings and considered both the pedestrian and the train driver, thus potentially considering all relevant user groups.

4.3.4. Number of system levels considered in studies

The relationships were also reviewed to determine which hierarchical levels had been explored, based on where the identified components were found in Fig. 1. For example, if a study considered the impact of enforcement of road rules on motorist behaviour, this was classified as consideration of the physical and organisational systems. Because the inclusion criteria of the review required a link to human behaviour or cognition, all publications considered the physical environment to some extent. Where the relationships involved components within the organisational management system or the social and political environment this was documented.

As displayed in Table 2, the majority of studies considered only the physical system, some also took into account factors within the organisational system, such as train scheduling and risk management processes, while very few considered the wider social and political environment. This can be seen by reviewing the relationships shown in Fig. 3, where the concentration of these linkages are found within the physical layer of the system. Very few relationships are found at the outer layer, and the narrow widths of the lines also reveal the low frequency of studies considering these relationships. For example, the relationship between motorists and the road rules was identified twice within the 124 publications.

4.3.5. Type of model described in research

Publications were further classified according to the philosophy underpinning the analysis of behaviour. The model types used for classification were normative, descriptive-normative, descriptive and formative. Rather than reflecting the way data was collected or how research questions were framed, this categorisation was based on how data or findings were presented, interpreted or modelled within the publication. Most studies did not present explicit models of cognition or behaviour, but could be classified based on the way

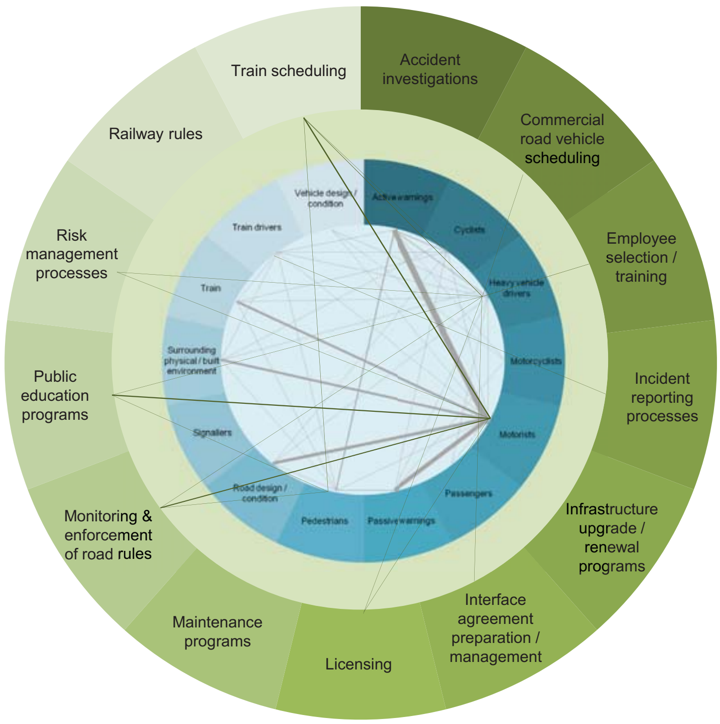

Fig. 2. Relationships between components at the organisational and physical levels of the system.

the results of analyses were interpreted and explained within the publication.

As shown in Table 2, close to three-quarters of the studies were classified as descriptive-normative, indicating that the research involved comparisons of observed behaviour with a normative standard. This standard was invariably the road rules applicable to the jurisdiction in which the research was undertaken. A further 24.2% of publications were classified as descriptive and the remaining 1.6% encompassed normative models. The lack of normative models was unexpected, but represents the dominance of experimental studies, rather than task analysis methods, within this field. No studies were classified as providing a formative analysis. As discussed previously, only a formative approach provides the opportunity to identify present and potential emerging phenomena, and all possible variations of behaviour.

5. Discussion

The aim of this review was to evaluate the current research on rail level crossings to determine to what extent a systems approach has been utilised. None of the publications reviewed contained research consistent with a systems approach, as defined by the measures developed from attributes of systems theory in this paper. Some of the research tended towards a systems approach but no analyses demonstrated all aspects. Only one publication was found that included analysis of all relevant user groups, however this research considered only the physical level of the system, and used a descriptive-normative approach to describe the findings. No formative approaches were identified and the bulk of the studies considered only the physical level of the level crossing system hierarchy.

Based on the review it is concluded that the research on rail level crossings conducted to date can be characterised as taking an individual, reductionist approach, with a focus on motorists and their interactions with specific warning devices at level crossings. Further, as Fig. 3 demonstrates, as a whole the body of literature has taken a narrow view of the system, with many avenues not explored. Although the boundaries drawn in this analysis and the way in which the components have been categorised may be debated, the findings indicate that the approach taken to rail level crossing research has not kept pace with theoretical advances in safety science (e.g. Leveson, 2004; Rasmussen, 1997b; Reason, 1997) and is incongruent with the current human factors approach to safety research. The findings of this review align with those uncovered by Waterson (2009) in the patient safety literature.

It is therefore concluded that research is needed in the rail level crossing domain that takes a systems approach. Specifically, the research approach should have the capability to deal with emergent phenomena, performance variability, the dynamic nature of systems, and to take into account the hierarchical structure and relationships across system levels. This may require more use of exploratory or qualitative research methods that are becoming more widely applied to the analysis of complex systems. Analyses should encompass the whole range of users, as there is little information currently existing regarding train drivers, signallers, heavy vehicle drivers and motorcyclists. Further, there is an opportunity to better investigate multi-directional relationships. For

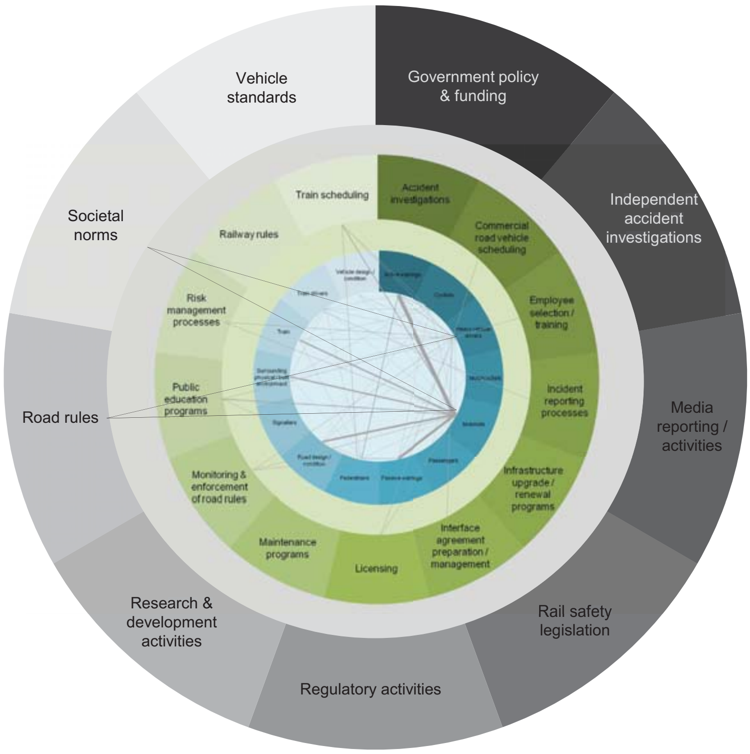

Fig. 3. Relationships between components at the socio-political, organisational and physical levels of the system.

example, research has noted the impact the presence of pedestrians has on motorists (e.g. Meshkati et al., 2006; Salmon et al., 2010c), but it is unknown whether or not pedestrians take cues from, or are distracted by, motorists when approaching or crossing the tracks.

The level crossing system is essentially about interactions at the intersection between the road and rail systems. However, the current literature base predominantly features road safety research with a strong focus on motorist behaviour. This reflects the prevalence of the individual view of accident causation at level crossings. Traditionally, the rail system has viewed road users as external disturbances to an otherwise well controlled, almost closed, system. However, analysing road and rail components and the relationships between them together is the only way to understand and improve system performance.

5.1. Challenges in applying a systems approach

The conclusion that a genuine system approach is not apparent in the literature is not a criticism of the 30 years of research effort on this topic. The benefits of the systems approach have been recognised for many years, however methods that would assist in taking such an approach to understand cognition and behaviour have not been widely known and understood outside specialist academic and practitioner groups. The systems approach has only recently begun to be explored in the road and rail domains. Further, systems-based methods such as cognitive work analysis are difficult to actualise in the real world. They are time and resource consuming (Naikar and Sanderson, 2001) and thus require significant investment from government or academic funding bodies. This can be challenging with methods that are not widely recognised and are exploratory; rather than promising to immediately determine the effectiveness of new countermeasures, as short observational studies may purport to do. It can be difficult to predict at the outset of such research the detailed outputs and outcomes that funders will receive from such a venture, thus funders are required to be open to innovation in research and research teams are required to find effective means to communicate the benefits of this type of research.

The nature of complex systems limits the ability to develop a complete system description using any method. Systems are dynamic and adaptive and they tend to change before they can be fully described (Dekker, 2011). Thus, even methods based on systems theory will be unable to provide a complete description of a system or accurately predict future system behaviour.

5.2. Proposed systems-based research approach

While methods may be limited in their ability to completely describe a complex system, this should not preclude efforts to understand, and improve such systems. Accident analysis methods such as Accimap (Rasmussen, 1997b) and STAMP (Leveson, 2004) and system design and evaluation methods such as cognitive work analysis (CWA, Vicente, 1999) are consistent with systems theory and can support analysis that takes into account many principles of systems theory (Salmon et al., 2012). While it would be beneficial to begin to apply systems-based accident analysis methods in the level crossing context, fortunately accidents are a relatively rare occurrence limiting the available cases for analysis.

Further, when events do occur there is often limited data available to investigators and other agencies about the systemic factors involved in the accident, making it difficult to populate these methods comprehensively.

It is recommended that, as an alternative to a reactive analysis following an accident; greater benefit would be gained from a proactive application of systems-based modelling methods to provide a more comprehensive understanding of the system through the identification of the constraints that shape the system's behaviour. CWA has been widely utilised to understand and improve the design of complex systems (e.g. Hilliard and Jamieson, 2008; Naikar et al., 2003; Reising and Sanderson, 2002). The CWA framework consists of five phases of analysis that commences by modelling the environmental constraints within the domain, and progressively narrows its focus to consider the tasks, strategies, allocation of functions and competencies required by people interacting within the domain (Vicente, 1999). As a formative approach that describes how behaviour could be within the system, CWA has the potential to provide a new perspective on the current and potential functioning of the level crossing system. The ultimate purpose of applying this framework is to understand the system in order to inform design, or re-design, of complex socio-technical systems (Vicente, 1999).

The existing literature base reviewed in this paper could complement the findings of a cognitive work analysis due to the complementary nature of systems and reductionist approaches (Salmon et al., 2010a). The systems view provided by CWA affords a holistic understanding of the system and its function, while reductionist methods can subsequently be applied to provide a more specific understanding of the relationships between different components (Bertin-Jones, 2010). The holistic view will greatly benefit this area of research as it can assist to reconcile any differences in findings between individual reductionist studies, to identify research gaps, and to prioritise research and safety initiatives.

6. Conclusion

Although much research has been undertaken, the existing methods and approaches have not yet provided the answers needed to improve safety in the level crossing context. The existing research has not applied a systems approach, and thus has not identified, described or explained emergent phenomena, variability in system functioning, dynamic aspects of the system and how influences at different system levels interact. Instead, research has favoured measurement of motorist behaviour, to the exclusion of other user groups, and has generally been based on an individual, experimental approach. Research findings have built up over time in a piecemeal fashion which can make it difficult to integrate the findings into a broader, holistic understanding of system functioning. The current body of knowledge is limited in its ability to describe how and why accidents happen in this system, as accidents are emergent properties of the various interactions. There is a need for the application of methods based on the systems approach to better understand all the relationships and interactions within the level crossing system, and to propose and evaluate countermeasures that will promote system safety, rather than optimise the reliability of individual components. There may be challenges ahead in such an endeavour, but if this new approach can deliver the promised benefits, it will be well worth the effort.

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2.2 Discussion

The review of the literature provided in this chapter uncovered a clear need for the application of systems-based approaches, such as CWA, to understand RLX functioning from a systems perspective.

2.2.1 The dominant paradigm

The findings of the analysis of the RLX literature show the clear bias towards investigating motorist behaviour, as opposed to the behaviour of all road users including cyclists, motorcyclists, heavy vehicle drivers and, importantly for this thesis, pedestrians. Potentially, this research bias towards motorist safety at RLXs may reflect the priority for government funding for safety initiatives. Interestingly, however, in Australia and the United States at least, recent data suggests a downward trend in motorist fatalities at RLXs, while the trend for pedestrians remains stable (Beanland, Lenné, Salmon & Stanton, 2013; Metaxatos & Sriraj, 2013). Of concern is that this this safety issue has remained on a stable trend over the last 10 years (Australian Transport Safety Bureau, 2012) with a very limited research base to inform safety improvements. Previous reviews have similarly noted the paucity of research on pedestrian behaviour at RLXs (e.g. Edquist, Stephan, Wigglesworth & Lenné, 2009; Freeman, Rakotonirainy, Stefanova & McMaster, 2013).

Further, based on the findings of the literature review, the knowledge that is available has not been developed using a systems approach and may therefore have missed the opportunity to understand safety in this complex system and how design can be improved. A critical conclusion for this thesis is that currently we do not understand RLX accidents involving pedestrians from a systems perspective.

2.2.2 Key findings for pedestrian safety

As previously noted, the dominance of experimental approaches applied within the literature has limited the ability to understand interactions and emergence within the RLX system. However, the existing literature has explored some interactions between pedestrians and other aspects of the system which are of use in beginning to build up an understanding of the RLX system. Some illustrative findings from the literature are shown in Table 2.1.

Table 2.1. Illustrative findings from the literature interactions involving pedestrians and other aspects of the RLX system.

Interaction	**Description / comments**
Pedestrians - Active warnings	- After active warnings were installed to warn of trains, pedestrians stopped looking for trains (Siques, 2002). - Pedestrians were observed to walk around road boom gates (Ko, Washburn, Courage & Dowell, 2007). - Pedestrian gates had a strong effect on deterring pedestrians from crossing the tracks illegally (Metaxatos & Sririj, 2013). - Pedestrians reported that the auditory warning presented at the RLX was the most important piece of information affecting their decision making, in contrast to motorised users who predominantly relied on visual cues (Beanland, Lenné, Salmon & Stanton, 2013). - A dynamic warning sign to warn of another train approaching reduced the number of pedestrians crossing in front of an approaching train, particularly within four seconds of train approach (Farradyne & Sabra Wang and Associates, 2002).
Pedestrians - Passive warnings	- Crossing knowing that a train is approaching is more likely to occur at passive crossings than at active crossings (Clancy, 2007).
Pedestrians - Surrounding physical / built environment	- Users having a poor viewpoint and being unable to see a train approaching was identified as an influencing factor on behaviour and pedestrian errors (Human Engineering, 2008). - Housing developments near the RLX increase its use by pedestrians as well as road traffic (Davis Associates Ltd, 2005).
Pedestrians - Train drivers	- Train drivers use their judgement as to whether or not to sound the whistle at whistle boards on approach to RLXs and to determine for how long the whistle is sounded (Arthur D Little, 2006).
Pedestrians - Train	- The characteristics of train horns can make them more or less audible for pedestrians with hearing impairments, or where there is considerable background noise (Arthur D Little, 2006). - The presence of a train at the station contributes to incidents where pedestrians are involved in collisions with another train approaching (Arthur D Little, 2008). - During non-compliant RLX encounters, pedestrians were more likely to use information about whether they could see or not see a train in their decision making, than during compliant encounters (Mulvihill, Salmon, Lenné, Beanland & Stanton, 2014). - Pedestrians reported violating the road rules at an RLX after, rather than before, a train has passed (Freeman & Rakotonirainy, 2015).
Pedestrians - Monitoring & enforcement of road rules	- Failures to implement enforcement strategies can lead to users having no personal experience of enforcement, with the result that they are not deterred from engaging in violations (Stefanova, Burkhardt, Filtness, Wullems, Rakotonirainy & Delhomme, 2015).
Pedestrians - Public education programs	- Education (coupled with enforcement programs) led to a reduction in risky behaviour at the RLXs studied (Sposato, Bien-Aime & Chaudhary, 2006).
Pedestrians - Train scheduling	- Pedestrians perceive RLXs to be dangerous when trains are fast and frequent, and safe when trains are slow and infrequent (Arthur D Little, 2001).
Motorists - Pedestrians	- Motorists reported improvement at an RLX due to the addition of separated pedestrian lanes separated from the road traffic (Haga, Watanabe & Kusukami, 1989).

Within Table 2.1, findings are included from five studies that became available after the review paper was published. One study, conducted in the United States by Metaxatos and Sririj (2013) involved interviews with pedestrians as well as observations of pedestrian behaviour using CCTV recording. As an exploratory study, the results were reported in a descriptive-normative manner with a focus on identifying violations of the road rules. The study reported on eight relationships between components (spanning both the physical and organisational levels of the system) and considered two user groups: pedestrians and cyclists. As with many of the studies in the review, some interesting results were yielded yet the approach was not underpinned by the systems perspective.

The additional four studies were conducted in Australia. In the first of the Australian studies, a daily questionnaire about RLX encounters, incorporating questions based on the critical decision method probes, was completed by pedestrians, drivers, cyclists and motorcyclists over a two-week period (Beanland, Lenné, Stanton & Salmon, 2013). The study reported on the cues and information used by these four user types to made decisions on approach to RLXs within an exploratory, descriptive analysis. Within the study, 28 relationships were identified or analysed. While a large number of interactions were considered, relative to the wider literature, all of the components involved in these interactions were at the physical level of the system, reflecting the focus of the study.

In another study, the data from the survey of road users were employed to develop decision ladder models to describe and compare decision making processes during compliant and non-compliant encounters with RLXs (Mulvihill, Salmon, Lenné, Beanland & Stanton, 2014). This study was exploratory and, although the study applied one of the tools from CWA, the results were analysed in a descriptive-normative manner, with comparisons made between compliant and non-compliant use of RLXs. In total, 29 relationships were identified within the study, involving the four road user groups (pedestrians, cyclists, motorists and motorcyclists). As with the previous study, however, all of the components considered were in the physical realm of the system. This is a reflection of the use of the decision ladder alone. The application of the WDA in conjunction with the decision ladder would provide an opportunity to better represent aspects of the system at the higher hierarchical levels.

A survey methodology was also utilised by Freeman and Rakotonirainy (2015) to gather self-report data about errors and violations at RLXs. The analysis focussed generally on individual attributes of a large sample of participants (N=636) such as their age, gender and sensation seeking tendencies and took a descriptive-normative approach. Only three interaction relationships were identified, which spanned the physical and organisational levels of the system. The study involved pedestrians only and did not appear to consider interactions between different road users at RLXs.

The final additional study published following the literature review presented in this chapter was conducted by Stefanova and colleagues (2015). This study employed focus groups with pedestrian users of RLXs to collect data about the factors influencing their decision making and used the data gathered to develop a framework for understanding pedestrian behaviour at RLXs (with a focus on errors and violations). The paper also described two case studies of pedestrian violations at RLXs using the AcciMap method (Rasmussen, 1997b) which classifies factors associated with an event at various hierarchical levels. The study represents an exploratory, descriptive-normative analysis of pedestrian behaviour, with comparisons made of factors leading errors and violations. A total of 17 relationships were uncovered by the analysis, including relationships between components at all three levels of the RLX system (the physical, organisational and socio-political). In fact, some components identified within the framework were additional to those used for categorisation in the published literature review. For example, the framework and AcciMaps identified the influence of rail staff and enforcement officers on behaviour, as well as the influence of road traffic management and urban planning on safety outcomes. While this study does not meet the criteria set within the literature review for a systems approach, as it did not provide a formative analysis and focussed on errors and violations rather than acknowledging performance variability within the system, it had strong features of a systems approach. Specifically, the AcciMap method is a systems-based approach for the retrospective analysis of events and in this study assisted the identification of a range of factors, across multiple system levels, which influence pedestrian behaviour.

2.3 Conclusion

Overall, the literature review demonstrated that the issue of RLX safety, and pedestrian safety particularly, is not understood from a systems perspective. Consequently, there is no research basis for systems-based interventions to solve the problem of accidents in this domain.

The findings from the literature review have provided evidence of a key gap in the literature, in that no previous work has taken a systems approach, as defined by specific criteria, to analysing RLXs. Further, while there have been numerous studies into motorist behaviour at RLXs, there are few investigations of pedestrian behaviour. Although there is little existing knowledge in the area, a number of the publications released subsequent to the published literature review suggest that the systems approach may be growing. These publications reflect the shift towards a systems approach to understanding RLX safety from a systems perspective and represents the beginning of a promising line of inquiry within which this thesis is positioned.

The relationships and interactions studied prior to this shift have generally been reductionist in nature and have predominantly focused on responses to active and passive warning devices. However, Table 2.1 shows that these investigations have raised some interesting findings. For example, while pedestrians rely more on audible warnings and information when making decisions at RLXs (Beanland, Lenné, Salmon & Stanton, 2013), train drivers use their judgement as to whether or not to sound the whistle at whistle boards, meaning that auditory cues may not be provided to pedestrians consistently (Arthur D Little, 2006). Such findings from the existing literature provide initial data for the CWA application undertaken in this thesis. The use of CWA will extend the existing knowledge base by identifying the constraints on pedestrian behaviour within the RLX system, enabling a formative understanding of behaviour.

The following chapter will turn to the consideration of CWA as a framework for system design, and will provide a review of design applications reported in the literature to determine how the framework might be utilised to solve the RLX design problem.

3 Literature review part 2 – Review of the CWA design literature

3.1 Introduction

The criteria for an approach aligning with systems theory, applied in the RLX literature review, identified that formative methods would be most beneficial to understand complex, open systems. CWA, as a formative method that is well-aligned with systems theory (Stanton & Bessell, 2014), was identified as the most appropriate analysis approach.

While CWA is positioned as a framework for analysis for the purposes of design or engineering of complex cognitive systems, there is some debate regarding the extent to which CWA analyses directly inform design (e.g. Jenkins, Salmon, Stanton, & Walker, 2010; Lintern, 2005; Mendoza, Angelelli, & Lindgren, 2011). While the utility and uniqueness of the approach for understanding complex system performance is well-established, the extent to which outputs are used directly in the design process is questionable. Jenkins and colleagues (2010) note that evidence for CWA directly informing design is lacking while others have described CWA as "more of a philosophical tool for the designer than a full-fledged method that can be applied without much effort" (Mendoza, Angelelli & Lindgren, 2011, p.58). Lintern (2005) explains that CWA provides recommendations for system design; however the designer must then decide how these will be implemented.

To gain insight into the extent to which CWA outputs have directly informed design, this chapter aims to provide a review of CWA design applications reported in the literature.

3.2 About CWA

CWA identifies constraints within the system through five phases of analysis beginning with an ecological perspective, progressively narrowing down to tasks, strategies and allocation of functions, and finishing with the identification of the competencies required by workers (Vicente, 1999). The five phases of analysis are described in Table 3.1, which identifies the tools and methods that can be applied within each phase.

Table 3.1. Phases of CWA.

Phase	Purpose	Tools / methods
Work domain analysis (WDA)	To identify and describe the functional purpose and structure of the work domain.	- Abstraction hierarchy (AH) - Part-whole decomposition - Abstraction-decomposition space (ADS)
Control task analysis (ConTA)	To identify and describe the activities and tasks performed in the system.	- Contextual activity template (CAT) - Decision ladder
Strategies analysis (SA)	To identify the strategies that can be employed to perform the activities and tasks.	- Information flow diagram - Strategies analysis diagram (SAD)
Social organisation and cooperation analysis (SOCA)	To identify how tasks and activities are distributed across agents within the system.	- Annotated versions of the above tools
Worker competencies analysis (WCA)	To identify the cognitive skills and processes employed during task performance.	- Skills, rules and knowledge (SRK) inventory - SRK taxonomy

CWA is underpinned by general system theory and Gibson's ecological psychology theory (Fidel and Pejtersen, 2005). The influence of the ecological approach is most dominant in the WDA phase, which is the most frequently applied of the CWA phases, and provides the foundation for the remainder of the phases of analysis. For example, within the WDA, the concept of affordances (Gibson, 1979) is incorporated within the means-ends links between physical objects and object-related processes.

As a result of the ecological focus of CWA, the existing design philosophy is heavily influenced by the EID approach. EID aims to make system constraints visible to interface users in a way that supports skill-based, rule-based and knowledge-based processing. Application of EID generally draws on information discovered during the WDA phase, and the SRK taxonomy from the final phase of CWA, to guide interface design.

Another approach related to CWA is that of Applied Cognitive Work Analysis (ACWA; Elm, Potter, Gualtieri, Roth & Easter, 2003). This approach intends to provide a practical methodology that can be integrated within systems engineering processes for the design of decision support tools and systems. It involves the development of a set of related representations that build upon one another beginning with the development of a functional abstraction network to represent the concepts and relationships within the work domain. Next, cognitive work requirements are identified and overlaid onto the functional abstraction network to show the cognitive demands that require support by the designed system. Following this, information / relationship requirements needed to support the cognitive work requirements are identified. The fourth step in the process is the creation of a set of design documents called representation design requirements which outline the form in which the information should be presented to the user. Finally, presentation design concepts are developed to implement the representation design requirements. The final design concept produced from this process can then be handed over to system developers.

While ACWA draws from the CWA philosophy in that it promotes the design of decision support systems that support the skill, rule and knowledge-based cognitive processes of its users, the representations used within the method, including the functional abstraction network, are somewhat removed from the conception of work analysis discussed by Vicente (1999). The notion of interlinking representations providing structure and traceability however is a valuable aspect of the approach as is its strong focus on ensuring a match between the decision support system and the cognitive processes of the user.

Both EID and ACWA appear to be focussed on interface design yet it has been suggested that interfaces designed with EID can be difficult to integrate into work systems (Vicente, 2002). Broader application of CWA to work system design has been encouraged (e.g. Sanderson, Naikar, Lintern and Goss, 1999; Naikar, Pearce, Drumm & Sanderson, 2003). Namely, CWA can be applied beyond the provision of interfaces that enable users to understand and act on the existing system, to fundamentally change the system itself.

The extent to which CWA has been applied beyond interface design is not known, nor is there any existing literature that has comprehensively investigated the way in which CWA has been used for design. The goal of HFE is to apply knowledge to influence design, resulting in improved system performance. Accordingly, it is vital that frameworks such as CWA go beyond analysis to support design, resulting in safer and more productive systems. In this literature review, CWA design applications reported in the literature were reviewed to determine firstly, what has been designed with CWA (e.g. interfaces, devices, training programs), and second, what strategies have been employed to utilise CWA outputs in the design process. This will inform the need for further methods, processes or guidance for assisting practitioners to traverse the analysis-design gap.

3.3 Analysis of the CWA literature

3.3.1 Case selection

A search of relevant databases, journals and the reference lists of publications was undertaken to identify journal articles, conference papers and book chapters describing CWA design applications. Databases searched included ScienceDirect and the websites of publishers Taylor and Francis, Sage and Springerlink. Keywords used for the search included 'cognitive work analysis' and 'ecological interface design'.

To be included in the review a design application needed to involve, or be based on, the use of at least one phase from the CWA framework, applied in a manner consistent with its underlying philosophies as outlined by Rasmussen, Pejtersen and Schmidt (1990) and Vicente (1999). As such, applications of ACWA were not included in the review, nor were other methods and approaches aligned with cognitive systems engineering more generally. To be included in the review publications also needed to describe design solutions, design requirements or recommendations, in contrast to providing only an evaluation of the current system using CWA. Further, only applications where sufficient detail was provided about the design process to enable categorisation were included. It is notable that a number of publications did not provide sufficient detail to enable inclusion in the review. In total, 60 design applications met the inclusion criteria for the review.

3.3.2 Coding procedure

Each of the 60 CWA design applications were categorised on a number of dimensions. Firstly, the subject of the design process was classified into different aspects of system design, inspired by human factors activities in system design discussed by Czaja and Nair (2005). The categories used were:

- Interface design.
- Function allocation (e.g. decisions regarding automation).
- Job / team design.
- Design of support materials (e.g. training, procedures).
- Design of the physical workplace.
- Organisational design (e.g. the design of organisational structures, business strategies).

Multiple categories could be selected for each design application.

Secondly, the design applications were classified on the basis of the design strategy utilised. That is, how the CWA outputs were interpreted or used in the design process. The design strategy categories were identified through an initial bottom-up process of coding from the literature, with the broad categories defined, followed by a top-down process involving the codes being re-applied to each publication. The final categories were:

- *Direct contribution*: CWA outputs were directly mapped to design (with explicit mappings described) or the description indicated direct use of CWA outputs with no mention of any other methods, criteria or guidance used in design. For example, Dinadis and Vicente (1999) mapped each cell of an abstraction-decomposition space to features of a cockpit display in a military aviation application.
- *Restructure of CWA outputs*: CWA methods and tools (i.e. the AH, decision ladders) were used in an iterative manner to build up design requirements. Methods were nested within one another in a manner tailored for the design problem being addressed. For example, in their development of an interface for a command and control environment, Jenkins and colleagues (2008) built up the CWA outputs from different phases in an iterative manner and then combined these into a table of requirements.
- *Additional guidelines, principles, criteria*: CWA outputs were used in conjunction with HFE guidelines, principles for interface design or systems design, or other criteria relevant to the design being undertaken. For example, in their development of an interface for solar car racing, Hilliard and Jamieson (2008) applied design heuristics, knowledge about human perceptual capabilities and limitations as well as principles of display proximity.
- *Additional method / process*: CWA outputs were used within a wider design process, outside of the CWA framework. For example, a user-centered design process or structured workshops with subject matter experts. For example, Mendoza and colleagues (2011) developed paper prototype interfaces based on their knowledge gained from conducting a WDA on driving as well as requirements identified from previous work. The prototypes were subject to usability evaluation processes and expert heuristic evaluation with the outcomes used to further refine the design for an advanced driver decision support system.

Where multiple categories were relevant (i.e. principles for interface design in addition to workshops with subject matter experts), the most dominant approach was selected, based upon the description in the publication.

Finally, the domain in which the application was undertaken was classified as either *intentional* or *causal*. Rasmussen and colleagues (1994) describe five types of system based on the extent to which the system is controlled through the causal constraints of the physical components within the system (i.e. by the laws of nature) or through the intentions of people within the system (shaped by rules and social practices). In this part of the analysis, a judgment was made as to whether the domain contained predominantly causal or intentional constraints. The purpose of this classification was to explore whether the way in which CWA was used for design differed between intentional and causal domains of application, given that the framework was originally developed for the design of interfaces for controllers operating within causal domains.

As it is difficult to categorise work systems as solely intentional or causal (as constraints of both types will be present in most systems), a category was chosen based on a judgment on within which category the system in question best fit, taking into account the purpose of the design. For example, although driving is essentially intentional, the design of an interface to represent aspects of the vehicle's functioning was classified as causal, as this is influenced more by engineering principles than human actions and intentions.

3.3.3 Results

Firstly, the results of the subject of design classification are presented in Table 3.2. This shows that CWA is largely used for the design of interfaces as opposed to other aspects of the work system such as the design of jobs and training programs. This is not surprising given the focus on computer supported work and advanced information systems in the seminal CWA literature (e.g. Rasmussen, Pejtersen & Schmidt, 1990; Vicente, 1999). It should however be noted that Rasmussen (1998) explains that his use of the term 'interface design' is not a reference to the human-computer interface but to any interface between an actor and the deep relational structure of the work domain within which decisions are made. Burns and Hajdukiewicz (2004) also refer to mediated environments, rather than necessarily human-computer interfaces. In this review, the term interface was used to refer to such mediated environments and this included the physical design or functionality of equipment, as well as non-visual displays (such as auditory warnings and alarms). However, the majority of interfaces designed were visual information displays. These included consumer interfaces as well as those used in work systems.

Table 3.2. CWA design applications by system component.

System component	Number of applications
Interface design	56
Function allocation	6
Job / team design	4
Design of support materials	5
Workplace design	2
Organisational management	3
Total	*76*

Secondly, Table 3.3 shows each design application classified by design strategy and whether the design was for an intentional or causal domain. The results of this aspect of the analysis demonstrates the tendency for analyses of systems dominated by causal constraints to directly contribute to design, with approximately two-thirds of the design applications for causal domains falling within this category. In comparison, less than half of design applications for intentional domains fell within the category of direct contribution, demonstrating that practitioners have more often required additional guidance, more sophisticated use of CWA outputs or additional methods to support design in domains characterised by intentional constraints.

A number of the design applications classified in Table 3.3 as involving a direct contribution to design were interface designs that utilised the EID approach. One example of an EID approach identified during the review was the design of a display for pilots to support better vertical terrain awareness (Borst, Suijkerbuijk, Mulder & Van Paassen, 2006). This was categorised as a design application for a causal domain as it was focused on modelling the interaction between the aircraft and the environment (i.e. terrain). The AH was used to inform the content and structure of the interface. The functional purpose of the AH was identified as terrain avoidance and constraints associated with aircraft performance and dynamics were modelled within the AH. These constraints were then used to augment an existing ‘vertical situation display’ which featured the depiction of the terrain profile but did not include any of the constraints associated with the aircraft itself such as the climb performance capability of the aircraft. Such additional constraints were added to the display in a way that supported the three levels of cognitive control outlined in the skills, rules and knowledge taxonomy.

Table 3.3. CWA design applications by design strategy and domain type.

Design method	Causal domain	Intentional domain
Direct contribution	**16:** Aviation (Borst, Suijkerbuijk, Mulder & Van Paassen, 2006); Simulated power plant (Burns, 2000); Network management (Burns, Kuo & Ng, 2003); Military aviation (fuel and engine function; Dinadis & Vicente, 1999); Oxygenation management in intensive care (Effken, Loeb, Johnson, Johnson & Reyna, 2001); Manufacturing (Horiguchi, et al, 2007); Nuclear power (Itoh, Sakuma & Monta, 1995); Petrochemical processing (Jamieson & Vicente, 2001); Nuclear reactor plant (Lau et al, 2008); Hydropower system (Memisevic, Sanderson, Choudhoury, & Wong, 2005); Intensive care (Miller, Scheinkestel & Steele, 2009); Tidal information (Morineau, Beuzet, Rachinel & Tobin, 2007); Aviation (Nadimian & Burns, 2004); Neonatal intensive care (Sharp & Helmicki, 1998); Airborne trajectory revision (van Marwijk, Borst, Mulder, Mulder & van Paassen, 2011); Dual Reservoir System Simulation (Vicente & Rasmussen, 1990)	**14:** Naval command and control (Burns, Bryant, & Chalmers, 2005); Tactical situation awareness (using air-borne sonobuoy; Chen & Burns, 2007); Financial investment (Dainoff, Dainoff & McFeeters, 2004); Microsystem design management (Durugbo, 2012); Social networking (Euerby & Burns, 2012); Military aid to civilian emergency response (Jenkins, Salmon, Stanton & Walker, 2010); Automated assessment and monitoring of rehabilitation (Li, Burns, & Kulić, 2014); Airlift mission planning (Lintern, Miller & Baker, 2002); Fighter pilot training (Naikar & Sanderson, 1999); Library information retrieval (Rasmussen, Pejtersen & Goodstein, 1994); Motorcycle riding (Regan, Lintern, Hutchinson & Turetschek, 2009); Intelligent Transport Systems (Salmon, Regan, Lenné, Stanton & Young, 2007); Automated flight deck (Xu, 2005); Workstation design (Xu, Dainoff & Mark, 1999)
Restructure of CWA outputs	**0**	**5:** Maritime tactical picture compilation (Burns, Torenvliet, Chalmers & Scott, 2009); Command and control microworld (Jenkins, Stanton, Walker, Salmon & Young, 2008); Apple ipod (Jenkins, Stanton, Walker, Salmon & Young, 2010); Command and control on naval vessels (Lamoureux & Chalmers, 2008); Passenger experience on rail transport (Stanton, McIlroy, Harvey, Blainey, Hickford, Preston & Ryan, 2013)
Additional guidelines, principles, criteria	**2:** Petrochemical processing (Jamieson, 2003); Milk pasteurization system (Reising & Sanderson, 1998; Reising & Sanderson, 2002)	**6:** Unmanned aerial vehicle control (Burns, Ho & Arrabito, 2011); Solar car racing strategy (Hilliard & Jamieson, 2008); Simulated environment for military decision making training (Jenkins, Stanton, Salmon, & Walker, 2011a); Military analysis (Lintern, 2006); Pilot training (Naikar & Saunders, 2003); On-board pilot support system (Van Dam, Mulder & van Paassen, 2008)
Additional method / process	**7:** Petrochemical processing (Burns, Garrison & Dinadis, 2003); Electricity distribution (Drivalou & Marmaras, 2009); Ethylene processing (Jamieson, Miller, Ho & Vicente, 2007); Mobile application for diabetes management (Kwok & Burns, 2005); Process control health monitoring (Upton & Doherty, 2008); Anesthesia monitoring (Watson & Sanderson, 2007); Driving (vehicle functioning; Young & Birrell, 2012)	**10:** Customer support (Asano, Yonemura, Hamada, & Ogawa, 1995); Navy surface combatant (Bisantz, Roth, Brickman, Gosbee, Hettinger & McKinney, 2003); Shipboard command and control (Chalmers & Lamoureux, 2005); Missile retargeting (Cummings, 2004); Tanker loading system within a gas plant (Hassall, Sanderson & Cameron, 2014); Incident response (Humphrey & Adams, 2013); Train driving (Jansson, Olsson & Erlandsson, 2006); Advanced driver assistance systems (Mendoza, Angelelli & Lindgren, 2011); Airborne early warning and control system (Naikar, Pearce, Drumm & Sanderson, 2003); Mission communication planning (Stanton & McIlroy, 2012)

An example of a design application identified in the review for an intentional domain using an additional method or process is the team design process undertaken by Naikar and colleagues (2003). The aim of this design process was to design a team structure for a first-of-a-kind military system, the airborne early warning and control system. This involved developing two CWA representations: the AH from the WDA phase and the CAT from the ConTA phase. These analysis outputs were used with SMEs to evaluate potential team concepts (i.e. number and type of role of team members to operate the system) using a desktop analysis approach based on realistic scenarios. Firstly, the work demands that might be experienced by the crew for each team concept given a particular scenario were identified by the SMEs and consideration was given to how they might be handled. The work demands identified were then categorised within the generic work demands outlined in the CAT to ensure that they were not specific to a particular scenario (and were therefore typical rather than atypical). The work demands were then analysed for recurring patterns which were evaluated with reference to their effect on the nodes in the AH (e.g. whether the pattern would support or hinder the functional purposes of the system). Based on this evaluation, the researchers identified design requirements and developed a team concept that met these requirements. In comparison to the EID interface developed by Borst and colleagues (2006), which involved a relatively direct mapping between the constraints identified in the AH and the content of the interface developed, this design approach illustrates how the researchers needed to undertake considerable addition activities to negotiate the gap between the analysis and the final design.

3.4 Discussion

An important early step in this thesis was to understand how CWA has previously been used in the design of sociotechnical systems. Consequently, the aim of this review was to clarify the nature of CWA-based design applications reported in the literature. The review has demonstrated that the majority of CWA-based design applications have involved interface design. Further, when designing for causal domains, CWA has more commonly had a direct contribution to design, with less application of further supplemental design methods or processes than for intentional domains.

A summary of the key findings of the review and the implications for this thesis are discussed in the following sections.

3.4.1 Evidence for the gap between analysis and design

In exactly half of the design applications (30 of 60 applications) CWA was not used in a direct manner to inform the design artefact meaning that the analysis was supplemented with other activities such as the researchers taking the outputs and restructuring them in novel ways, the use of design guidelines or criteria or the use of additional design methods and approaches. This finding provides support for the assertion that a gap exists between CWA analysis and design. The gap was particularly evident for designs for intentional systems. Therefore, it is concluded that methodological support for translating CWA outputs into effective design solutions could be beneficial.

3.4.2 EID supports a direct contribution to design but could be supplemented

The majority of designs utilising EID fell within the category of direct contribution to design. Thus, for interface design alone, the EID philosophy may provide an appropriate approach for design. Comprehensive guidance is available for EID, including a visual thesaurus for representing data relationships (Burns & Hajdukiewicz, 2004) and numerous case studies (e.g. Bennett & Flach, 2011).

However, interface design could also benefit from the other phases of CWA (i.e. ConTA, SA and SOCA) and from a wider consideration of the system in which the ecological interface will be implemented. This could be achieved from conducting CWA with a wider scope and considering the design of aspects of the system beyond interfaces, such as job design, training design, organisational design, etc. This would support consideration of the interdependencies between social and technical aspects of the system (Clegg, 2000) as well as improve coherence between different system aspects (Gonzalez Castro, Pritchett, Bruneau, & Johnson, 2007). Another area where improvements could be made to EID to support implementation and user acceptance is the development of methods and guidance for improving the aesthetics of ecological interfaces (Mendoza, Angelelli & Lindgren, 2011).

3.4.3 Scarcity of five-phase CWA applications

Related to the prevalence of EID, it was noted that few design applications employed all five phases of CWA. It has been suggested that the gap between analysis and design could be ascribed to the use of only some phases of the framework (e.g. Jenkins, Stanton, Walker, Salmon & Young, 2008). Each phase of CWA provides a different lens through which the system can be viewed and in combination they provide a holistic understanding of the constraints and goals affecting behaviour. However, even with the use of all phases, there remains a need for guidance about how the analysis outputs can be used to generate and prioritise design requirements and recommendations. Further, the values and principles arising from sociotechnical systems theory could be used to assist designers to determine how to implement the design requirements effectively, and to ensure consistency and compatibility between different system elements.

3.4.4 The need for theoretical consistency

During the review, supplementary design methods were identified that may be incompatible with the theoretical and foundational concepts underlying CWA. In one example, CWA was used within a user-centered design process (Jansson, Olsson & Erlandsson, 2006). Vicente (1999) warns that user-centered design tends to create designs that align with user mental models that are often in incorrect or incomplete in complex systems. The benefit of CWA, particularly WDA, is that is provides a representation of the actual functioning of the system.

This concern, however, need not limit the use of CWA with user-centered or participatory design methods. Indeed, a participatory design process driven by CWA could identify and resolve conflicts between user mental models and the underlying regularities of the work domain through discussion, leading to the identification of valuable re-design opportunities. For example, in the study by Jansson and colleagues (2006) the users involved in the design process were provided with the CWA findings at the beginning of the design process. Whether the final interface developed was verified with reference to the CWA outputs is not described in the paper, but could be a way to ensure that designs benefit from both expert approaches (i.e. CWA) and user-led, participatory design approaches. Guidance for ensuring theoretical consistency and achieving design outcomes that ensure the benefits of CWA are retained in mixed method design approaches would be beneficial.

3.4.5 Issues associated with design process descriptions in peer-reviewed literature

Compared to the wider literature describing the outputs of CWA analyses, there was relatively little literature describing subsequent CWA-based design applications in sufficient detail to assist others in the design task. As noted by Lintern (2012), design is a highly iterative process, but descriptions in the literature can make it appear sequential and structured. This does not assist the CWA practitioner community to benefit from past design activities and there is insufficient information to replicate the methodologies undertaken. Therefore, more detailed descriptions of design processes are required. Further, given that not all CWA design applications are published, alternative means of eliciting knowledge about how CWA is being used for design from practitioners is required to overcome the limitations of interpreting descriptions from the published literature.

3.5 Conclusion

Despite many design applications, it would appear that there are many variations in the way in which CWA is being used for design. The outcomes of this review suggest the existence of a gap between CWA analysis and design given that in half of applications a direct design strategy was not adopted. Where a direct strategy was adopted this often followed an EID approach, indicating that EID provides a useful design strategy for the design of interfaces. However, interface design as an isolated process may not always be desirable. It may be that EID can be extended to whole system design, but this would require use of all CWA phases and further guidance or methods may still be needed.

The difficulty of translating analysis findings into designs is not limited to CWA, but applies to many HFE methods. HFE methods contribute to design through analysis and evaluation functions, but do not perform the actual design work (Stanton & McIlroy, 2012). It is argued in this thesis that this situation should be improved. With appropriate CWA-based design guidance, HFE has the potential to improve its positive impact on system design.

Before such guidance can be developed, further information about current practice is needed given the lack of detail provided in the published literature. Alternative methods to uncover how CWA is used in design may provide further insight and guidance into current practice and the successes and challenges faced by practitioners of CWA. The following chapter will describe the results of a survey of CWA practitioners which aimed to uncover additional information about the use of CWA in design that could not be accessed through a review of published literature alone.

4 Current practice using CWA for design

Read, G. J. M., Salmon, P. M., Lenné, M. G. (2015). Cognitive work analysis and design: Current practice and future practitioner requirements. *Theoretical Issues in Ergonomics Science, 16*, 154-173.

4.1 Introduction

The review of the literature describing CWA design applications found evidence for the gap between analysis and design, particularly for intentional systems and for designing beyond interfaces. It also highlighted the lack of detail provided about design processes adopted in the published literature. To learn more about current practice using CWA for design to inform the development of a new design approach an online survey methodology was utilised to gather information directly from CWA practitioners. This methodology provided an opportunity to learn about design approaches that may not have been published in the academic literature and also provided CWA practitioners with an opportunity to provide their views and opinions on what a useful design process should encompass.

The aim of this chapter is to describe the results of the survey. The chapter will highlight key findings relating to current design practice with CWA, as well as practitioners views and opinions on the need for, and aspects of, a new design approach.

Declaration for Thesis Chapter 4

Declaration by candidate

In the case of Chapter 4, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Primary author. Co-conceived the idea for the study. Developed and distributed the questionnaire, collated and analysed results. Responsible for the initial drafting and subsequent editing of the paper.	80%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	Nature of contribution	Extent of contribution (%) for student co-authors only
Paul M. Salmon	Co-conceived the idea for the study. Reviewed and piloted draft version of questionnaire. Provided critical review of draft versions of the paper.	n/a
Michael G. Lenné	Co-conceived the idea for the study. Provided critical review of draft versions of the paper.	n/a

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's Signature	[redacted]	**Date** 2 July 2015
Main Supervisor's Signature	[redacted]	**Date** 2 July 2015

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Cognitive work analysis and design: current practice and future practitioner requirements

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Cognitive work analysis (CWA) is a unique analytical framework which provides analysis information to inform system design. However, the literature describing CWA applications indicates that its use in design is not straightforward. An online survey was used to gather information from CWA practitioners about how they have used CWA in design applications and to gather their views and attitudes on aspects of CWA and design. The survey found that there was no typical means of using the outputs of CWA within design processes across survey respondents. Over half of the respondents indicated that there is a need for an additional approach or method to enhance the contribution of CWA to design. It is concluded that the field could benefit from the development of an additional design approach, with associated guidance, to assist in using the outputs of CWA in design processes.

Keywords: cognitive work analysis; human factors integration; systems analysis; system design; design processes

1. Introduction

1.1. Cognitive work analysis

Cognitive work analysis (CWA) is an analysis framework within the cognitive systems engineering field (Sanderson 2003a). It was developed to provide a means to identify and represent the constraints of a complex system, capturing the range of potential system functioning and the degrees of freedom for action available to decision-makers (Rasmussen, Pejtersen, and Goodstein 1994; Vicente 1999). The framework provides information about the system which is 'deliberately geared toward uncovering implications for system design' (Vicente 1999, 301), facilitating designs that provide workers or users with the flexibility to manage unanticipated events (Sanderson 2003a; Vicente 1999). The outputs of CWA are also useful for other activities such as the evaluation of current or proposed system designs and the design of research (Vicente 1999).

CWA has been characterised as a mature analytical framework which can more extensively address system design issues than other methods from cognitive engineering (Lintern 2008). It is unique in its formative, constraint-based approach, in that it models the possibilities for behaviour, rather than describing actual behaviour or prescribing normative behaviour (Naikar 2013; Vicente 1999). It also has strong roots in systems theory (Fidel and Pejtersen 2005; Sanderson 2003b).

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In CWA, system constraints can be analysed through five phases: work domain analysis (WDA), control task analysis (ConTA), strategies analysis (SA), social organisation and cooperation analysis (SOCA), and worker competencies analysis (WCA). The application of all five phases is not mandatory. Rather, analysts choose which phases, and tools within each phase, are appropriate for the requirements of the project (Sanderson 2003b; Stanton and McIlroy 2012).

The current study is concerned with how CWA, as an analysis framework, is used to inform design processes. For clarity, a distinction will be made between analysis and design, although in practice these activities are closely associated and mutually informing (Vicente 1999). The use of the term 'analysis' is intended to refer to the process of understanding the constraints of a complex system using the tools of the CWA framework. The analysis outputs include representations such as the abstraction hierarchy (AH), the decision ladder and contextual activity template. The term 'design' is intended to refer to the process of defining the function and form of the target of the design process (e.g. interface, team or procedure). Design artefacts include statements of requirements, specifications, prototypes, design concept drawings, sketches or descriptions, prototypes and the final physical manifestations of the design process. There is a further distinction within a design process between defining the function of the design (which may be outlined in requirements and specifications) and the form of the design (such as is explored through sketches, prototypes and instantiated in the final product).

1.2. Ecological interface design

Ecological interface design (EID) is a design strategy for visual displays that uses the AH tool from the WDA phase, coupled with principles from the skills, rule and knowledge taxonomy (Vicente and Rasmussen 1992). The principles of EID specify that an interface should not require an operator to employ a higher level of cognitive control than necessary for the demands of the task. Further, the interface should support each level of cognitive control (skill, rule and knowledge-based behaviour). EID aims to make the interface transparent; its goal is to support direct perception and action, while correspondingly providing support for problem-solving activities (Vicente and Rasmussen 1990). EID has been applied to the design of interfaces within varied domains including nuclear process control (e.g. Burns et al. 2008), road transport (e.g. Young and Birrell 2012) and healthcare (e.g. Watson and Sanderson 2007).

When applying EID, the AH is the key analysis tool; it provides the information content as well as informing the structure of the interface (Burns and Hajdukiewicz 2004; Jamieson 2003). Guidance and principles have been developed, additional to CWA, to then determine the form or representation of the information requirements derived from the AH. For example, a visual thesaurus for representing data relationships has been assembled based on previous applications of EID (Burns and Hajdukiewicz 2004). Further, case studies and examples illustrating different techniques for EID are available (e.g. Bennett and Flach 2011; Burns and Hajdukiewicz 2004). It should be noted that analysis tools additional to the AH can be used to enrich the analysis component of EID; for example, hierarchical task analysis and decision ladders have been used to explore the task-related requirements for a process control interface (Jamieson et al. 2007). Experimental evaluations have demonstrated that ecological interfaces elicit better performance than traditional interfaces (see, for example, reviews by Burns and Hajdukiewicz 2004; Vicente 2002).

However, EID is for designing displays and computer-based interfaces, and it only uses selected phases of CWA, predominantly the AH. Some researchers have used CWA to design interfaces without applying the standard EID process (e.g. Jenkins et al. 2010), while others have experienced difficulties applying the approach to non-visual displays (e.g. Watson and Sanderson 2007).

1.3. System design

Vicente (2002) discusses the importance of an integrated approach to system design, as preferable to the implementation of a stand-alone ecological interface. An integrated approach would ensure that all the elements of the system including the interface, decision support, automation, training, selection, alarms, procedures and team collaboration are based on a common philosophy, and are coordinated to avoid inconsistencies and contradictions. CWA could potentially assist the expansion of EID (Vicente 2002); however, supporting the integrated design of system elements is a challenge for the framework (Naikar 2006a).

An understanding of the constraints of a system gained through CWA has been used to support effective worker adaptability and flexibility through means other than interfaces. This broader use has been demonstrated in a number of applications (e.g. Durugbo 2012; Naikar and Saunders 2003). Three examples are detailed below to demonstrate the challenges encountered when using CWA outputs to inform the design of system elements other than interfaces.

Naikar (2006a) and Naikar et al. (2003) developed a technique for team design based on CWA through a project to develop a team design for a first-of-a-kind military system; the Airborne Early Warning and Control (AEW&C) system. An AH and a contextual activity template were developed and utilised within table top analyses involving subject matter experts (SMEs). Potential team concepts were considered with scenarios to identify the work demands that might be experienced by the crew and how these could be handled by the team concept. These work demands were later categorised within the generic work demands outlined in the contextual activity template to ensure that they were not specific to a particular scenario. The work demands were then analysed for recurring patterns, which were evaluated in terms of their impact on the nodes in the AH (i.e. whether the pattern supported or hindered the systems' functional purposes, value, priority measures, etc.). Based on this evaluation, design requirements were identified which formed the basis for a proposed team design.

Another application of CWA to the design of a first-of-a-kind system, a navy surface combatant, was reported by Bisantz et al. (2003). This design work occurred concurrently with the systems engineering design process and focused on defining the role of personnel on the ship, levels of automation and concepts for information displays. An AH and decision ladders were developed, as were additional cross-linked matrices which provided a link between the analysis and the system function decompositions being developed in the system engineering process. A cognitive function matrix documented insights arising from the AH and decision ladders as well as drawing on design principles and research findings from the human-centred automation literature.

Jenkins et al. (2011a) used the decision ladder to provide a structured means of identifying requirements for a synthetic environment for military decision-making training. A prototypical decision ladder was developed for a scenario; in this case, the decision whether to engage a potential target. Next, relationships between elements of the decision ladder were mapped within a matrix, enabling consideration of potential relationships between the resultant knowledge states on the left-hand side of the ladder: system states, information and options. The categorisation of elements as being located in the external environment, internal environment or in documentation was then documented in a separate matrix. The matrices were reviewed according to nine accepted dimensions of simulation and through this the information contained in the matrices was converted into a specification for the synthetic environment.

The applications described above (Bisantz et al. 2003; Jenkins et al. 2011a; Naikar et al. 2003) demonstrate that the information captured in the CWA outputs required additional structuring, and sometimes coupling with additional domain-specific principles and research, or other design tools such as scenarios. Each design application was different and utilised a different approach. Naikar et al. (2003) specifically noted that the CWA outputs are used differently for team design than for interface design.

The examples suggest that like any human factors analysis framework or methodology, CWA does not directly provide a design, but provides information that informs design. Information requirements for interfaces may be reasonably straightforward to derive using guidance provided for EID; however, defining requirements for other system elements may require further work. Moving from requirements to creating the form of design is still less structured. While CWA provides recommendations for system design interventions, it leaves open many options for how these should be fulfilled (Lintern 2005).

1.4. The current study

While EID provides guidance for interfaces, there have been descriptions of design processes not involving interfaces or EID, as discussed above. There are few comprehensive descriptions of these and the level of detail provided about the design process varies widely across papers. Further, it is likely that not all applications are being published, with CWA use not confined to academic settings.

To overcome this knowledge gap, a survey of CWA users was undertaken. The survey aimed to elicit information, in a structured manner, about how the analysis tools of CWA are being used to inform design. A survey methodology enabled engagement with CWA users to elicit this more in-depth and specific information that is typically not detailed in the published literature. It also provided an opportunity to ask CWA users about why they use CWA as part of a design process, any challenges they have faced in doing this and about the need for an additional design approach or process to assist in translating the analysis products of CWA to inform design. With CWA being used internationally, an online survey methodology provided an efficient means to reach the population of interest.

2. Method

2.1. Participants

Thirty-eight CWA practitioners participated in the online survey. The term practitioner in this context related to anyone involved in the practice of CWA, whether in academia, industry or government settings.

2.2. Survey instrument

The survey instrument was developed based on issues and questions arising from the CWA literature and from the researchers' own experience of the framework. The survey was reviewed by two human factor specialists employed by a partner organisation on the

Table 1. Sample of questions included in the survey instrument.

Question	Question type
Section 1: Your experience with the CWA framework	
In which industries/domains have you applied CWA?	Close-ended question – select all that apply
How many years' experience do you have using CWA?	Open-ended question – free text
Have you used the CWA framework, or part of it, as part of a design process?	Close-ended question – forced choice
Section 2: Your use of CWA in a specific design application	
Can you think of an example of a recent project where you used the CWA framework, or part of it, as part of a design process?	Close-ended question – forced choice
What was the subject of the design?	Close-ended question – select all that apply
What data sources did you use to inform the development of the CWA?	Close-ended question – select all that apply
Please provide an overview of the process you undertook to use the outputs of the analysis to inform design.	Open-ended question – free text
What additional approaches, methods, tools, techniques or guidance were used and how were they used in the design process?	Open-ended question – free text
How successful was the design produced using CWA? (consider aspects of the design such as whether it was implemented in practice, acceptance by end users, acceptance by project stakeholders, results of formal evaluations, whether the design process met performance indicators such as on time, within budget, etc).	Close-ended question – forced choice
Section 3: Your use of CWA in design generally	
Please describe any challenges you have faced when using CWA for design or any lessons that you have learned that could benefit other practitioners undertaking this task.	Open-ended question – free text
Section 4: Your views on additional approaches or methods	
Do you think there is a need for an additional approach or method that extends, or can be used in addition to, CWA to more directly inform the design process?	Close-ended question – forced choice

grant under which this research was funded. The survey was then piloted by an experienced user of CWA (the second author). The final version included four sections consisting of close-ended and open-ended questions. A selection of example questions from the survey are provided in Table 1.

2.3. Procedure

The survey was disseminated electronically to corresponding authors of journal and conference publications on the topic of CWA or utilising its phases and tools. The survey was also advertised through professional newsletters and social networking sites (e.g. LinkedIn groups for professionals working in cognitive engineering). Recruitment materials asked the addressee or reader to forward the invitation to those in their collegiate networks who may be interested in participating.

Participants completed the survey online. The survey instrument guided respondents to answer only those questions relevant to their use of CWA, based on their responses to previous questions. Variations in numbers of responses for each question were taken into account in the analysis.

3. Results

The results are presented in four parts: a summary of respondents' experiences with CWA; descriptions of the methods and processes used for design; use of concept maps to structure and represent respondents' use of CWA in design both for the specific example and generally; and finally, discussion of respondent's views towards the need for a new design approach.

3.1. Experiences with CWA

The majority of respondents had used CWA for 10 years or less (72%). Two respondents had used the framework for more than 25 years. Self-ratings of expertise indicated that no respondents were novice users of CWA, 13.9% were beginners, 63.9% were either competent or proficient and 22.2% were expert. The majority (85.3%) had spent up to 30% of their time in the previous year on CWA-related activities, with over half (61.8%) spending only 10% or less of their time using CWA.

The majority of respondents (63.9%) had applied CWA, in any capacity (i.e. for analysis, design evaluation), to one or two domains. Two respondents (5.6%) had applied CWA in more than five domains. The domains selected most often were navy (12 respondents), nuclear power (10 respondents) and civilian air transport (9 respondents). Almost all respondents (89.2%) indicated that they had used the CWA framework, or part of it, as part of a design process. It is expected that those who indicated that they had not used CWA for this purpose had only used the framework for its other purposes such as to build system understanding or to evaluate a current or envisaged system.

3.2. CWA analysis and design processes

Figure 1 provides an overview of the results regarding the analysis and design processes used in the specific design application described by respondents. Shading is used to indicate the most commonly selected responses. Reading across the diagram it can be seen that, for the design application examples selected by respondents for discussion, the most frequent application domain was *Healthcare*, with the most common data inputs to the CWA being *Document review* and *Interviews with workers*. The most commonly used analysis phase was *WDA*, with the *Abstraction hierarchy* being the most frequently used analysis tool. Each subsequent consecutive phase and their related tools were applied less often in a sequential manner. Seven respondents reported applying *WDA* alone, another seven used the first two phases only (*WDA* and *ConTA*), while only two respondents reported using all five phases. The most frequent review method was *Review by SMEs*. In relation to design processes, the most common additional method used to assist design was *Task analysis*,

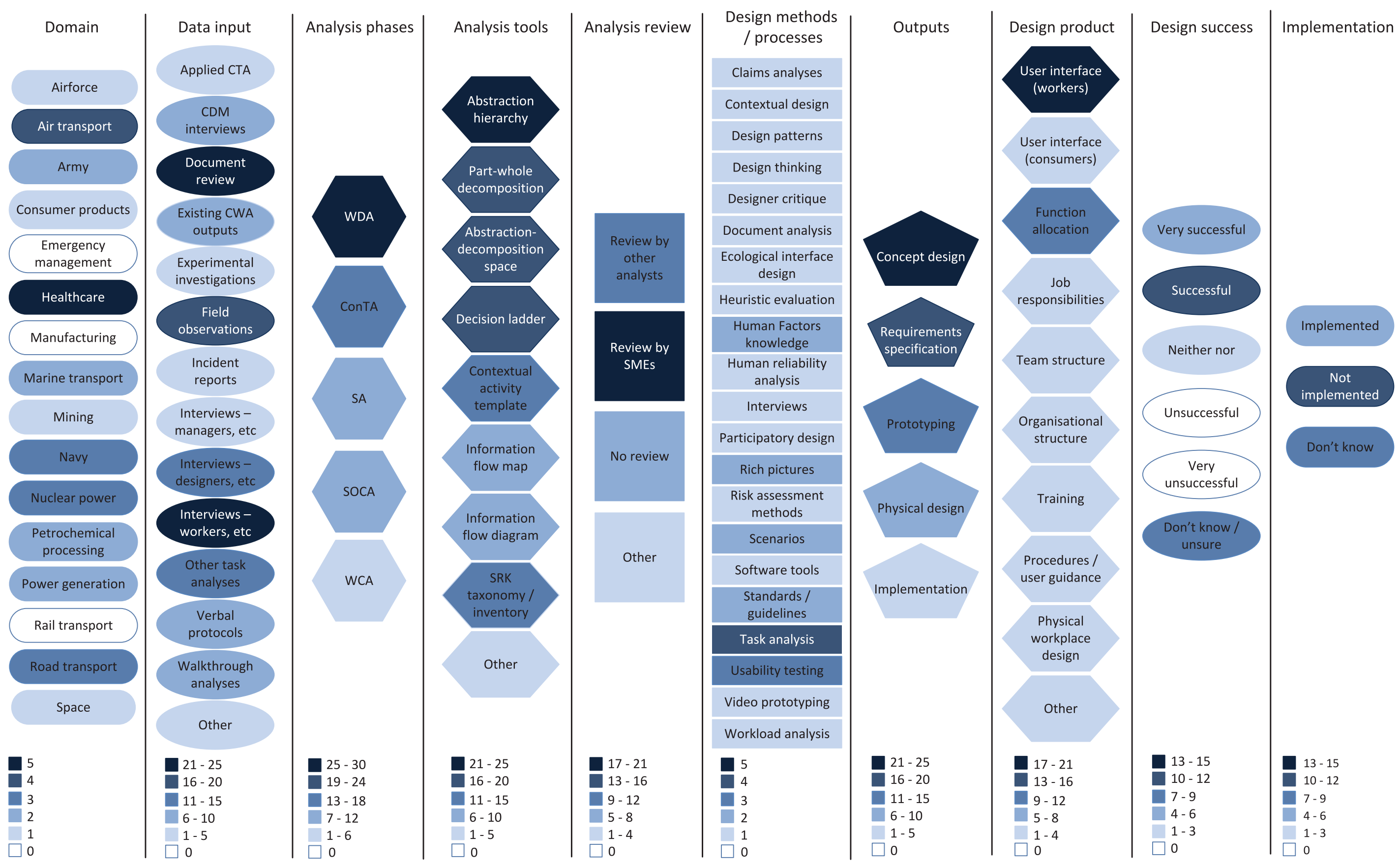

Figure 1. Processes used in CWA for design, and resulting outputs. The legend for each column represents the number of respondents that indicated the option was used or relevant to the specific example they provided. The shading is intended to enable comparison within columns rather than between columns due to variations in response rates and in magnitudes across columns.
Note: CTA – cognitive task analysis, CDM – critical decision method.

although this was only applied by five respondents. The highest frequency output of the design process was *Concept design* and the most common product designed was *User interface for workers*. The majority indicated that the design project was *Successful*; however, when asked about implementation, the most common response was that the design was *Not implemented*.

Six respondents indicated in their descriptions of the analysis and design process that they had applied EID. However, only one of these respondents indicated that they had used EID design principles in response to the question *What additional approaches, methods, tools, techniques or guidance were used and how were they used in the design process?*. Accordingly, there is only one mention of EID in Figure 1, while the other respondents who used EID may not have considered it to be 'additional' to the CWA framework.

While the results above identify which processes were used most often, further analysis highlighted the variety in the number of approaches used. For example, the 12 respondents who used additional design methods used on average just over two and a half methods (Table 2) of the 21 methods used across all 12 respondents (as seen in Figure 1). Further, on average, respondents created just fewer than two types of design products. These products were generally user interfaces and associated concepts for function allocation.

3.3. Views and opinions on CWA and design

Responses to the open-ended questions were coded into concepts and linking phrases (combined into propositions) by a single analyst (the first author) using an iterative, bottom-up process. A total of 796 propositions were identified from the text, comprising 252 concept codes. To the extent possible, the language of respondents was maintained within the propositions, maintaining the authenticity of the coding representation. An example coding is provided in Figure 2.

The propositions were refined for further analysis by removing those not related to design and by removing those incorporating concepts appearing only once in the coding set. A pilot inter-rater reliability test of the coding was then undertaken involving a second analyst (the second author) independently coding a sample of the propositions (20%) using the codes developed by the initial analyst. This process led to some revision of the codes and to amendments to some of the coding that had been applied to excerpts from the text. A further inter-rater reliability test was undertaken with a different 20% sample of propositions. A percentage agreement of 77.14 was obtained, with a Cohen's kappa

Table 2. Mean number of processes and resulting outputs reported for specific CWA design applications.

	N	Mean	SD	Minimum	Maximum
Data input methods	30	4.9	2.62	1	12
Analysis phases	27	2.44	1.28	1	5
Analysis tools	27	4.19	1.52	1	8
Design methods	12	2.58	1.73	1	5
Outputs	28	2.36	1.22	1	5
Design products	30	1.9	1.30	1	5

Figure 2. Example coding of survey response excerpt: *The AH model was used to define information requirements*.

statistic of 0.73 which can be considered a substantial level of agreement (Landis and Koch 1977).

Following the achievement of an adequate level of inter-rater reliability, the 276 propositions relating to CWA and design were entered into a master concept map to gain an overall picture. The highest frequency concepts arising within the coding were *Design* (49 instances), *Additional design methods* (33 instances), *New design approaches* (27 instances), *Contextual design* (21 instances) and *CWA* (21 instances).

Separate concept maps were then created for each of the key open-ended questions. Concept maps provide a visual representation of the meaningful relationships between concepts in relation to a topic (Crandall, Klein, and Hoffman 2006). Traditionally, they have been employed in an interview context where the analyst and an SME would collaborate to map the concepts and relationships. In this study, the responses from multiple SMEs have been combined within concept maps for the purposes of synthesising and communicating the qualitative data in a holistic manner. The map does not, however, intend to represent an agreed or consensus view amongst the survey respondents.

Within each concept map, the text size of the concepts denotes the relative frequency in which the concept appeared in all propositions relating to CWA and design. The thickness of the lines linking the concepts gives an indication of the frequency of that specific proposition within the survey responses. In some cases, within the responses to survey questions, there were a small number of propositions that did not link in with the other responses. To link these propositions into each concept map and generally ensure completeness and logical connectedness within each individual concept map diagram, dashed lines were used to indicate propositions that were identified in the overall analysis of propositions related to CWA and design, but were just not present in the responses to the particular question to which the concept map related. This provides a greater depth to the concept maps while enabling the identification of those propositions that were elicited directly from the question responses as well as those secondary relationships indicated by respondents relating generally to CWA and design.

3.3.1. Processes used to inform design

The first focused concept map (Figure 3) outlines the propositions coded from responses to a question about the process undertaken to use of the analysis outputs to inform design. This concept map contained the most concepts of all focused concept maps and references many of the high frequency concepts. The concept *Design* has high importance in this map, being linked to seven other concepts. The concept of *Designers* also had a relatively high frequency of connections with links to six other concepts. Interestingly, the role of analysts in the design process did not appear. In relation to frequencies of statements, it can be seen that the highest frequency propositions were that *Brainstorming* contributes to *Design* and that *SMEs* are involved in *Design processes*. Figure 3 suggests that the process is not well defined and varies amongst applications. Many concepts appear; however, there are few linkages between concepts.

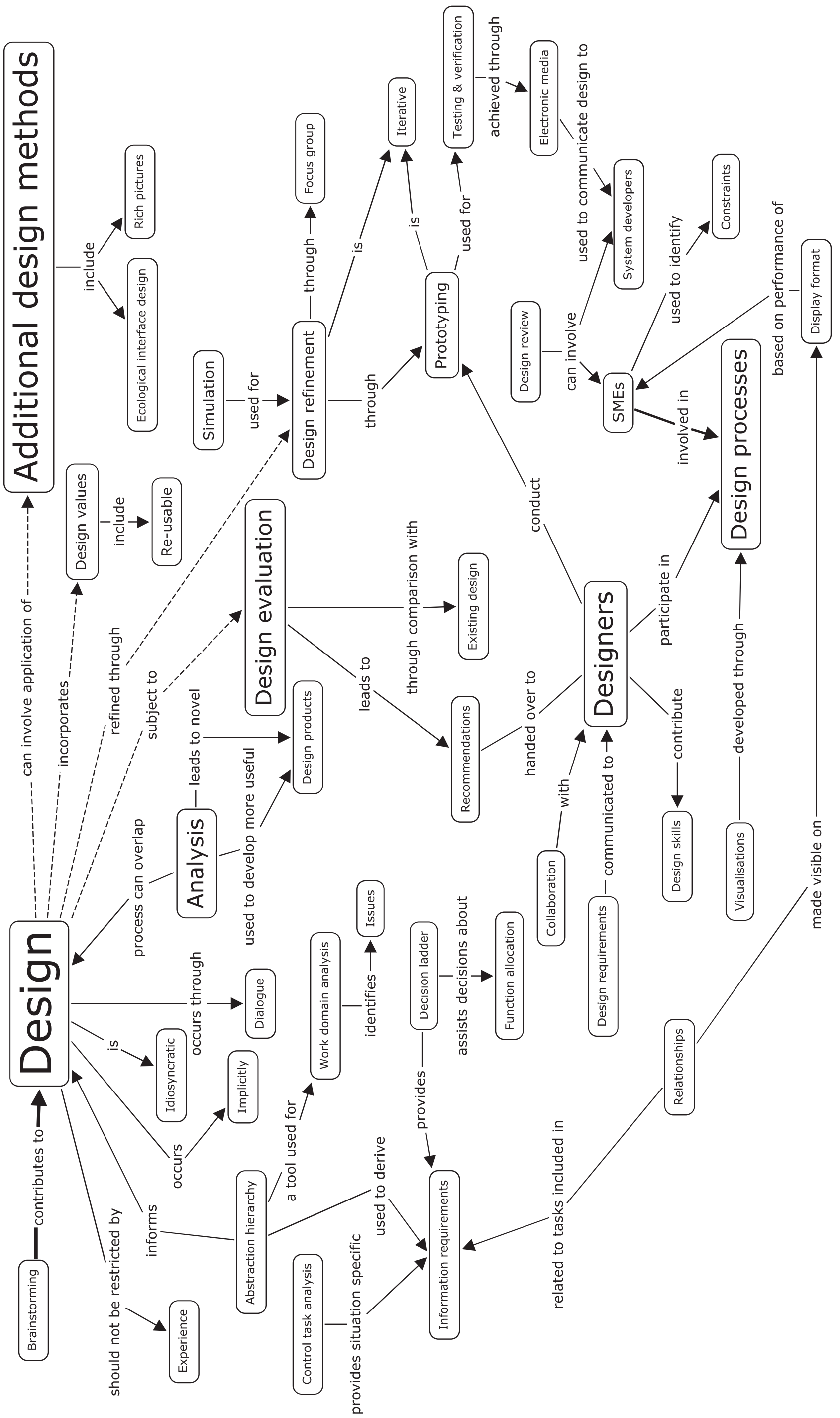

Figure 3. Concept map of responses to the question: *Provide an overview of the process you undertook to use the outputs of the analysis to inform design.*

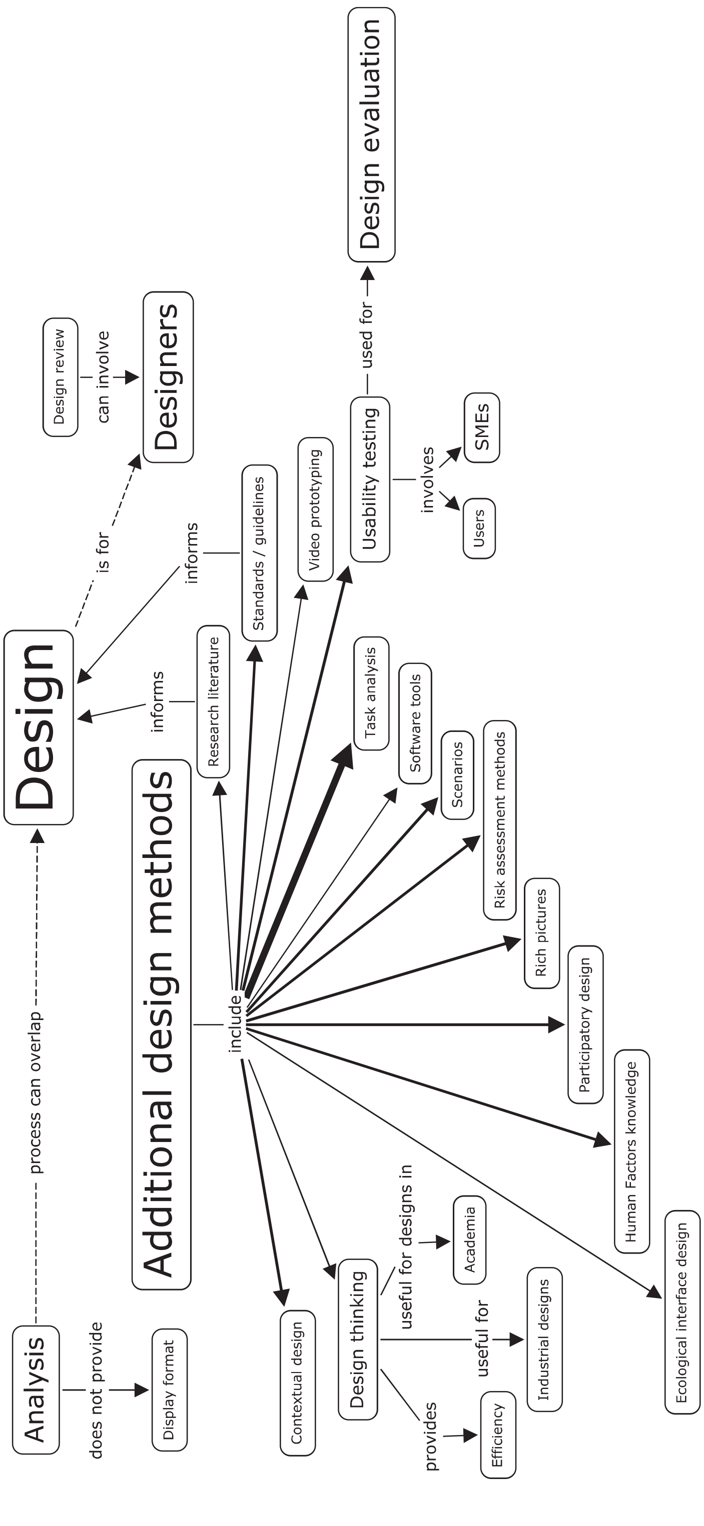

Figure 4. Concept map of responses to the question: *What additional approaches, methods, tools, techniques or guidance were used and how were they used in the design process?*

3.3.2. Additional approaches guiding design

The second concept map (Figure 4) displays the responses gathered regarding the use of additional approaches, methods, tools, techniques and guidance in the design process. The nature of the question leads to the concept *Additional design methods* having a key influence. This concept map reflects and extends the data regarding the use of additional design methods displayed in Figure 1 by illustrating how these concepts relate to broader design concepts. Interestingly, respondents did not discuss relationships or interactions between design methods, indicated by the lack of links between these concepts. The large number of additional design methods coupled with the comment that *Analysis* does not provide *Display format* suggests a need for more than just an analysis process to create a design.

3.3.3. Actors involved in the design process

Figure 5 provides a summary of responses regarding who was involved in the design process. It hints at the importance of collaboration between analysts and designers. The most frequent propositions were that *Designers* should participate in *Analysis* and that *Analysts* are involved in *Design processes*. The concept map also highlights issues associated with attempts to *Handover* the analysis or the insights that arise from conducting the analysis to designers who have not previously been involved. A number of respondents highlighted the *Rich understanding* and *Tacit knowledge* gained through performing the analysis. One exception to this was a statement that the analysis can be handed over to *System developers*.

3.3.4. Challenges using CWA for design

The responses to a general question about the challenges faced when using CWA for design are provided in Figure 6. Unsurprisingly, the concept of *Design* is central to this concept map. There is some consistency with previous figures regarding the difficulty of handing over the analysis findings, and the role of analysis in providing *Insights*. The diagram also documents the views that *Guidance* for analysis and design is lacking and that *Design processes* are not clearly outlined in the *CWA literature*.

While some responses note that CWA or its Outputs provide information for Design, or that CWA is for Design, there is a theme visible within the map suggesting that CWA does not directly inform design. This is drawn from propositions that a *Gap* exists between *CWA* and *Design*, and that *CWA* is not a substitute for a *Creative design process*. Further, one respondent stated that *Ecological interface design* is not about *Design* and has not been a commercial *Success*. This respondent appeared to view EID as an analysis approach, rather than an approach for informing detailed design.

3.3.5. Views on the need for additional approaches or methods for design

Respondents were asked, by means of a forced-choice question, whether there was a need for an additional approach or method to extend CWA to more directly inform design. Just over half (56.7%) of respondents to this question answered in the affirmative, with a number (26.7%) indicating that they were unsure.

Respondents were also asked to provide comments regarding their views on this question. These responses are summarised in Figure 7. The responses confirm the theme outlined in Figure 6 that analysis does not directly inform design. Propositions in this concept map supporting the theme include that *Analysis* does not directly inform *Design*,

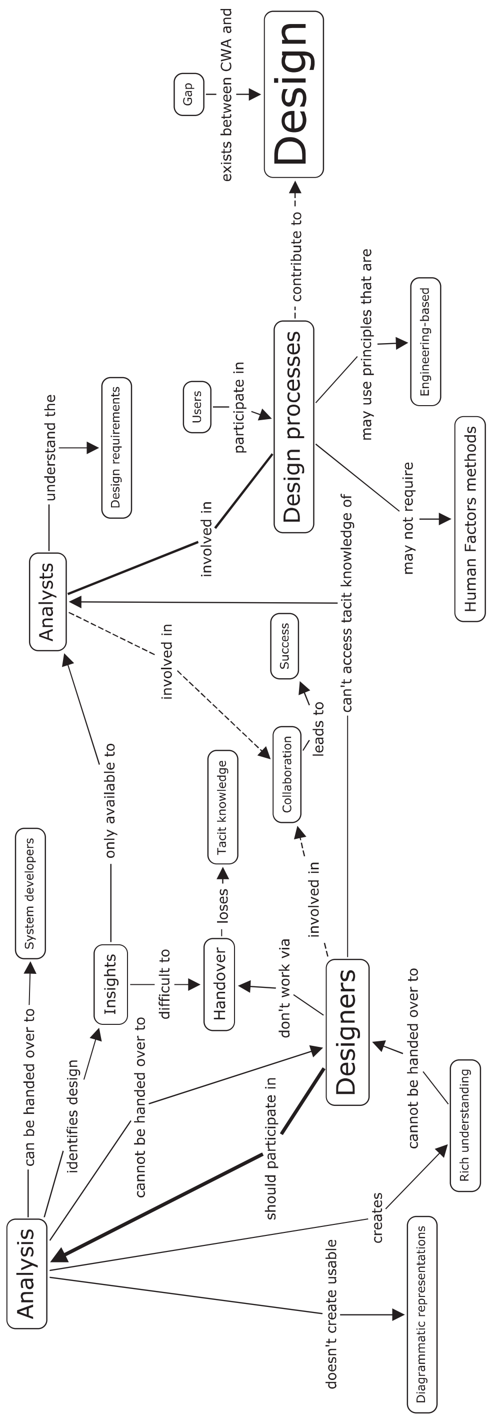

Figure 5. Concept map of responses to the question: *Were the people involved in the CWA application also involved in the design process?*

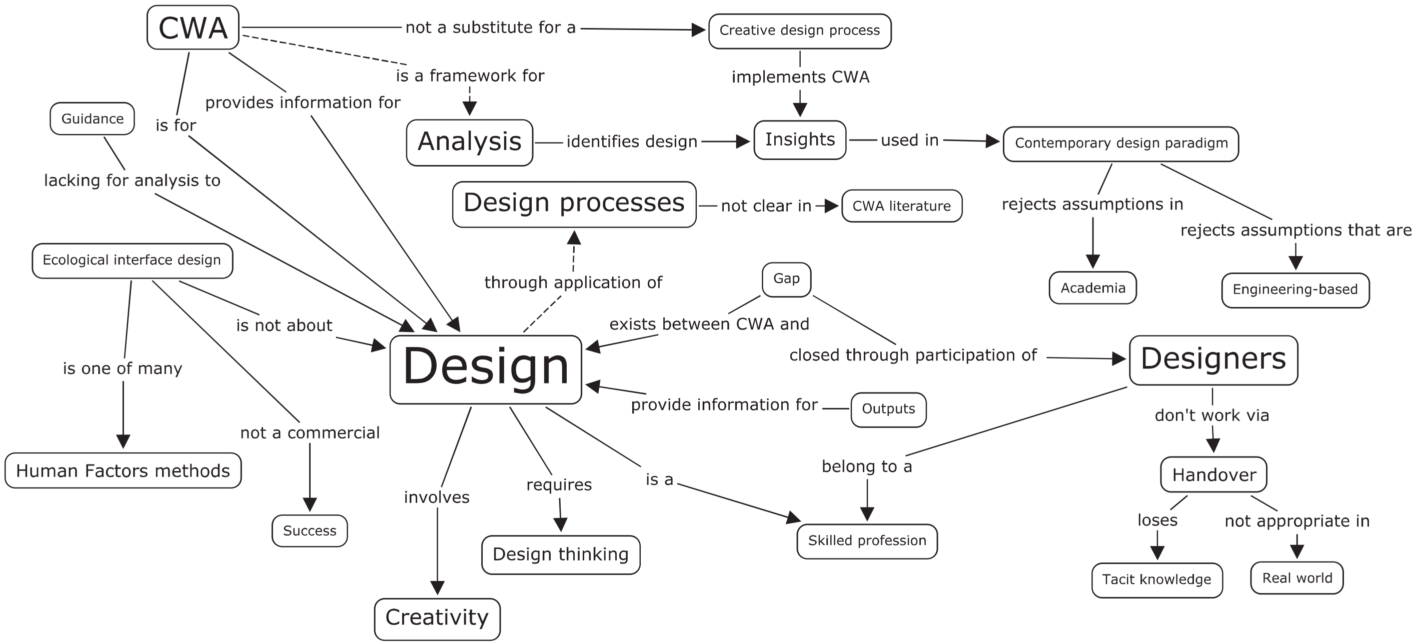

Figure 6. Concept map of responses to the question: *Describe any challenges you have faced when using CWA for design, or any lessons learned.*

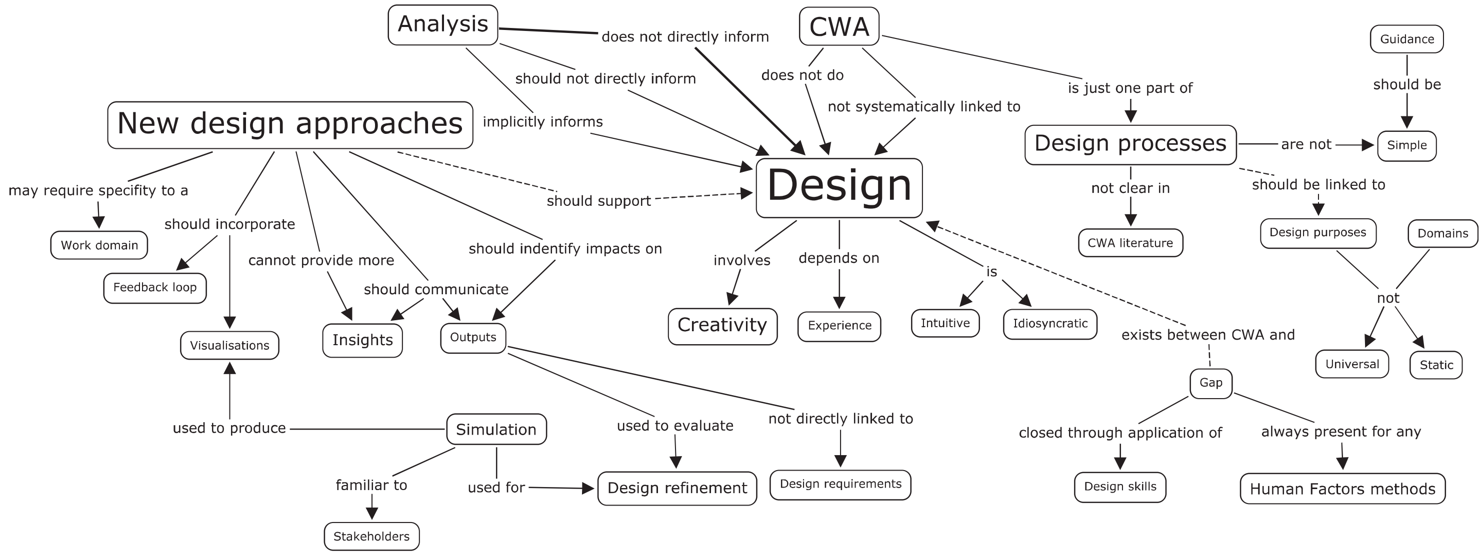

Figure 7. Concept map of comments relating to the question: *Do you think there is a need for an additional approach or method that extends, or can be used in addition to, CWA to more directly inform the design process?*

that *CWA* does not do *Design* and that *CWA* is just one part of *Design processes*. However, it is noted that the *Gap* between analysis and design is present for any *Human Factors methods*.

Those that indicated they believed there was a need for additional approaches or methods suggested that *New design approaches* were needed for *Detailed design* and should be able to communicate *Insights* and *Outputs.* Further, there were suggestions for aspects such as *Visualisations*, use of *Simulation* and *Feedback loops*, particularly to support iterative design evaluation and refinement using the analysis outputs. Respondents who were unsure or did not think that a new design approach was needed proposed that this was because such an approach may need to be specific to a *Work domain* rather than applying generally across domains and that a *New design approach* would be unable to provide more design *Insights*. Figure 7 further indicates that *Design* was characterised by the survey respondents as *Creative*, *Idiosyncratic* and *Intuitive* and requiring the application of *Design skills*.

4. Discussion

The purpose of this study was to explore current practice when using CWA to inform design and whether practitioners currently using the framework perceived a need for an additional process or approach to support the use of CWA outputs to aid design. Translating the outputs of human factors analyses has long been a challenge for the discipline (Dul et al. 2012); however, the extent to which the CWA framework experiences this problem has not previously been explored in this manner. While it is difficult to know to what extent the survey sample is representative of CWA users generally, the results have provided information about the processes used in specific examples of CWA outputs being used in design, and the views and opinions of practitioners on the topic of CWA and design.

The findings demonstrate that CWA is being applied within many different domains; both causal and intentional. Also notable is the finding that most respondents appear to use CWA infrequently. This was unexpected as CWA is a flexible framework that has the capacity to be applied within many domains and for many purposes. It may be that conducting CWA modelling can be time consuming (Sanderson 2003b) making the resources required to undertake the analyses prohibitive for some projects. Further, management or client support for the use of CWA could be difficult to obtain (Vicente 2002). Further research into how human factors professionals select analysis tools for different types of projects would be informative.

Examination of the processes used in the specific applications described by respondents found that most did not include all CWA phases, with on average just under half being used. All but one application used WDA and most applications incorporated an AH. This supports observations in the literature that the majority of CWA applications focus on WDA (e.g. Jenkins et al. 2009; Naikar 2006b).

The emphasis on WDA, and to some extent ConTA, may be attributed to the fact that the methods available for these phases are better developed and explained than the latter phases (Cornelissen et al. 2012; Salmon et al. 2010). In addition, this finding may relate to many applications occurring at the early stages of design (concept design and requirements specification), and analysts may have determined that the initial phases provide sufficient detail for this purpose (McIlroy and Stanton 2012). However, the latter phases of the framework also afford the means to inform and explore system design options. For example, the SA phase provides an understanding of the different ways that tasks could be undertaken within the system, and during SOCA, it is possible to consider various different ways of allocating functions across the human–machine system. It is reasonable to propose that expanding the analysis to all five phases, where practicable, could assist in achieving integrated systems design as envisaged by the developers of CWA.

The diversity of processes was demonstrated in relation to the use of design processes with between zero and five used by individual respondents, of the total 21 processes used across the 12 respondents who indicated they applied methods or processes in addition to CWA. The use of additional processes for design is apparent in the literature. For example, the use of scenarios by Naikar et al. (2003) and cross-linked matrices used by Bisantz et al. (2003). This suggests potential benefits of combining the tools of CWA with other methods from human factors and design disciplines, although currently it is for the analyst to determine the most appropriate combination to apply.

Interestingly, of the 17 design applications described, only four were known to have been implemented. This suggests that translation of CWA-based designs in the real world may be limited. Alternatively, if they are being implemented, those responsible for the CWA outputs underpinning them are not aware of the implementation of their designs, and so are not able to assess their effectiveness. While it would have been informative to compare design processes where the design had been evaluated successfully and implemented with those that were not successful and/or not implemented, there were insufficient data to enable such comparison. Further research should explore this area, preferably applying more specific and objective measures of success and implementation, to investigate whether there indeed are widespread issues with the implementation of designs flowing from CWA analyses, as compared with other human factors methods. It should also investigate the various barriers and enablers to implementation of CWA-based designs.

While it is possible that those respondents who chose to share their views within open-ended questions held stronger views than other respondents, or held particularly negative views, the concept maps derived from the open-ended survey responses uncovered some interesting themes. One theme was the lack of direct contribution of the CWA analyses to the design process (see Figures 6 and 7). While this view was not endorsed by all respondents, it was supported by the 57% of respondents who indicated that an additional design approach is needed. Further, it is supported by the finding that many varied design processes are being used in conjunction with CWA. This indicates that although the CWA outputs inform design, additional processes need to be undertaken before design can occur. Even three of the six respondents who had applied EID expressed the view that an additional design approach is needed.

Another theme arising from the concept map analyses was the lack of guidance available for analysis and design (see also Lintern 2005; Read, Salmon, and Lenne 2012). This is a key area to address to improve the contribution of CWA to design. While there are guidelines for completing the different phases of CWA (e.g. Naikar 2013; Vicente 1999), and for EID (Bennett and Flach 2011; Burns and Hajdukiewicz 2004), there is as yet no comprehensive approach and guidance to assist CWA users to design beyond interfaces using the outputs of the analysis. Although this problem of translating analyses into design is not limited to CWA, due to the framework's unique position and potential to inform system design, it is proposed that solving this issue for CWA should be a priority.

To address this need, an approach and guidance to support the use of CWA outputs in design processes is currently under development. In line with a view expressed in the survey that different domains and design purposes may require different design approaches, a toolkit-type approach is intended; providing guidance to users, rather than a standardised methodology. While standardisation may be appropriate for some human factors tools, such as for data collection and some analysis methods, it was not considered appropriate to constrain design in this way. Further, a flexible approach echoes the framework approach of CWA itself, where the analyst selects methods relevant to the scope and aims of the analysis, rather than following a set formula.

The design toolkit aims to inform both the function of design and its form. In relation to defining the function, the approach will draw together strategies described in the EID and general CWA literature, as well as in the survey responses to define requirements and document the insights derived from CWA outputs. The question of the form, or detailed design of system elements, is more challenging, and here the approach will draw upon and refer to the guidance already provided for EID, as well as the approaches that have been described in the literature and the survey. It is also important to consider the views provided in the survey regarding the need to support how design occurs in the real world. For example, the participation of designers in the analysis process was suggested due to issues associated with handing over insights and tacit knowledge gained during the analysis. This aligns with recommendations from the literature (e.g. Jamieson 2003; McIlroy and Stanton 2012). Further approaches exist to achieve the idea of a feedback loop to support the evaluation of design ideas using the CWA outputs (e.g. Jenkins et al. 2011b). Such recommendations will be incorporated into the approach developed. An important consideration for the development of an approach is that it aligns with the key underlying principles of CWA so as not to negate the unique perspectives and insights uncovered from its formative nature and systemic approach.

5. Conclusions

While the CWA framework has strong support and evidence for its analysis function, with the exception of EID which provides some guidance for certain types of design applications, it does not provide a design process. As shown by the findings of the survey, users of the framework must craft their own approach to design. It is concluded that an additional approach, with associated guidance, is needed to assist a sector of CWA users who perceive the need for additional assistance using the outputs of the analysis in a design process. Without such an approach, CWA's full potential may not be being realised.

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4.2 Discussion

The survey of CWA practitioners reinforced the finding of the literature review presented in Chapter 3, that there appears to be no standard approach to designing with CWA and that practitioners tend to craft their own methods and approaches. Part of the initial rationale for conducting the survey was to gain an understanding of the 'standard' process of design with CWA to enable a comparison with the design approach to be developed. However, no such standard was found. This finding offers an even stronger rationale for the need for further guidance and tools to support CWA-based design.

4.2.1 Implications for the development of a design approach

Key themes from the survey responses which are considered important for informing the development of the new design approach are presented in Table 4.1. The themes were: collaboration, design skills and knowledge, insights, creativity and the need for iteration.

Table 4.1. Key themes from survey responses to inform CWA-DT development.

Theme	**Propositions from concept maps**
Collaboration	- Design occurs through dialogue. - Designers contribute design skills. - Handover loses tacit knowledge. - Users participate in design processes. - Collaboration between analysts and designers leads to success. - Design methods include participatory design. - Design review can involve SMEs.
Design skills & knowledge	- Designers contribute design skills. - Gap closed through application of design skills. - Design methods include contextual design. - Design methods include design thinking. - Design requires design thinking. - Designers belong to a skilled profession.
Insights	- Analysis implicitly informs design. - Analysis identifies design insights. - Insights are only available to analysts. - Analysis creates rich understanding. - New design approaches should communicate insights.
Creativity	- Design involves creativity. - Design methods include design thinking. - Design requires design thinking. - CWA is not a substitute for a creative design process.
Iteration across analysis, design, evaluation	- Design refinement is iterative. - The analysis process can overlap design. - New design approaches should incorporate a feedback loop. - New design approaches should identify impacts of design solutions on outputs. - Design evaluation through comparison with existing design.

Anecdotally, many of these themes did not appear to be present in the review of the academic literature. Exceptions to this include Mendoza and colleagues (2011) who called for more consideration of user experience and user acceptance in EID, and Jansson and colleagues (2005) who argued that a user-centred design process is a superior approach to the SRK inventory proposed in CWA. It may be that there are distinct groups within the CWA practitioner community: those who subscribe to an expert (top-down) design perspective and those who advocate the use of (bottom-up) participatory approaches in conjunction with CWA. Potentially, the survey reached a number of those using CWA within a participatory design paradigm who may not be publishing their work widely in the academic literature.

Of interest for the development of a design approach is that the use of participatory approaches, as well as collaboration between analysts, designs and other experts, align well with the sociotechnical systems theory approach.

4.3 Conclusion

The review of current practice in the use of CWA in design has reinforced the need for additional guidance and tools. Key themes emerging from the survey results can be used to inform the development of a new design approach to better support CWA practitioners in the efforts to design sociotechnical systems.

This chapter concludes Part One of this thesis. Thus far, this thesis has described the problem of pedestrian safety at RLXs and the paucity of previous research from a systems perspective. CWA has been identified as an appropriate systems analysis framework and its use in design has been explored both through a review of the published literature and a survey of CWA practitioners. This has provided evidence that reinforces statements in the CWA literature that there are difficulties associated with the translation of analysis outcomes into system design processes. Part Two of this thesis will respond to this problem by describing the development of a new design approach, the CWA-DT, which aims to provide guidance and a process for moving between analysis and design with CWA, drawing on the values and principles from sociotechnical systems theory. Part Two begins with a chapter that considers the synergies between CWA and the sociotechnical systems theory approach and uses this to define requirements for the CWA-DT.

Part Two

Design approach development and refinement

5 Defining the requirements for a CWA-based design approach

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5.1 Introduction

Sociotechnical systems theory provides a long-standing approach for the design of sociotechnical systems and has provided the foundations for participatory design methods now ubiquitous in HFE and design practice. Similarly to CWA, it is underpinned by general systems theory and intends to design systems that comply with open systems principles. That is, it aims to design systems encompassing properties that enable them to adapt to changes and disturbances in the external environment in order to continue to function effectively and to meet their goals.

A number of the methods and approaches identified in the review of the CWA design literature (Chapter 3) and the responses to the CWA practitioner survey (Chapter 4) were consistent with the sociotechnical systems theory approach (e.g. the use of participatory design methods). Interestingly however, there was no specific reference to sociotechnical systems theory nor its design principles identified in the literature or the survey responses.

The aim of this chapter is to explore connections between CWA and the sociotechnical systems theory approach to identify what this could provide for design and to define requirements for a design approach for use with CWA. It is proposed that putting the theory of sociotechnical systems back into CWA practice can provide theoretical consistency across the analysis, design and evaluation of sociotechnical systems.

Declaration for Thesis Chapter 5

Declaration by candidate

In the case of Chapter 5, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Primary author. Conceived the idea for the analysis, conducted the analysis, responsible for the initial drafting and subsequent editing of the paper.	85%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Paul M. Salmon	Reviewed the analysis and provided critical reviews of draft versions of the paper.	n/a
Michael G. Lenné	Reviewed the analysis and provided critical review of draft versions of the paper.	n/a
Neville A. Stanton	Reviewed the analysis and provided critical reviews of draft versions of the paper.	n/a

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's Signature	[redacted]	**Date** 2 July 2015
Main Supervisor's Signature	[redacted]	**Date** 2 July 2015

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Designing sociotechnical systems with cognitive work analysis: putting theory back into practice

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Cognitive work analysis (CWA) is a framework of methods for analysing complex sociotechnical systems. However, the translation from the outputs of CWA to design is not straightforward. Sociotechnical systems theory provides values and principles for the design of sociotechnical systems which may offer a theoretically consistent basis for a design approach for use with CWA. This article explores the extent to which CWA and sociotechnical systems theory offer complementary perspectives and presents an abstraction hierarchy (AH), based on a review of literature, that describes an 'optimal' CWA and sociotechnical systems theory design system. The optimal AH is used to assess the extent to which current CWA-based design practices, uncovered through a survey of CWA practitioners, aligns with sociotechnical systems theory. Recommendations for a design approach that would support the integration of CWA and sociotechnical systems theory design values and principles are also derived.

Practitioner Summary: Cognitive work analysis (CWA) is commonly used by ergonomics practitioners for evaluating complex systems and informing the development of design improvements. Despite this, translation from analysis to design is not straightforward. Building upon synergies between CWA and sociotechnical systems design principles, recommendations for a design toolkit are specified.

Keywords: cognitive work analysis; sociotechnical systems theory; system design; complex systems

1. Introduction

Cognitive work analysis (CWA) is a commonly used framework of methods (Salmon et al. 2010) that aims to improve system design (Vicente 1999). While CWA has been used in many design applications (e.g. Bisantz et al. 2003; Naikar et al. 2003; Jenkins, Salmon, et al. 2010; Stanton and McIlroy 2012), like all human factors/ergonomics (HFE) analysis methods, the outputs of CWA provide information to support design activities rather than yielding concrete designs per se. The analysis outputs provide recommendations for various types of interventions, rather than specifying a system fully (Lintern 2005). Furthermore, there has been limited evidence in the open literature of the direct application of CWA outputs in design (Salmon et al. 2010), and the majority of those available describe the design of interfaces within causal domains (those primarily driven by the laws of nature), rather than intentional domains (those driven by human intentions) (Read, Salmon, and Lenne 2012). For HFE practitioners to fully realise the utility of the CWA framework, there is a need for new approaches and guidance for designing beyond interfaces and in different types of domains, using the outputs of CWA. In this article, it is proposed that the values and principles of sociotechnical systems theory can assist to create a theoretically consistent design approach for use with CWA.

Both CWA and sociotechnical systems theory are concerned with the design of sociotechnical systems; being systems that contain both social (human-related) and technical (non-human) aspects that interact to pursue a common goal (Walker et al. 2008). They are both underpinned by the systems perspective and open systems principles. Notably, both aim to design systems that are adaptable in the face of disturbances arising from the external environment. The use of systems-based approaches is especially important in the modern of age of technologically complex, distributed, high-risk domains for which reductionist approaches with assumptions of linearity and rationality are no longer appropriate (Walker et al. 2010; Dekker 2011).

While CWA has been described as a sociotechnical systems approach (e.g. Jenkins et al. 2009; Stanton and McIlroy 2012; Stanton and Bessell 2014), Walker et al. (2008) clarify the distinction between the term sociotechnical systems and sociotechnical systems theory. They note that the former refers to any system of social and technical aspects engaged in goal-directed behaviour, while the latter 'reflects certain specific methods of joint optimisation in order to design

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organisations that exhibit open system properties and can thus cope better with environmental complexity, dynamicism, new technology and competition' (480). In this article, we adopt the terminology of sociotechnical systems theory and view the specific methods of joint optimisation as the design values and principles espoused in the sociotechnical systems theory literature. Therefore, while CWA is concerned with designing sociotechnical systems, to date CWA and sociotechnical systems theory have evolved independently of one another and there have been very few attempts in the literature (cf. Jones 1995), to explicitly combine the CWA framework with sociotechnical values and principles.

This article aims to examine these two systems-based approaches with an emphasis on the synergies between them. The article further aims to explore the extent to which the tools currently used in CWA-based design practice can support a sociotechnical systems approach to design. Finally, recommendations for an approach to design involving both CWA and sociotechnical systems theory are derived.

1.1. Cognitive work analysis

The CWA framework is unique in its formative, constraint-based approach that models the possibilities for behaviour within complex systems, rather than describing actual behaviour (i.e. how work is done), or prescribing normative behaviour (i.e. how work should be done) (Vicente 1999).

CWA has its origins in studies at the RISØ laboratory in Denmark beginning in the 1960s. The research program was concerned with designing safe nuclear power installations and, following work to ensure the technical reliability of a nuclear power plant, the researchers realised the need to consider to the role of the human operator. A key finding of their investigations was that accidents were likely where the operator was faced with situations unanticipated by the designer (Vicente 1998). The studies culminated in the emergence of the cognitive systems engineering approach (Wilson 2014), including the CWA framework of tools to assist in the design of adaptive systems that enabled the worker to 'finish the design' (Vicente 1999).

CWA has since been widely used to analyse complex systems including nuclear power generation (e.g. Burns et al. 2008), military command and control (e.g. Jenkins, Stanton, Walker, et al. 2008), air traffic control (e.g. Ahlstrom 2005), disaster management (e.g. Jenkins, Salmon, et al. 2010), health care (e.g. Miller 2004), road transport (e.g. Cornelissen et al. 2013) and rail transport (e.g. Stanton, Mcilroy et al. 2013). It is an established analysis framework, with some evidence showing that its application can improve system design. For example, designs based on CWA have been judged better than other options by subject matter experts (Naikar et al. 2003) and have been demonstrated to improve task performance in empirical studies (e.g. Sharp and Helmicki 1998; Reising and Sanderson 2002). Yet despite the framework's increasing use, questions remain over its use as a design tool, that is, the extent to which CWA outputs directly inform design, and details regarding how it is used in design applications are sparse (Lintern 2005; Jenkins, Salmon, et al. 2010; Mendoza, Angelelli, and Lindgren 2011). Without improving the link between analysis outputs and design, the framework's potential utility for design may not be fully realised. As it is theoretically consistent with CWA and provides various design principles, sociotechnical systems theory may offer some assistance in this regard.

1.2. Sociotechnical systems theory

Sociotechnical systems theory has its origins in the studies of the Tavistock Institute in the 1950s following the introduction of mechanisation in the UK coal mining industry (Trist and Bamforth 1951). The approach is aligned with systems theory and underpinned by notions of participative democracy and humanistic values; being as concerned with the performance of the work system as with the experience and well-being of the people performing the work (Clegg 2000; Walker et al. 2008). Many years of action research implementing innovations in organisations have led to the evolution of principles of sociotechnical design (e.g. Cherns 1976; Davis 1982; Clegg 2000; Walker et al. 2009). These principles are intended to support the design of sociotechnical systems that meet open systems principles.

Being open systems, sociotechnical systems undertake processes that convert inputs to outputs and they contain part-whole relationships where the whole is more than the sum of the parts. Furthermore, they possess the quality of equifinality, meaning that within the system there are many means of achieving goals. Finally, open systems adapt to changes in the external environment in the endeavour to maintain a steady state (Badham, Clegg, and Wall 2006; Walker et al. 2008; Waterson 2009). Another important characteristic of sociotechnical systems is that they comprise social and technical aspects which engage in goal-directed behaviour. The interaction of the social and technical aspects creates conditions for either successful or unsuccessful system performance (Walker et al. 2008). A core assumption of sociotechnical systems theory is that joint optimisation (as opposed to optimisation of *either* the social or technical aspects) is required for successful system performance (Badham, Clegg, and Wall 2006).

Application of sociotechnical systems theoretical approaches to successful system design/re-design have been reported in the literature. For example, Pasmore et al. (1982) report a meta-analysis of 134 studies measuring the impact on dimensions such as productivity, cost, quality and safety following the implementation of a sociotechnical systems theory driven innovation. The findings were overwhelmingly positive, although the authors note that failures may not be disseminated. Furthermore, they note that the innovations typically did not involve all sociotechnical systems theory principles. For example, although joint optimisation is a core goal of sociotechnical design, there were very few efforts to make changes to the technical system, rather the focus tended to be the social system. This concern has been echoed by other authors who have suggested that in sociotechnical systems design the technology is often a given, with interventions focussed on designing the social system to align with the new technology (Clegg 2000). Furthermore, it has been noted that the approach has been applied overwhelmingly to the introduction of new technologies (such as IT systems) within organisations (Davis et al. 2014). Proponents of the sociotechnical approach have called for its expansion to the entire work system (including the design of physical working environments) (Davis, Leach, and Clegg 2011) as well as to broader societal issues that span multiple organisations such as security, sustainability, health-care provision and urban planning (Davis et al. 2014).

1.3. Aligning CWA with sociotechnical systems theory design principles

Although sociotechnical systems theory originated in organisational development and sociology, applied in the coal mining industry, and CWA was developed by engineers working on nuclear power plant functioning, both have a strong systems thinking orientation and stress the importance of system adaptability to enable resilience in the face of external disturbances. Furthermore, both approaches aim to support equifinality through promoting flexibility within the system. They promote worker autonomy and control as a means to support system flexibility as well as for its benefits on worker health. For example, Vicente (1999) notes the relation between job autonomy and worker health and argues that CWA's formative nature and focus of design on supporting flexible strategies provides that autonomy. Importantly, the CWA framework provides a means to jointly analyse and optimise the social and technical system (Stanton and McIlroy 2012) – a key underpinning principle of sociotechnical systems theory. For example, Naikar et al. (2003) used CWA to design teams for a first-of-a-kind military system. The proposed design was adopted, and subsequent changes were made to the technical system concept to better support teamwork.

Thus, many of the design principles of sociotechnical systems theory are implicitly incorporated in CWA and the designs underpinned by CWA. Table 1 outlines the properties of CWA that align with a recent interpretation of sociotechnical principles by Walker et al. (2009).

Table 1 demonstrates the general alignment of the CWA framework with sociotechnical principles and supports statements from the literature that CWA encompasses sociotechnical ideas (e.g. Jones 1995; Baxter and Sommerville 2011). However, there appears to be few, if any, design applications that have explicitly sought to use CWA and sociotechnical systems design values and principles in concert.

It is notable that some CWA applications have not attempted to incorporate some of the more humanistic values underlying sociotechnical systems theory. For example, many CWA applications occur within military domains (e.g. Naikar and Sanderson 1999; Bisantz et al. 2003; Stanton and Bessell 2014) and while values around compliance with rules of engagement and the minimisation of collateral damage are sometimes included in the analysis, the boundaries of the system are drawn in a way that the appropriateness of a military response is assumed. In addition, other applications of CWA do not incorporate any discussion of quality of working life for the human operators within the system (e.g. Higgins 1998). Such examples illustrate that while there is a general alignment of philosophies, the application of CWA alone does not guarantee a sociotechnical systems theory approach.

Of the many CWA applications that have been consistent with sociotechnical systems theory, it is notable that there appears to be no practical assistance to support CWA users to apply the design values and principles in design. Accordingly, it may be of benefit to develop a design approach that would prompt consideration of sociotechnical values and principles during CWA-based design activities. From a practical perspective, this would mean that HFE practitioners using CWA will have a theoretically consistent design approach to bridge the gap between CWA analysis and design activities. From a conceptual perspective, numerous approaches have sprung from systems theory which are being developed, discussed, critiqued and refined in detached spheres of academia and practice. However, there has been little cross-fertilisation amongst these approaches (Baxter and Sommerville 2011). By bringing these approaches together, we can engage in cross-learning from areas within HFE which should strengthen theoretical development and improve practical outcomes. The inclusion of sociotechnical systems theory values in CWA-based design may also address calls for a more comprehensive consideration of ethics and values in HFE (Dekker, Hancock, and Wilkin 2013).

Table 1. Alignment of sociotechnical systems principles and the CWA framework.

Sociotechnical systems principles [adapted from Walker et al. (2009)]	CWA framework
The technical system does not exist in isolation, rather the social and the technical system have to be designed together.	The CWA framework consists of five phases of analysis that describe the constraints (both social and technical) on human behaviour within the system. For example, the AH from the work domain analysis phase identifies high-level social constraints within the system including its purpose and the priorities and measures that humans use to evaluate system performance. It also identifies the technology within the system and how the technical functions contribute to the overall system purpose.
Top-down design approaches are appropriate for complicated, large-scale problems, whereas bottom-up approaches are appropriate for complex, emergent problems. Sociotechnical systems theory and human factors integration is about achieving the correct balance.	CWA provides an understanding of system functioning that can be used to input to both top-down design processes and bottom-up, incremental improvements that can be built upon over time. Specifically, the AH can be used to identify opportunities for top-down design opportunities involving changes to the purpose/s of the system and can be used to evaluate how this change would affect the system's functioning. The AH can also be employed to inform bottom-up design through the addition of new physical objects at the lowest layer of the hierarchy, with consequential evaluation of the impacts of this on higher levels of abstraction, including the systems purpose/s. The CWA framework is designed to be appropriate for complex systems exhibiting emergent properties and captures the potential for emergence through its formative approach.
Design choices are contingent and do not necessarily have universal application. What works in one situation and context may not work in another. Design choices may themselves have unintended consequences, creating effects that can become magnified or attenuated out of all proportion.	CWA is applied to the particular domain of interest to provide recommendations for bespoke design based on the findings of the analysis. It does not incorporate design rules or off-the-shelf solutions. The outputs of CWA can be used to evaluate the consequences on the functioning of the system of a particular design choice, enabling the identification of unintended consequences prior to implementation.
Systems may embody 'needs' that will be subsequently discovered by users. These users may not even be the anticipated benefactors of the system. User requirements co-evolve and will only unpack themselves over time.	CWA defines the constraints within the system and the degrees of freedom available for behaviour. The framework's underlying philosophy is based on the notion that designers are unable to anticipate all potential situations that will be faced by workers, therefore workers should be given freedom to 'finish the design' during system operations (Vicente 1999). Designing for flexibility and adaptability provides latitude for unanticipated needs and use by unanticipated users, at least to some extent.
Users of systems interpret it, amend it, massage it and make such adjustments as they see fit and/or are able to undertake. Therefore, design should incorporate adaptability and change.	As described earlier, the CWA philosophy promotes flexibility and adaptability through enabling workers or users to finish the design (Vicente 1999). While this notion in CWA arose from a focus on unanticipated safety-critical situations, it could also apply to enabling users to make day-to-day amendments and changes to meet other goals such as efficiency or individual preference.
Design of systems should produce useful, meaningful, effects-based, whole tasks which enable people to see the significance of the work they are doing.	Vicente (1999) discusses the need to design for safety, productivity and worker heath. Vital to supporting worker health is design that maximises decision latitude by providing workers with the autonomy to make decisions. Work should also provide the opportunity to exercise and develop skills and more broadly to enable workers to participate fully in life and society.
One should not over-specify how a system will work. Whilst the ends should be agreed and specified, the means should not. Design should provide open, democratic, flexible type of technology that users can tailor to suit their own needs and preferences, in other words the design should be based on minimal critical specification.	The formative nature of CWA enables the framework to consider all the potential ways that goals can be achieved within a system. For example, the strategies analysis phase aims to identify the many ways that functions and tasks can be executed. This informs designs that support flexibility, rather than specifying one 'optimal' means (as normative models do), or describing current means (as descriptive models do). In relation to participation and democracy in initial and on-going design, CWA outputs provide a useful medium for communication (e.g. Stanton and Bessell 2014).

TABLE 1 – *continued*

Sociotechnical systems principles [adapted from Walker et al. (2009)]	CWA framework
Systems should be congruent with existing practices which may on occasion appear archaic compared with what technology now offers.	Existing practices are documented throughout CWA's five phases of analysis. Changes to the system can be evaluated using the analysis outputs to determine issues around congruence with existing practices and unintended effects of the change on the functioning of the overall system (e.g. Stanton et al. 2009). CWA can highlight incongruence within a system and assist in the creation of more compatible designs (e.g. Stanton and McIlroy 2012).
From the moment users start to use the system they are on the road to co-evolution. The perceptive designer will see that the design of future capabilities is already underway.	Co-evolution and co-design is incorporated in the philosophy of workers finishing the design (Vicente 1999). This has been illustrated by Euerby and Burns (2012) who used CWA to inform the design of social engagement within communities of practice. A website interface was designed which intentionally traded-off the benefits associated with a structured design to enable emergence based on how members of the communities chose to use the technology.

1.4. Design approach development

But what might such a design approach entail? This article attempts to take some initial steps towards answering this question. With one of the key principles of sociotechnical systems theory acknowledging design as a sociotechnical system which must itself be designed (Clegg 2000), this article uses the abstraction hierarchy (AH) tool from CWA to explore relationships within a 'CWA-sociotechnical system design system' (CWA-STS design system) and to ultimately provide recommendations for the development of a design approach, consistent with sociotechnical systems principles, for use in conjunction with CWA.

The AH tool has been used previously for design in numerous applications (e.g. Naikar and Sanderson 1999; Burns 2000; Reising and Sanderson 2002; Drivalou and Marmaras 2009; Birrell et al. 2012), while a related tool, the abstraction-decomposition space, has been used for investigating the management of design processes (Durugbo 2012). While CWA has been applied to design processes previously, to the authors' knowledge this is the first time that CWA has been applied to reflect upon itself and its role in system design. This article begins by describing the development and content of an exploratory 'optimum' CWA-STS design system AH. Next, this optimum system AH is refined based upon the findings of a survey of CWA practitioners and is then used to explore the extent to which the tools currently used in CWA-based design practice can support a sociotechnical systems approach to design. Finally, the refined AH is used to provide recommendations fora design approach.

2. Structure of the AH

The AH is a tool that is used as part of the work domain analysis phase of the CWA framework to describe the structure of the system within which behaviour occurs. An AH provides a functional view of a sociotechnical system, encompassing five levels of abstraction, with means-ends links between nodes at adjacent levels. It describes the constraints of the system within which behaviour is possible. The representation identifies the physical resources available within the system, the processes afforded by those resources, the functions supported by the processes, the values and priorities that are measured and monitored within the system, and finally, the overall purpose of the goal-directed work domain (Vicente 1999).

The optimal CWA-STS design system AH presented in this article is underpinned by HFE literature on CWA, sociotechnical systems theory, desirable attributes of HFE methods and system design. To inform the development of the AH, a search for relevant literature was undertaken using the Science Direct and Web of Knowledge databases as well as the search functions of Sage Journals and Taylor and Francis Online. The keywords adopted for the literature search included 'sociotechnical principles', 'sociotechnical values', 'socio-technical', 'cognitive work analysis', 'human factors methods', 'ergonomics methods', 'methodological attributes' and 'method development'. The reference lists of journal articles were also reviewed to identify pertinent literature. An overview of the structure of the AH in relation to how the literature was used to inform the various levels of abstraction is provided in Figure 1.

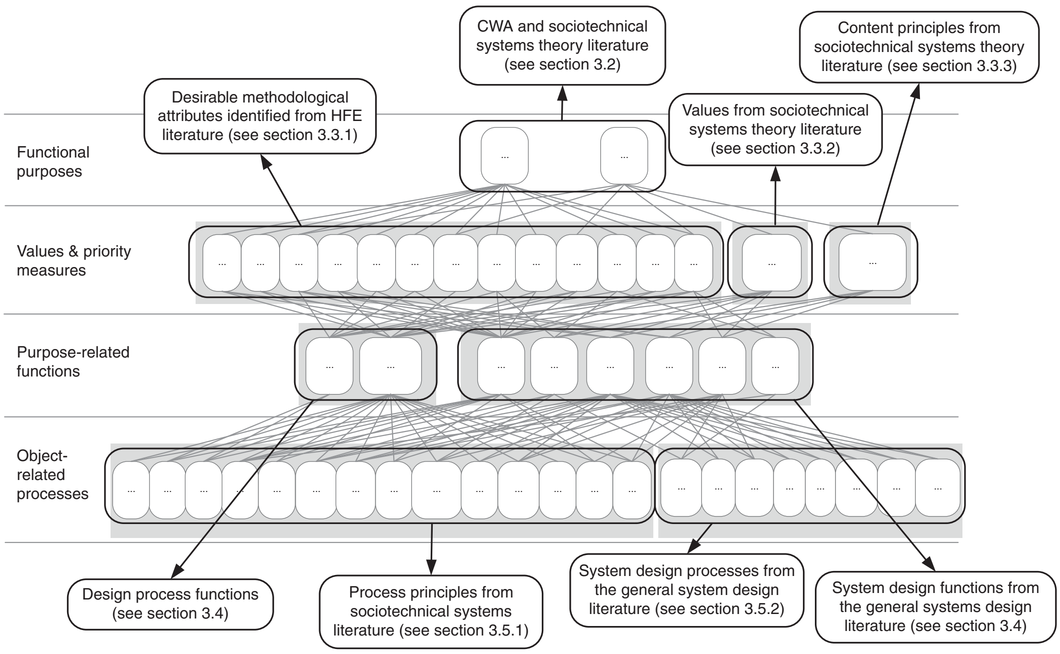

Figure 1. Structure of AH indicating the data sources for each level of abstraction.

3. Developing an 'optimal' CWA-STS design system AH

The AH was developed by a sole analyst and reviewed by a second analyst. The primary analyst was an HFE specialist with knowledge of CWA and some experience applying the framework to support design. The second analyst had extensive experience in CWA and had used the framework in numerous design applications. This analyst also had a good knowledge of sociotechnical systems theory and had implicitly applied a sociotechnical approach when using CWA to support design processes.

Any disagreements encountered were resolved through discussions following an iterative process until consensus on the accuracy and completeness of the nodes and means-ends links was achieved. The following sections first describe the boundaries of the analysis and then describe how the literature was used to populate the first four levels of the AH: the functional purpose/s, the values and priority measures, the purpose-related functions and the object-related processes.

3.1. Identifying the boundaries of the analysis

Prior to commencing development of the AH, the boundaries of the analysis were considered. The focus of the analysis was determined to be the work domain of a design team, working to achieve a design brief based on a CWA evaluation of a system. It was assumed that CWA had already been employed to investigate and identify the current constraints of the system of interest. The AH was intended to be exploratory in nature, to consider the potential means-ends links between nodes at the four levels of abstraction, rather than to necessarily document current practice.

3.2. Identifying the functional purposes

The top level of the AH identifies the functional purpose/s of the system under investigation (Vicente 1999). This is the purpose or purposes that the system has been designed to achieve. As shown in Figure 1, the functional purposes for the AH was identified from the CWA and sociotechnical systems literature.

Based on this literature, two functional purposes were identified for the CWA-STS design system. The first is to support system design. This refers to the need to conduct integrated systems design, as opposed to designing an element or elements in isolation. It also encompasses the need to ensure the HFE input is integrated into the overall systems design process. The second purpose is to ensure adaptive capacity of the designed system. As noted previously, sociotechnical systems theory aims for joint optimisation of technical and social systems to enable worker flexibility, adaptation and innovation (Cherns 1976). CWA is also concerned with facilitating designs that support the adaptive capacity of a system, and individual adaptation through providing workers with information about the deep functional structure of the system to enable them to cope with unanticipated situations (Vicente 1999).

3.3. Identifying values and priority measures

The second level of abstraction relates to the values and priority measures within the system. These are criteria that can be used to determine whether the system, in this case the CWA-STS design system, is meeting its functional purpose (Vicente 1999). As shown in Figure 1, these were derived first, from the methodological attributes identified from the literature and second, from the sociotechnical systems literature.

Based on these data sources, it was identified that the success of the CWA-STS design system can be measured by the extent to which: it satisfies measures associated with desirable methodological attributes; the design process aligns with sociotechnical systems theory values; and the outcome of the design process aligns with sociotechnical systems theory content principles. Decompositions of each of these three categories of values and priority measures are discussed in the following sections.

3.3.1. Methodological attributes

The literature review resulted in the identification of 14 generally accepted methodological attributes. These are outlined in Table 2 with some examples of supporting statements from the literature.

3.3.2. Sociotechnical systems theory values

Another value and priority measure for designing with CWA should be the extent to which the design process aligns with sociotechnical systems theory values. An original principle in Cherns' (1976) list of sociotechnical principles was the principle of design and human values; however, in his revised list, Cherns (1987) instead proposed that human and social values should underpin all aspects of the design process. The values described in the following point to the humanistic philosophy behind sociotechnical systems theory.

Humans as assets. Rather than characterising humans as unpredictable, error-prone and the cause of problems in an otherwise well-designed technological system, sociotechnical systems theory acknowledges that no technical system is perfect and that people are assets as they are capable of identifying the need for change and of learning and adapting, making them effective problem-solvers (Clegg 2000; Norros 2014).

Technology as a tool to assist humans. The second value is a corollary of the first and states that technology should be viewed as a tool to assist people to meet their goals, rather than an end in its own right (Clegg 2000; Norros 2014). This value aims to avoid the common scenario where a technical solution is implemented as a panacea to a problem, with little or no consideration of the goals of people's work or the social system required to make the technology work within an open system (Clegg 2000). Eason (2014) suggests that the aim of technology should be to promote human adaptability and learning, rather than requiring the human to adapt to it.

Promote quality of life. This value is associated with promoting the quality of working life for employees and designing tasks which have meaning for people. This value advocates that people cannot be considered as simply machines or extensions of machines (Robinson 1982). Quality work can be conceptualised as that which is challenging, has variety, includes scope for decision-making and choice, facilitates ongoing learning, incorporates social support and recognition of people's work, has social relevance to life outside work and provides a feeling that the work leads to some sort of desirable future (Cherns 1976, 1987). Instead of humans being allocated those tasks that cannot be performed by technology, humans should only be allocated those tasks that justify the use of humans and utilises human skills and judgement. Technology should be designed to fulfil the remaining functions (Hendrick 1995).

Respect for individual differences. The fourth value refers to the fact that people have different needs and wants. For example, some people may prefer high levels of autonomy and control in their work, while others may not. The design process should recognise and respect these differences and should aim to achieve a flexible design that incorporates different preferences, acknowledging that meeting all needs may not always be possible (Cherns 1976, 1987). As an underpinning principle, understanding and respecting different preferences and ways of working amongst those involved in the design process is also important.

Table 2. HFE methodological attributes synthesised from the literature.

Attribute	Definition	Selected supporting literature
1. Creativity	Design process facilitates creativity and/or innovation.	– Design is a creative process that should not be controlled by formal, normative procedures. Designers are inspired through the findings of the analyses (Rasmussen, Pejtersen, and Schmidt 1990). – Design problems require innovation and new perspectives. Needs to be an opportunistic and explorative process (Militello et al. 2010). – Need to maintain creativity in the design process (Hajdukiewicz and Burns 2004). – A challenge for HFE is supporting the creative features of the design process (Norros 2014).
2. Efficient	Design process is efficient and/or cost effective.	– Resources consumed in the analysis and design processes should be proportionate to the benefits gained (Potter et al. 1998). – Criteria for evaluating HFE methods have included efficiency (Hoffman, Crandall, and Shadbolt 1998; Potter et al. 1998), resource usage (Shorrock and Kirwan 2002), affordability (Pretorius and Cilliers 2007) and training and application time (Stanton et al. 2005). – A method should aim for maximum cost-effectiveness to improve its chances of being applied in practice. This incorporates whether or not the method is time intensive, resource intensive as well as costs of training users (Older, Waterson, and Clegg 1997).
3. Holistic	Design process supports coordinated design of all system elements (e.g. interfaces, training, support materials, team structures).	– All aspects of a system should be designed in a coordinated fashion (Vicente 2002). – Coherent design, where different aspects of the system are designed so that they are compatible and integrated, has been proposed to promote efficiency and to reduce errors (Gonzalez Castro et al. 2007). – The discipline of HFE is holistic. Its outputs need to consider the impact on all stakeholders and should enhance multiple goals (Wilson 2014).
4. Integrated	Design process can integrate with existing systems engineering processes.	– It is important that design processes integrate with system design and development processes (Bisantz et al. 2003; Gualtieri, Szymczak, and Elm 2005) and are consistent with existing tools and methods (Clegg et al. 1996). – Methods should have some relation to wider design processes and the products of the design should be integrated into this wider process (Potter et al. 1998).
5. Iterative	Design process facilitates iteration.	– Cognitive systems engineering methods are generally intended to facilitate ongoing re-evaluation and re-consideration of the problem being investigated as new information arises, or as the analyst progressively builds their understanding of the system (Militello et al. 2010). – As analyst understanding evolves throughout the process, there is benefit to be gained in incorporating a means for the analysis to grow from subsequent design activities (Potter et al. 1998). – The boundaries of the system are continually reconsidered as the design process progresses (Edwards and Jensen 2014). – Design processes need to be iterative to enable opportunism and innovation (Militello et al. 2010). – Iteration enables decisions to be amended and re-evaluated as the process proceeds (Older, Waterson, and Clegg 1997).
6. Reliable	Design process produces consistent results each time it is applied.	– Reliability and validity (see Attribute 13) are generally proposed as the basic objective measures of the success of an HFE method (Stanton and Young 1999; Baber and Stanton 2002). – A method cannot be valid if it is not reliable (Gawron 2000). – Reliability is concerned with whether measurements are repeatable and accurate (Gawron 2000) between different analysts (Stanton and Stevenage 1998; Baber and Stanton 2002; Baysari, Caponecchia, and Mcintosh 2011) and within the same analyst over time (Annett 2002; Baber and Stanton 2002). – Criteria for evaluating HFE methods have included evidence of reliability (Hoffman, Crandall, and Shadbolt 1998; Patrick et al. 2006; Stanton, Salmon, et al. 2013).
7. Stakeholder involvement	Project stakeholders (e.g. designers, engineers, management) are involved in the design process.	– Participative involvement of various stakeholders ensures that the system design meets the needs for which it is required (Older, Waterson, and Clegg 1997). – Stakeholders have different perspectives on a system, and different views of a design problem (Baxter and Sommerville 2011). – Involvement of stakeholders with diverse knowledge, skills and expertise can facilitate multidisciplinary education and is more likely to foster creativity and innovation (Clegg 2000).

TABLE 2 – *continued*

Attribute	Definition	Selected supporting literature
8. Structured	Design process has structure.	– Degree of structure has been used as a criterion to evaluate human factors methods (e.g. Clegg et al. 1996; Shorrock and Kirwan 2002). – A structured approach to design provides a link between the analysis of the system and the cognitive artefacts produced (Elm et al. 2008). – Structure provides accountability in the design process and enables the specification of a clear path forward with the ability to trace and understand reasons for past decisions (Elm et al. 2008). – Structure can improve efficiency, communication between analysts and reduce training time (Rehak, Lamoureux, and Bos 2006).
9. Tailorable	Design process can be tailored for different system types (e.g. intentional, causal, first-of-a-kind).	– Methods need to support application to specific situations (Older, Waterson, and Clegg 1997). – Methods should be flexible (Clegg et al. 1996; Hoffman, Crandall, and Shadbolt 1998). – Methods should be sensitive to contextual factors within the system in which it is applied (Shorrock and Kirwan 2002).
10. Theoretical	Design process is consistent with the underpinning theory and principles of CWA	– A valid method is one based on an appropriate underlying theory (Baber and Stanton 2002), and having an internal structure that aligns with that theory (Shorrock and Kirwan 2002).
11. Traceable	Design process provides a detailed record of design decisions.	– Where designers have not been involved in the analysis, a traceable process enables designers to discover the rationale behind, and justification for, decisions that affect the subsequent design process (Kilgore, St-Cyr, and Jamieson 2008). – A traceable process provides auditable documentation (Shorrock and Kirwan 2002) enabling updating and supporting communication within the design team (Potter et al. 1998). – Traceability enables testing of whether the design adequately addresses what was uncovered by the analysis (Elm et al. 2008).
12. Usable	Design process is usable for CWA practitioners, systems designers, engineers, etc.	– Usability has been used as a criterion for evaluating human factors methods (e.g. Clegg et al. 1996; Shorrock and Kirwan 2002; Baysari, Caponecchia, and Mcintosh 2011). – A method that is usable and straightforward to learn is more likely to be selected for use in practice (Older, Waterson, and Clegg 1997) and will promote better consistency amongst analysts and less errors than one which is difficult to use (Baysari, Caponecchia, and Mcintosh 2011).
13. Valid	Design process does what it says it will do (e.g. produces effective designs).	– Validity is generally considered the cornerstone measure of a robust methodology (Stanton and Young, 1999). – Various types of validity have been proposed including face validity, construct validity and predictive validity (Baber and Stanton 2002). – Concepts of predictive power (Potter et al. 1998), predictive accuracy (Shorrock and Kirwan 2002) and face validity (Pretorius and Cilliers 2007) are important for establishing the efficacy of HFE methods. – Criteria for evaluating HFE methods have included evidence of validity (e.g. Hoffman, Crandall, and Shadbolt 1998; Koubek et al. 2003; Stanton, Salmon, et al. 2013).
14. Worker/user involvement	Workers/end users are involved in the design process.	– User participation in design is a common approach within the HFE discipline (e.g. Dul et al. 2012) and has been used as a criterion to evaluate HFE methods (e.g. Clegg et al. 1996; Waterson, Older Gray, and Clegg 2002).

Responsibility to all stakeholders. In line with open systems principles, the effects of the system on all stakeholders should be considered (Cherns 1987). Stakeholders of a CWA design process could include end users, manufacturers, unions, industry bodies, government bodies and the wider community. Potential negative effects on these groups are broad and could include physical damage or injury to individuals (e.g. through accidents), economic loss, social harms or environmental harms (Cherns 1987). Impacts on stakeholders should be considered throughout all stages of the system lifecycle including design and implementation processes, as well as system operation.

3.3.3. Sociotechnical systems theory content principles

The final category of value and priority measure is the extent to which the outcome of the design process aligns with the content principles of sociotechnical systems theory. Content principles in this context refer to aspects of the designed system, following Clegg (2000) who proposed a breakdown of the sociotechnical principles into content principles, process principles and meta-principles. The terminology of content principles and process principles is adopted in the article to clarify that the success of a design process in achieving adaptive capacity can be measured by how well the final design can be shown to meet the content principles, while it is the process principles (see Section 3.5.1) that enable the design of a system that meets the content principles.

A detailed list of the proposed content principles is provided in Table 3. The principles have been synthesised from previous conceptualisations in the literature and have been re-phrased to more fully explain the principle with the aim of assisting the operationalisation of these concepts for measurement purposes.

3.4. Identifying purpose-related functions

The third level of abstraction outlines the general functions that the design system needs to carry out to achieve its functional purpose (Vicente 1999). Two categories of functions were identified. The first category is associated with the design process itself and a core proposition of this article, that the incorporation of CWA outputs and sociotechnical systems theory principles in design will realise the functional purposes of supporting system design and ensuring adaptive capacity of the designed system.

The second category of purpose-related function can be decomposed into functions associated with system design. As shown in Figure 1, these functions were identified from the literature (particularly the systems engineering and design literature). The order of functions presented is not intended to suggest an order of activities, recognising the iterative nature of design. Each function is described in the following.

The values and principles of sociotechnical theory suggest the need for planning of the design process, thus design planning is a function of an optimal CWA-STS design system. For example, Cherns (1987) discusses the need for agreed values to drive the design, perhaps in a formal statement of philosophy, while Walker et al. (2009) refer to the need to ensure appropriate resources are allocated to the design process and that an appropriate design process is selected to align with the fundamental nature of the design problem or domain of implementation.

Another general function of design is the identification or specification of key requirements that the design should achieve. This involves selecting key information gathered during the wide-ranging analysis process to provide focus for design activities and a means to verify whether the final design meets the needs of stakeholders. Outputs from the CWA tools can provide or inform the requirements, for example, the purpose-related function/s in the AH provide high-level requirements while the findings from the latter stages of analysis can provide more specific requirements. For example, decision ladder analyses can provide situation awareness requirements (Jenkins, Stanton, et al. 2010). In line with notions of design as an iterative process, the requirements should evolve and adapt with the process of design, to reflect the changing understanding of the design team and design participants.

The third function identified was concept design. This function encompasses the divergent ideation required for creative thinking and the development of a high-level concept or series of concepts to meet the design requirements. These concepts could be in the form of early mock-ups, drawings or descriptions. The next function identified, detailed design, involves decisions about the specifics of the design and may be embodied in the form of sophisticated prototypes, models and detailed specifications.

Another function, that of evaluation and design refinement, is associated with evaluating either the design concepts or detailed designs prior to implementation through activities such as prototyping, simulation and user trials. The design can then be refined and improved, or discarded, based on the findings.

The final function identified was testing and verification. This relates to implementation and the processes of testing and verifying that the implemented design operates as intended and aligns with the design requirements and the intentions of the design team and participants. This may, for example, involve testing software code to ensure accurate implementation and reliability of automated functions.

Due to the boundary of the analysis being drawn around the work of a design team tasked with the re-design of a system, further lifecycle stages such as system operation, maintenance and decommissioning were not included in the AH. However, this is not intended to undervalue the need to consider these activities within a design process.

3.5. Identifying object-related processes

The fourth level in the AH identifies the processes that contribute to the purpose-related functions. As shown in Figure 1, the object-related processes were identified from the literature around sociotechnical systems theory process principles and from generic system design processes.

Table 3. Sociotechnical systems theory content principles.

Content principle	Adapted from previously proposed sociotechnical systems theory principles
Tasks are allocated appropriately between and amongst humans and technology	– Complementarity (Davis 1982) – Design entails multiple task allocations between and amongst humans and machines (Clegg 2000) – Design useful, meaningful, effects-based whole tasks (Walker et al. 2009)
Useful, meaningful and whole tasks are designed	– Core processes should be integrated (Clegg 2000) – Design useful, meaningful, effects-based whole tasks (Walker et al. 2009)
Boundary locations are appropriate	– Boundary location (Cherns 1976, 1987; Davis, 1982) – Core processes should be integrated (Clegg 2000) – The workgroup creates boundaries (Hirschhorn, Noble, and Rankin 2001) – Clarity of systems boundaries and boundary constraints (Sinclair 2007)
Boundaries are managed	– Boundary location (Cherns 1976) – Boundary management (Davis 1982) – Incompletion of role boundaries, to allow for changing contexts (Sinclair 2007)
Problems are controlled at their source	– The sociotechnical criterion (Cherns 1976) – Variance control for system stability (Davis 1982) – Variance control (Cherns 1987) – Problems should be controlled at the source (Clegg 2000) – Learning from variances (Hirschhorn, Noble, and Rankin 2001) – Variance control should be available where the variance happens (Sinclair 2007)
Design incorporates the needs of the business, users and managers	– Design should reflect the needs of the business, its users and their managers (Clegg 2000)
Intimate units and environments are designed	– Make large small (Davis 1982)
Design is appropriate to the particular context	– Organisational uniqueness (Davis 1982) – Design is contingent (Cherns 1987) – Use bottom-up processes based on subsumption (Walker et al. 2009)
Adaptability is achieved through multifunctionalism	– The multifunctional principle (Cherns 1976, 1987) – Multifunctionalism (Davis 1982) – Design entails multiple task allocations between and amongst humans and machines (Clegg 2000) – Dynamic complementarity (Hirschhorn, Noble, and Rankin 2001) – Provide multifunctionality for roles, for job enlargement and system resilience (Sinclair 2007) – Design for adaptability and change (Walker et al. 2009)
System elements are congruent	– Support congruence (Cherns 1976, 1987; Davis 1982) – Management support (Robinson 1982) – System components should be congruent (Clegg 2000) – Ensure compatibility of roles with goals (Sinclair 2007) – Congruence capitalises on hard won co-evolution and system DNA (Walker et al. 2009)
Means for undertaking tasks are flexibly specified	– Minimal critical specification (Cherns 1976, 1987; Davis 1982; Walker *et al.* 2009) – The means of undertaking tasks should be flexibly specified (Clegg 2000) – Define roles with minimum critical specification (Sinclair 2007) – User requirements co-evolve (Walker et al. 2009) – Design for adaptability and change (Walker et al. 2009)
Authority and responsibility are allocated appropriately	– Minimal status differentials (Davis 1982) – Power and authority (Cherns 1987) – Core processes should be integrated (should have authority and resources to perform whole process) (Clegg 2000) – Match support provision to role requirements (Sinclair 2007)
Adaptability is achieved through flexible structures and mechanisms	– Self-maintaining organisational units (Davis 1982) – Design for adaptability and change (Walker et al. 2009)
Information is provided where action is needed	– Information flow (Cherns 1976, 1987; Davis 1982) – Core processes should be integrated (information systems should match the task) (Clegg 2000) – Feedback (Sinclair 2007)

3.5.1. Sociotechnical systems theory process principles

A list of process principles from the sociotechnical systems theory literature is provided in Table 4. As with the content principles outlined previously, a number of principles have been re-phrased to represent the process that the principle advocates; the original principles are provided in Table 4.

3.5.2. System design processes

In addition to the sociotechnical systems theory process principles, there are general processes that occur in system design relating to different elements of the system. These processes represent the micro-level of design as opposed to the functional purpose of system design which is a macro-level process involving integration of these elements. The processes include stakeholder needs analyses, function allocation, design of information systems and interfaces, design of jobs and tasks, design of teams, design of the physical environment for work or tasks, the design of support materials such as user guides, procedures and rules and design of the organisational management system including high-level policies, organisational structures and philosophies.

Table 4. Sociotechnical systems theory process principles.

Process principle	Adapted from previously proposed sociotechnical systems theory principles
Adoption of agreed values and purposes	– Design and human values (Cherns 1976) – Organisation philosophy (Davis 1982) – Values (Cherns 1987) – Values and mindsets are central to design (Clegg 2000) – Design useful, meaningful, effects-based whole tasks (Walker et al. 2009)
Provision of resources and support	– Resources and support are required for design (Walker et al. 2009)
Adoption of appropriate design process	– Compatibility (Cherns 1976, 1987; Davis 1982) – Design is itself an information-age entity (Walker et al. 2009) – Match design approaches/methods/techniques to the fundamental nature of the problem/environment (Walker et al. 2009)
Design and planning for the transition period	– Transitional organisation (Davis 1982; Cherns 1987) – Design practice is itself a sociotechnical system (Clegg 2000)
Documentation of how design choices constrain subsequent choices	– Design involves making choices (Clegg 2000)
User participation	– Compatibility (Cherns 1976, 1987) – Compatibility (Davis 1982) – Participation in design and operation (Davis 1982) – Systems and their design should be owned by their managers and their users (Clegg 2000)
Constraints are questioned	– Minimal critical specification (Cherns 1976) – Constraints used to criticise design ideas should be questioned, to avoid prematurely closing off options
Representation of interconnectedness of system elements	– Systemic integrity (Davis 1982) – Design is systemic (Clegg 2000) – Equipment does not exist in isolation (Walker et al. 2009)
Joint design of social and technical elements	– Joint optimisation (Davis 1982) – Compatibility (decisions should be reached for both technical and social reasons) (Clegg 2000)
Multidisciplinary participation and learning	– Design involves multidisciplinary education (Clegg 2000) – Multidisciplinary input (Walker et al. 2009)
Political debate	– System design involves political processes (Clegg 2000)
Design driven by good solutions – not fashion	– Design is socially shaped (Clegg 2000)
Iteration and planning for ongoing evaluation and re-design	– Incompletion (Cherns 1976) – Incompleteness (Davis 1982) – Incompletion or the fourth bridge principle (Cherns 1987) – Design is an extended social process (Clegg 2000) – Design practice is itself a sociotechnical system (Clegg 2000) – Evaluation is an essential aspect of design (Clegg 2000) – User requirements co-evolve (Walker et al. 2009) – Principle of internal continuous re-design (Eason 2014)

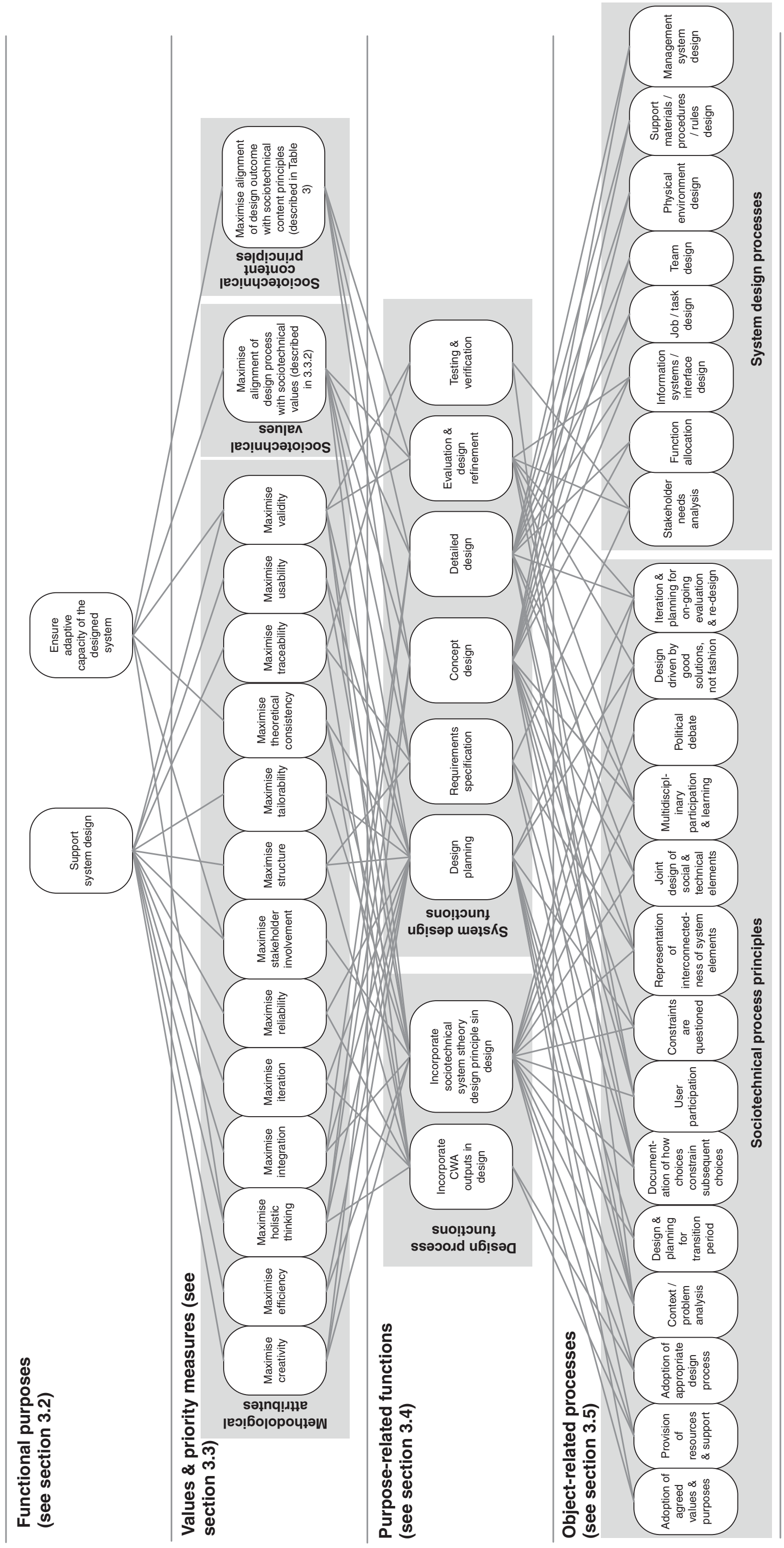

Figure 2. 'Optimal' CWA-STS design system AH.

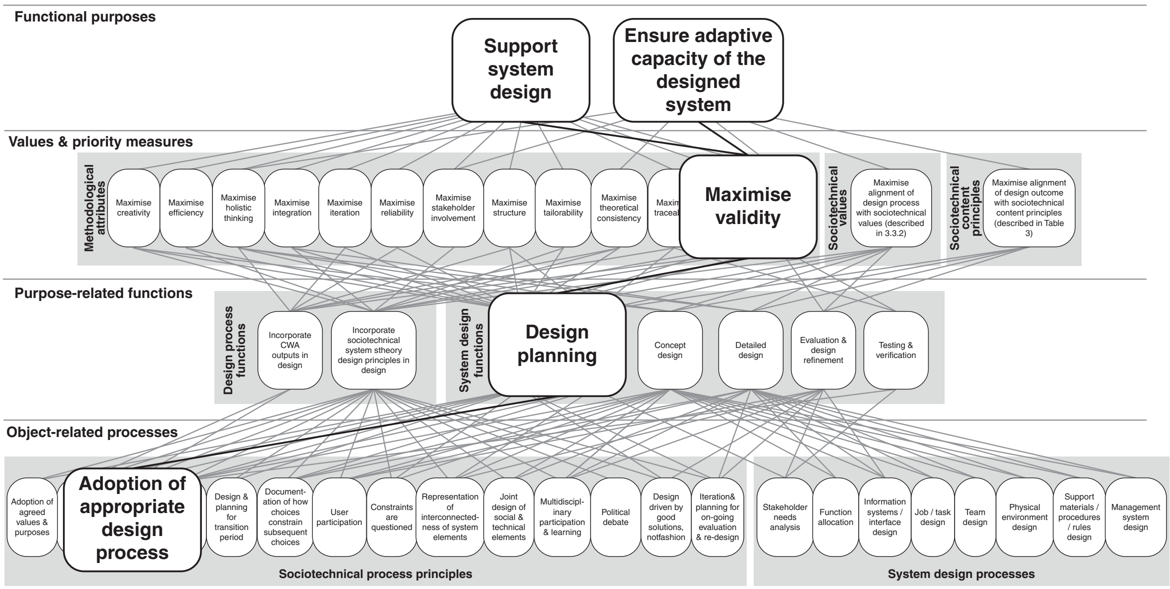

Figure 3. Representation of the AH focusing on the *Design planning* function.

4. Putting it together – content of the 'optimal' CWA-STS design system AH

The preceding discussion has identified relevant nodes for inclusion in the optimal CWA-STS design system AH (Figure 2). Figures 3 and 4 highlight particular examples of means-ends links between nodes within the AH. The means-ends links can be read using the 'why–what–how' relationship. Taking any node within the hierarchy as the 'what', nodes linked in the hierarchical level above the node indicate why it is necessary within the system and any nodes linked in the level below represent how the node is achieved (Vicente 1999).

Figure 3 shows the means-ends links for the *Design planning* function identified in the CWA-STS design system. It demonstrates the importance of design planning in that the means-ends links connecting this function up to the higher levels of abstraction show that it can support all four purposes of the system. Tracing through the AH, focusing on the highlighted nodes and means-ends links in Figure 3, if the *Design planning* node is taken as the 'what', it can be seen that this occurs to ensure the design system *Maximises validity* (the 'why') and it is supported by the *Adoption of an appropriate design process* (the 'how'). Moving up the hierarchy, and taking *Maximise validity* as the central node, it can be seen that the reason why the design system requires validity is that this *Supports system design*. If the design system lacks face validity, for example, it is unlikely to be used in practice, or to have the on-going confidence of design teams and stakeholders. A valid process also supports the design system to *Ensure adaptive capacity of the designed system*. If, for example, an inappropriate design process was adopted which failed to acknowledge the complexity of the design problem, it would not be able to support design for adaptive capacity within a complex system.

Figure 4 provides an example relating to the *Concept design* function within the AH. Reviewing the highlighted nodes in the figure it can be seen that one of the reasons for conducting *Concept design (*the 'what') is to *Maximise Creativity* (the 'why') and that this can be achieved through *Multidisciplinary participation & learning* (the 'how') (Clegg 2000; Baxter and Sommerville 2011). Furthermore, the *Maximise* *creativity* node is linked to *Support system design* because creativity and innovation are the foundation of design, even if the innovation is simply the application of an existing feature to a new domain or for a new purpose. Furthermore, where design stakeholders (including engineers who may usually lead system design) are involved in a creative process of conceiving design concepts, better engagement and ownership is likely leading to enhanced integration of HFE considerations in system design processes.

5. Refining the optimal AH and using it to evaluate current practice

5.1. Survey of CWA practitioners

A survey of CWA practitioners was undertaken for two reasons. First, to refine the values and priority measures within the 'optimal' CWA-STS design system AH and second, to populate the fifth level of abstraction – the physical objects.

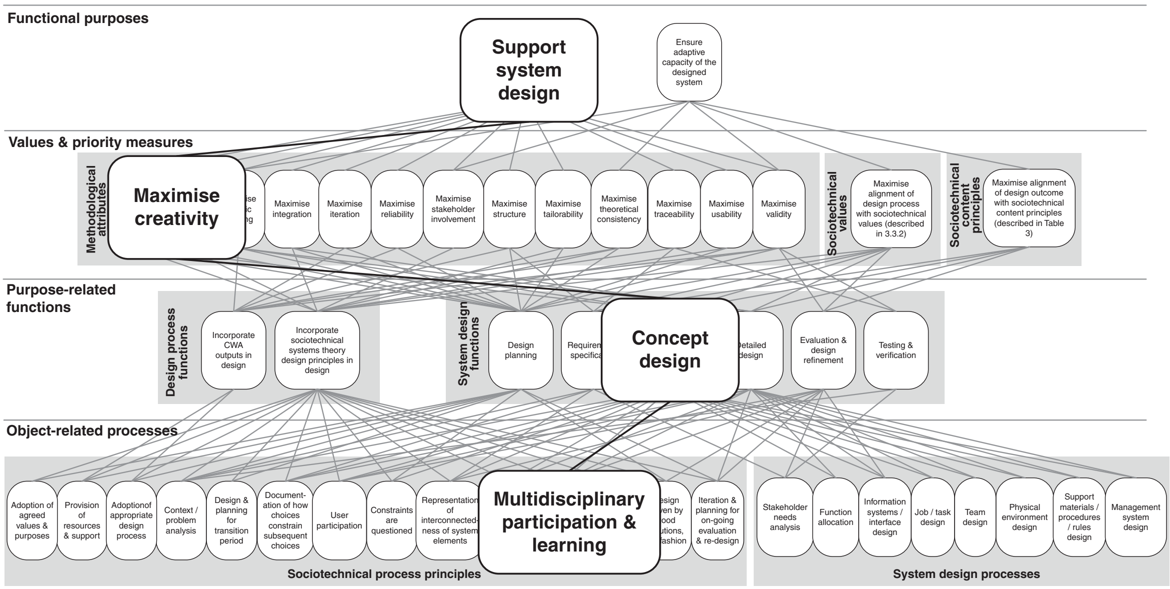

Figure 4. Representation of the AH focusing on the *Concept design* function.

Having developed the optimal AH, it was considered that the number of values and priority measures (13 methodological attributes, 5 sociotechnical values and 14 sociotechnical content principles) may be overly arduous for a design approach to meet. From a practical perspective, methods may not be able to meet all requirements or methodological attributes, and these need to be balanced or traded-off (Shorrock and Kirwan 2002). In order to achieve such balance, and to ensure the views of potential users were considered, CWA practitioners were asked to provide a priority ranking of the methodological attributes identified from the HFE literature. This prioritisation process was considered appropriate for the methodological attributes because they may be more or less desirable for different types of methods or approaches. For example, reliability may be considered more important for psychometric tests or questionnaires that aim to accurately categorise people or phenomena, but less important for approaches that are more exploratory in nature, such as design. No prioritisation was conducted on the sociotechnical values and content principles as these derive from established theory and are expected to be equally necessary across all application types.

In addition to providing a mechanism for CWA practitioners to provide their views on the methodological attributes, the survey also provided a means to capture the physical objects or tools that are currently being used by CWA practitioners when using the outputs of CWA to inform design processes. The physical objects identified were used to evaluate the extent to which current tools can support a sociotechnical systems approach.

5.1.1. Survey instrument

The survey instrument was developed based on issues and questions arising from the CWA literature and from the researchers' own experience of the framework. The survey was reviewed by two HFE specialists and piloted by an experienced user of CWA to ensure that the instrument had sufficient clarity and was usable for the target group. The survey included four sections consisting of forced-choice and open-ended questions.

The first section of the survey collected demographic information about participants, particularly in relation to their experiences with CWA. Section two asked respondents to describe a specific, recent experience involving the use of CWA for design purposes. The aim was to gather detailed descriptions of particular design applications including information about the domain in which CWA was applied, the analysis process, the design process and whether the design had been evaluated and implemented. To avoid limiting the results to one design application per respondent, the third section elicited information about use of CWA in design generally. Questions were posed regarding the resources, processes, tasks and activities that respondents would generally use in design with CWA. The final section focussed on respondents' views and attitudes towards the need for, and attributes of, a new approach to support CWA-based design applications.

To address our stated aims, a subset of the survey questions were designed to gather information that could be used to refine the values and priority measures and identify physical objects for incorporation in the AH. These questions are provided in the Appendix.

5.1.2. Procedure

A range of recruitment methods were used to target those using CWA in both academia and industry. The survey was disseminated electronically to corresponding authors of journal articles and conference papers on the topic of CWA or utilising the phases and tools of CWA. The survey was also advertised through professional newsletters and social networking sites (i.e. LinkedIn groups for professionals working in cognitive systems engineering) to target those using CWA in industry settings. The recruitment materials asked the reader to forward the invitation to those in their collegiate networks who may be interested in participating.

Participants completed the survey online. The survey instrument guided respondents to answer only those questions relevant to their use of CWA. For example, if the respondent indicated they had no experience using CWA for design, they were not asked further questions about their use of CWA in design.

5.1.3. Participants

Thirty-eight CWA practitioners participated in the online survey. The term practitioner in this context related to anyone involved in the practice of CWA, whether in academia, industry or government settings.

Respondents' years of experience using CWA ranged from less than 1 year to 30 years, with the majority of respondents having used CWA for 10 years or less (72%). Self-ratings of expertise indicated that no respondents were novice users of CWA, 13.9% were beginners, 63.9% were either competent or proficient and 22.2% were expert. The majority (85.3%) had spent up to 30% of their time in the previous year on CWA-related activities, with more than half (61.8%) spending only 10% or less of their time using CWA. The majority of respondents (63.9%) had applied CWA, in any capacity (i.e. for analysis, design evaluation), to one or two domains. Two respondents (5.6%) had applied CWA in more than five domains. The domains selected most often were navy (12 respondents), nuclear power (10 respondents) and civilian air transport (9 respondents).

5.2. Refining the value and priority measures of the AH

As shown in the Appendix, the survey question relating to the desirable methodological attributes involve participants being presented with a list of the 14 attributes described in Table 2, with the following instructions: *Imagine that an approach or method for assisting design following the application of CWA was being developed. Think about what attributes such an approach or method should possess. Rank the following attributes in order of importance, with 1 being the most important and 14 being the least important*.

To conduct the prioritisation, the individual rankings obtained from the survey results were transposed so that an attribute with a higher ranking was considered more important. An average ranking was then calculated for each attribute by summing the individual ranks and dividing by the number of respondents (there were 20 respondents to this question). The results of this analysis are presented in the second column of Table 5. As the average ranking tends to smooth the results, it may not truly represent the priorities of the respondents. Therefore, an additional analysis was also undertaken to give greater emphasis to those attributes that attracted first and second rankings. The attributes ranked first or second by each respondent were selected and a weighted score applied: a product of 3 was applied for first rankings and 2 for second rankings. The third column of Table 5 displays the results of these weighted scores.

Taking the top five ranked attributes from each analysis (i.e. the second and third columns of Table 5), the highly rated design attributes were identified as Creative, Holistic, Structured, Efficient, Iterative, Integrated and Valid. These were identified as values and priority measures that should be incorporated in the refined AH, as shown in Figure 5. The refined AH is similar to the optimal AH displayed in Figure 2, however, with the reduced number of methodological attributes identified as value and priority measures. Interestingly, the attributes of worker/user involvement and stakeholder involvement, which are core to sociotechnical systems theory design, received relatively low rankings. This may indicate that CWA users are not currently as concerned with these principles as the sociotechnical systems field. However, the refined AH still retains these important concepts through the object-related processes such as user participation, multidisciplinary participation and learning, and political debate.

Table 5. Results of ranking of methodological attributes.

Attribute	Average ranking	Weighted score
Creative	9.35	18
Efficient	9.15	12
Holistic	9.35	12
Integrated	8.2	3
Iterative	8.7	7
Reliable	6.95	11
Stakeholder involvement	6	2
Structured	7.9	15
Tailorable	7.55	5
Theoretical	6.6	5
Traceable	5.7	3
Usable	7.35	9
Valid	6.25	12
Worker/user involvement	6.6	5

5.3. *Using the AH to evaluate current CWA practice*

Having developed and described an optimal CWA-STS design system AH, this tool can be used to evaluate the extent to which the physical objects (e.g. tools and resources) currently in use for applying the results of CWA in design processes support this optimal system. The responses to a subset of the survey questions regarding the tools, objects, etc. that have been used by CWA practitioners were reviewed and all physical objects mentioned were documented to populate the fifth level of abstraction of the AH: the physical objects. Some extracts of the AH including this final level of abstraction are provided in Figures 6 and 7. In Figures 6 and 7, it should be noted that the means-ends links have been identified formatively, meaning that they link physical objects to what they could potentially support, even if the survey response did not specify this use. Figure 6 illustrates the physical objects that can contribute to the *Design planning* function, while Figure 7 displays the physical objects representing CWA outputs and illustrates how these can contribute to the CWA-STS design system.

5.3.1. *Physical objects contributing to the* Design planning *function*

Figure 6 shows the physical objects currently in use by CWA practitioners, formatively linked to the object-related processes supporting the *Design planning* function. Only three levels of the AH are displayed, with the higher levels for the *Design planning* function previously detailed in Figure 3. It can be seen from Figure 6 that *Project stakeholders* and *End users* contribute to the *Design planning* function through involvement in the *Adoption of agreed values and purposes* of the design and the *Provision of resources and support* for the design process. While the AH is intended to provide an actor-independent representation of a work domain (Vicente 1999), in this case it was important to understand the contributions of end users and stakeholders as resources for the design team. This is due to the importance sociotechnical systems theory places on participation in design and enables demonstration within the AH of what these human resources provide, as well as the extent to which these groups are currently involved in design. The inclusion of end users and stakeholders was not intended to suggest that they are merely resources in the design process; they are recognised as designers within participatory design processes and in on-going re-design during system operation (Eason 2014).

Figure 6 also shows how *Scenarios* contribute to *Design planning*. Scenarios can be developed about the current situation to assist the design participants in *Context/problem analysis* to explore and analyse in a general way the problems being faced. Scenarios can also be developed that focus on the transition period to support *Design and planning for the transition period* or that focus on the system in operation to assist *Iteration and planning for ongoing evaluation and re-design*. Such scenarios might assist in communicating with project stakeholders the importance of including these activities within the scope of the project. Finally, scenarios could be used to demonstrate the importance of avoiding design solutions that are fashionable (i.e. newly developed technologies) to ensure that *Design driven by good solutions – not fashion* (i.e. that solutions are adopted that are appropriate to the problem being addressed and the context within which they will be implemented).

5.3.2. *Contribution of CWA outputs to the CWA-STS design system*

Figure 7 focuses on the physical objects associated with the application of CWA. The tools used within CWA are ordered in relation to the phase of analysis to which they relate. Beginning with the work domain analysis phase, the *AH and*

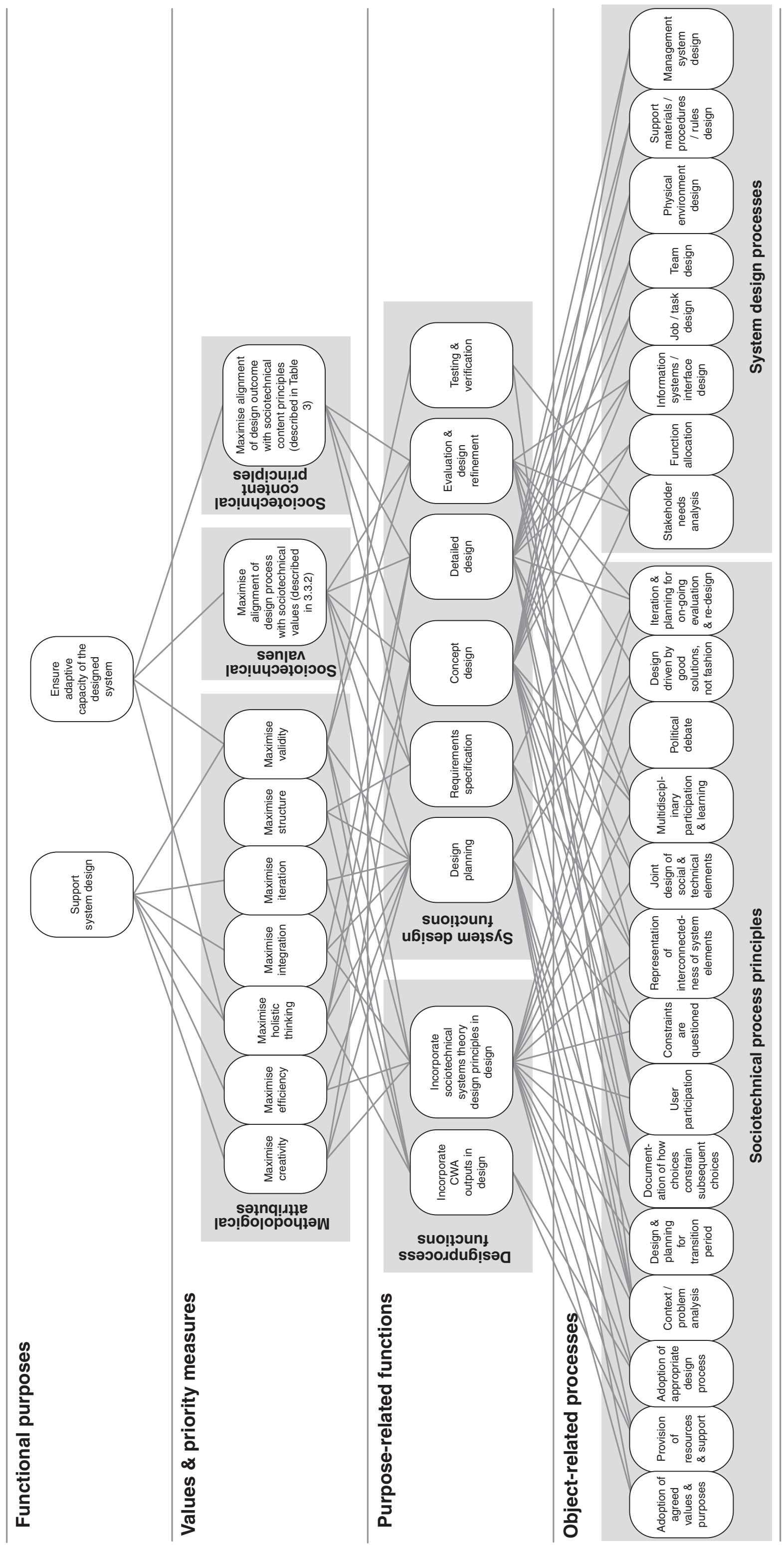

Figure 5. Refined AH, incorporating the prioritised values and priority measures.

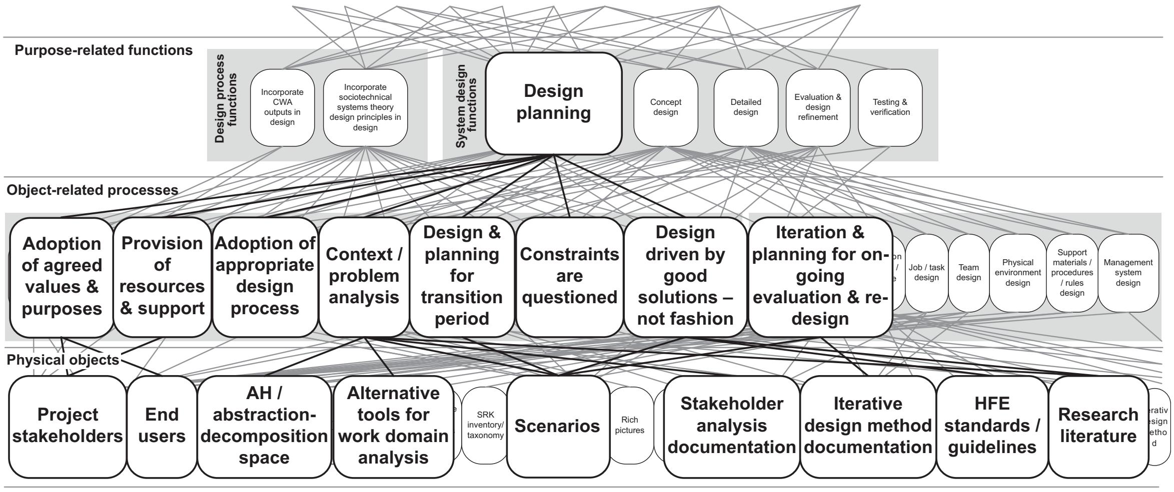

Figure 6. Representation of the AH displaying the physical objects supporting the *Design planning* function.

abstraction-decomposition space are included as physical objects, as are *Alternative tools for representing the work domain*. For the control task analysis phase, the *Contextual activity template* and *Decision ladders* are included, while for the strategies analysis phase *Information flow maps*, *Information flow diagrams* and *Alternative representations for strategies analysis* are included. The fourth phase, social organisational and cooperation analysis, is not separately listed as this phase builds upon the outputs of the previous phases to identify roles and responsibilities of actors in the system. The final phase, worker competencies analysis, is represented by the *Skills, rules, knowledge (SRK) inventory/taxonomy*. Another physical object relating to CWA is *Team CWA outputs.* This refers to CWA outputs that have been developed to better consider teamwork throughout the phases of CWA (Ashoori and Burns 2013).

The CWA representations, particularly those arising from the earlier phases of work domain analysis and control task analysis, contribute to a number of object-related processes that in turn support all of the functions within the system. Predominantly these processes include the system design processes such as *Function allocation*, *Information systems/ interface design*, *Team design*, etc. For example, it can be seen in Figure 7 that the *Contextual activity template* can be used to assist *Job/task design*. It does this through providing information about what functions can be performed in which

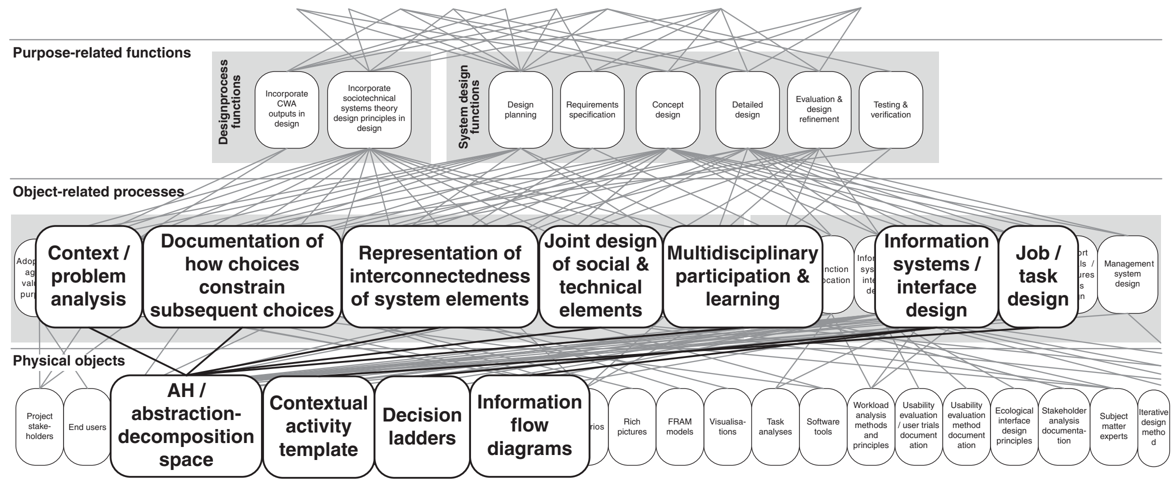

Figure 7. Representation of the AH displaying how the CWA outputs support the object-related processes and purpose-related functions of the AH.

situations. Furthermore, *Decision ladders* and *Information flow diagrams* can be used for *Interface design*; providing information about user information requirements and task flow options. The work domain analysis outputs can also support a range of the sociotechnical processes such as *Context/problem analysis* through providing a means for understanding the work domain on a deep level (Jamieson 2003; Kilgore, St-Cyr, and Jamieson 2008). They could further potentially provide *Documentation of how choices constrain subsequent choices*, and provide a *Representation of interconnectedness of system elements* through an analysis of means-ends links between nodes. The work domain analysis outputs can also assist in ensuring *Joint design of social and technical elements* particularly when used for the social organisation and cooperation analysis (Jenkins, Stanton, Salmon, et al. 2008). Finally, the outputs of work domain analysis can be communicated and shared with stakeholders, subject matter experts and users to promote *Multidisciplinary participation and learning* (e.g. Naikar et al. 2003; Stanton and McIlroy 2012).

5.4. Evaluation conclusions

It is clear that the CWA outputs are vital to the CWA-STS design system (see Figure 7). However, the outputs cannot support all of the object-related processes without the application of other tools and resources. While a number of additional tools and resources being used were identified from the survey results, unexpectedly it was found that some were not frequently mentioned. For example, while *HFE standards/guidelines* were used by 17 respondents, only three respondents mentioned use of *Scenarios* to aid design. Furthermore, only two respondents explicitly noted the use of *Research literature* in the design process. Both scenarios and research literature have the potential to support many processes with a CWA-STS design system (see examples shown in Figure 6).

Another finding of the evaluation was that some object-related processes identified in the optimal AH were unable to be linked to the physical objects derived from the survey responses. For example, no physical object was identified as being able to directly support the processes of *Constraints are questioned* or *Adoption of an appropriate design process*.

These key findings of the evaluation suggest that guidance for identifying appropriate tools and resources to support CWA-STS design may be beneficial for assisting practitioners who wish to use CWA outputs as part of a design process in line with sociotechnical systems theory. It is proposed that a toolkit-type approach would be most suitable. In accordance with the sociotechnical principles this provides the user with flexibility and respects their expertise to choose and adapt the most relevant tools based on the design problem. Theoretically grounded toolkits have previously been proposed as being of benefit for human-centred architectural design (Davis, Leach, and Clegg 2011).

6. Using the AH to inform the development of a CWA-STS design toolkit

Following authors such as Naikar and Sanderson (1999), the AH was used to provide design requirements and evaluation criteria for a CWA design approach that aligns with the principles of sociotechnical systems theory and the needs and expectations of CWA users. The AH was also used as a basis for identifying additional physical objects that could form part of a design toolkit.

The design goals and evaluation criteria were purposefully phrased in a broad sense to incorporate design processes within organisations as well as those that occur outside of organisations (for example, design of consumer products or infrastructure for public use). Whether this broad formulation of the sociotechnical design principles is valid outside of organisational contexts remains to be tested.

6.1. Design approach requirements and evaluation criteria

The design requirements for a CWA-STS design approach are drawn from the AH and are presented in Table 6. The first four high-level requirements are based on the functional purposes identified within the AH, with the remaining requirements referring to the purpose-related functions, object-related processes and physical objects levels.

Evaluation criteria for determining whether a design approach using the outputs of CWA is successful are drawn from the values and priority measures in the AH. The criteria are provided in Table 7.

6.2. Identifying tools for a toolkit

The AH was also used to identify additional physical objects that could be incorporated within a CWA-STS design approach, to support those object-related processes that are not well supported with currently used tools and resources. The more tools available for use increases the flexibility in the system and supports the principle of equifinality as well as autonomy for designers to choose how they undertake the design process. A toolkit approach supports many varied options, with guidance provided for choosing an effective combination for the design purpose. While the focus is on design, analysis

Table 6. Design requirements for a CWA-STS design approach.

Design requirement	Description
The approach should aim to support system design.	– The approach should support design (i.e. the creation or invention of an object, process, strategy, etc.). – The approach should support integrated systems design (i.e. to design system elements concurrently). – The approach should support integration of HFE considerations within system design processes.
The approach should incorporate CWA outputs in design.	– The approach should support the application of the information documented in CWA outputs in the design process. – The approach should support the use of insights arising from the process of conducting CWA in the design process. – There should be traceability between the findings of CWA and the design outcomes.
The approach should incorporate sociotechnical systems theory design principles in design.	– The approach should assist practitioners to adopt the philosophy, principles and values of sociotechnical systems theory during design. – This could be achieved through information and guidance for introducing the concepts to design participants, as well as tools such as workshop exercises for exploring the principles and values.
The approach should ensure adaptive capacity of the designed system.	– The approach should produce designs that align with open system principles, through the application of sociotechnical principles and values, and should specifically promote behavioural flexibility and adaptability. – Tools selected for use within the design process should align with the sociotechnical principles; consequently promoting adaptive capacity.
The design approach should provide guidance for supporting all of the purpose-related functions identified in the AH.	– The approach should ensure that CWA outputs are incorporated in the design process. – The approach should ensure that sociotechnical systems theory principles are incorporated in the design process. – The approach should provide information and guidance regarding the integration of CWA outputs and sociotechnical principles in each of the design functions: design planning, requirements specification, concept design, detailed design, evaluation and design refinement and testing and verification.
The design approach should support all of the object-related processes identified in the AH.	– The approach should provide guidance for ensuring that each of the object-related processes (i.e. the sociotechnical systems theory process principles and system design processes) take place, as appropriate, within a design process. – Guidance should be provided to ensure the selection of tools for use in design cover the range of processes.
The design approach should provide flexibility and choice in the physical objects used for design.	– The approach should ensure that the design process is appropriate to the context, the aims of stakeholders and the resources available for design. – The approach should acknowledge the expertise and knowledge of users of the approach, the individual differences in preference for design tools and should provide users with autonomy, thus remaining consistent with sociotechnical values.

Table 7. Evaluation for a CWA-STS design approach.

Values and priority measures	Evaluation criteria
Creative	The design approach facilitates creativity and/or innovation.
Structured	The design approach provides structure to the design process.
Holistic	The design approach supports coordinated design of all system elements, e.g. interfaces, training, support materials, team structures.
Integrated	The design approach can integrate with existing systems engineering processes.
Efficient	The design approach provides a process that is efficient and/or cost effective.
Valid	The design approach does what it says it will do, i.e. produces effective designs/designs sociotechnical systems with adaptive capacity.
Iterative	The design approach facilitates an iterative design process.
Process aligns with sociotechnical values	The design approach facilitates a process that aligns with the values of humans as assets, technology as a tool to assist humans, promote quality of life, respect for individual differences and responsibility to all stakeholders.
Outcome aligns with content principles	The design approach produces designs that align with the content principles described in Table 4 (i.e. useful, meaningful and whole tasks are designed, problems are controlled at their source, system elements are congruent, etc.).

Table 8. Examples of physical objects (tools) that have the potential to support the currently under-supported object-related processes.

Object-related process	Current physical objects	Example potential physical objects
Adoption of agreed values and purposes	Project stakeholders End users	– Guidance to introduce and communicate sociotechnical systems values and principles – Tools and technique/s to draw out and test stakeholder values and assumptions (e.g. Mumford 1995) – Use of stories (e.g. Erickson 1995) to communicate values and assumptions – Analysis brief (e.g. Liedtka and Ogilvie 2010) documenting agreed values and purposes
Provision of resources and support	Project stakeholders	– Project planning methodologies, e.g. Gantt chart can assist to estimate resources required – Analysis brief (Liedtka and Ogilvie 2010) outlining agreed resources for analysis phase – Design brief (Liedtka and Ogilvie 2010) outlining agreed resources for design phase
Adoption of appropriate design process	Project stakeholders	– A typology of systems with guidance about appropriate design processes for each type. Could draw upon existing distinctions of system types (e.g. Perrow 1984; Walker et al. 2009)
Design and planning for transition period	Scenarios (focussed on transition issues)	– Statement of agreed values and purposes (documented in analysis brief) acknowledging the transition period – Design brief (Liedtka and Ogilvie 2010) acknowledging the need to design the transition period – Business process maps (Neumann and Village 2012) for the transition period
Constraints are questioned	N/A	– Statement of agreed values and purposes (documented in analysis brief) to outline support for questioning system constraints – Design brief (Liedtka and Ogilvie 2010) to outline support for questioning system constraints – Guidance for questioning constraints, e.g. for challenging assumptions underlying the current design
Iteration and planning for ongoing evaluation and re-design	Scenarios	– Statement of agreed values and purposes (documented in analysis brief) acknowledging ongoing evaluation and re-design – Design brief (e.g. Liedtka and Ogilvie 2010) should explicitly include this in the scope of the project – Stories (Erickson 1995) that raise future needs – Agent-based modelling and simulation tools (e.g. Hughes et al. 2012) such as Brahms modelling software (Clancey et al. 1998; Lintern 2005)
Documentation of how choices constrain subsequent choices	Software tools AH/ADS	– Guidance for using the AH to evaluate the impact of choices – Template and guidance for documenting design choices and considering their impact
Stakeholder needs analysis	Stakeholder analysis documentation Subject matter experts	– Stakeholder object world representations (Naikar 2013) – Global organisational analysis documentation (Cummings and Guerlain 2003) – Envisioning Cards for value-sensitive design (Friedman and Hendry 2012)
Joint design of social and technical components	AH/ADS Scenarios	– Statement of agreed values and purposes (documented in analysis brief) should state that design will not be technology-led – Envisioning Cards for value-sensitive design (Friedman and Hendry 2012)
Political debate	N/A	– Design brief (e.g. Liedtka and Ogilvie 2010) should build in time and flexibility to enable this to occur – Stories (Erickson 1995) that raise issues for debate and promote understanding and empathy among participants – Envisioning Cards for value-sensitive design (Friedman and Hendry 2012)

tools in addition to the standard CWA outputs may also be advantageous where CWA does not support a particular process. Table 8 shows the object-related processes for which less than three supporting physical objects were identified. The table provides a list of objects that have been identified by the authors as having the potential to support each of these processes. This list of additional objects is intended to be illustrative rather than exhaustive.

The proposed objects include tools that could provide structure to the design process such as the concept of an analysis brief and design brief, part of a suite of documentation for design thinking (Liedtka and Ogilvie 2010), which has previously been proposed as a useful means of developing design concepts on the basis of CWA (G. Lintern, personal communication, May 24, 2012). The analysis and design briefs could document the agreed purposes of the activities the values that should underpin them, based on the outcomes of a participatory process that draws out and tests the values and assumptions of the participants. Such activities could draw from established participatory design techniques such as the Effective Technical and Human Implementation of Computer-based Systems method (ETHICS; Mumford 1995). The analysis and design briefs should also define the scope of activities and the resources required, including for designing the transition period and making provision for ongoing evaluation and re-design activities. Project planning tools could assist with estimating the required resources.

The proposed objects also include guidance material that would assist users to introduce and explain sociotechnical values and principles to participants in the process, to use an AH to show how design decisions impact the system and constrain further choices, to employ a template to document design choices and to challenge the assumptions underlying the current system. In relation to choosing an appropriate design process, it is suggested that guidance could draw upon existing literature that categorises systems into types based on differentiations between complex and complicated systems (Walker et al. 2009), complexity and linearity, tight and loose coupling (Perrow 1984), and between different types of cause and effect relationships (Snowden and Boone 2007).

A further physical object could be stories which can provide a communication tool to promote shared understanding between design participants. Stories differ from scenarios in that they are more concrete, more personal, and usually relate to actual events (Erickson 1995). They are used to engage with design participants and could be used to illustrate changing needs within systems, to raise topics for political debate and to explore values and assumptions.

Regarding stakeholder needs in design, there are two tools described in the CWA literature that are not necessarily part of the standard suite of analysis tools, but could contribute to a broader consideration of stakeholder needs. Representation of stakeholder object worlds may assist to represent a work domain from the perspective of different stakeholders (Naikar 2013). These representations can identify where there are shared or conflicting perspectives, which can be useful depending on the goals of the analysis. Another tool, global organisational analysis, was developed to identify the relationships between the system of interest and its broader stakeholders, in line with open systems ideas (Cummings and Guerlain 2003).

A further additional tool that could contribute to understanding the needs of a wide stakeholder group is the Envisioning Cards developed by Friedman and Hendry (2012). These cards are intended to be used in design processes to promote value-sensitive design. Each card describes a specific theme relating to one of four general themes (stakeholder, time, value and pervasiveness) and provides a design activity to explore the issue. The cards could contribute to understanding stakeholder needs, as well as to the joint design of social and technical components and to the identification of issues requiring debate amongst the design participants. For example, the cards may raise topics relating to traditions and norms which can be a challenge to design (Edwards and Jensen 2014) unless brought into open debate. They also raise values around responsibility to all stakeholders, which could potentially lead to a decision not to pursue a particular design solution where it has negative implications for the environment or for human health.

6.3. Summary of AH contributions to the development of a CWA-STS design toolkit

In summary, the five levels of abstraction within the AH have been used to define design requirements and evaluation criteria, and to identify tools for a CWA-STS design toolkit. Figure 8 shows how the levels of the AH informed the requirements discussed earlier.

7. Conclusions

The aim of this article was to explore the synergies between CWA and the sociotechnical systems approach, and investigate the extent to which the tools currently used in CWA-based design practice can support a sociotechnical systems approach to design. Through this analysis, recommendations for an approach to design incorporating both CWA and sociotechnical systems theory have been provided.

Building upon the work of a number of previous authors who have identified CWA as sociotechnical systems approach (Jenkins et al. 2009; Stanton and McIlroy 2012; Stanton and Bessell 2014), the findings make evident the link between CWA and sociotechnical systems theory. While CWA and sociotechnical systems theory evolved independently, they share an underpinning in general systems theory. The AH, while exploratory in nature, has demonstrated that CWA outputs, particularly those from the work domain analysis phase, support sociotechnical process principles. However, the AH also

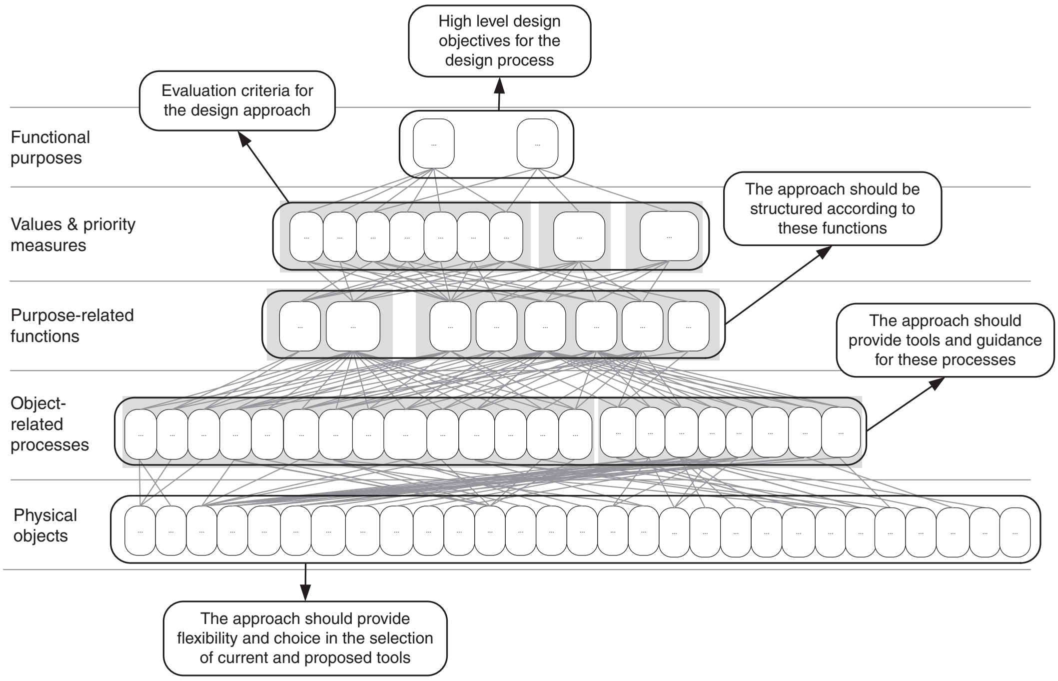

Figure 8. How the AH has informed the development of a design approach.

indicates that tools additional to those currently being used to design based on the application of CWA are required to fully support a comprehensive CWA-STS design approach.

Some care needs to be taken in interpreting the AH given that it is difficult to know to what extent the survey sample is representative of all CWA users and applications. In particular, it is unlikely that the survey captured all of the physical objects currently in use. Accordingly, it is acknowledged that other physical objects may be used by CWA practitioners when using the outputs of the analysis in design. The survey methodology was used to provide some evidence base for the analysis but it can neither account for the full complement of objects employed in real-world practice nor the full range of views regarding the prioritisation of desirable methodological attributes.

It is also worth noting that there are existing analytical processes used within the sociotechnical systems field, for example, soft systems methodology (Checkland 1981) and work system analysis and design phases (Kleiner 2006). The focus of this discussion has been upon what sociotechnical systems theory can provide to CWA to better enable use of CWA outputs to support sociotechnical systems design. CWA was chosen due to its uniquely formative, constraint-based approach (Vicente 1999; Naikar 2013), its current popularity with HFE practitioners and its reputation as a mature analytical framework which addresses system design issues (Lintern 2008). The focus on CWA was not intended to critique or ignore the contributions of existing analysis techniques. On the contrary, further work should consider these tools, techniques and methods and determine whether they offer benefits in addition to the standard tools of CWA. The use of multiple methods, provided they contribute to the overall aim of the process and are cost-effective to apply, should be encouraged and supported.

The sociotechnical systems approach has received criticism for a general lack of success in intervening in technological change and the design of new technologies (Clegg 2000; Badham, Clegg, and Wall 2006), due to a focus on social and organisational change. A CWA-STS design toolkit, in bringing together the fields of CWA and sociotechnical systems, can provide the means for joint optimisation of social and technical components. It also has the potential to facilitate expanding the application of sociotechnical principles to a broader range of complex systems within modern society, such as security, health-care provision and urban planning, as urged by Davis et al. (2014).

Further research will be required to evaluate the effectiveness of the toolkit against the evaluation criteria specified in this article. This should involve applications of the toolkit to real-world design problems along with both subjective and objective measures to evaluate both process and outcomes. An evaluation process will provide data regarding whether the toolkit is acceptable to practitioners, the barriers and enablers relevant to implementation of the approach (such as usability of the toolkit, time requirements, access to users and stakeholders) and should lead to on-going refinements and improvements to the toolkit. Further research should also investigate how practitioners trade off different value and priority measures, acknowledging that in real-world practice not all values can be considered equal. Practitioners will select tools that align with the values that are relevant to the scope of the design process and any project constraints such as time pressure, budget allocation and level of access to end users and subject matter experts. Potentially, such trade-offs could be explored through the application of the latter phases and tools of CWA such as decision ladders and strategies analysis.

It is proposed that future applications of CWA and sociotechnical systems theory in concert over time may lead to recommendations for improving the tools in the CWA framework or additions to the sociotechnical theory design principles. These advances are likely because sociotechnical systems theory thinking may change the way that CWA is undertaken or CWA thinking may change the way sociotechnical systems theory principles are interpreted and implemented. A more combined approach may also make the tools of CWA more attractive to sociotechnical systems theory practitioners, and may facilitate applications of CWA in combination with existing sociotechnical systems analysis processes. With design being a complex sociotechnical system, it will be interesting to monitor the effects of the explicit addition of sociotechnical systems theory to CWA practice.

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Appendix. Subset of survey questions used to inform the AH

Section 2: Your use of CWA in a specific design application

Did you use any specific approaches, methods, tools, techniques or guidance, in addition to CWA, during the design process *(for example, participatory design techniques, human factors design standards, etc)*?

☐ Yes
☐ No

What additional approaches, methods, tools, techniques or guidance were used and how were they used in the design process?

Section 3: Your use of CWA in design generally

What resources, processes, tasks and activities have you used in the past when designing with CWA? *(select all that apply)*

Abstraction hierarchy/Abstraction-decomposition space	☐
Contextual activity template	☐
Decision ladders	☐
Information flow maps	☐
Information flow diagrams	☐
SRK inventory	☐
Domain/subject matter expert input	☐
Project stakeholder input	☐
Iterative design methods	☐
Usability evaluation/user trials	☐
Prototyping	☐
Heuristic evaluation	☐
Participatory design	☐
Human factors standards/guidelines	☐
Semantic mapping	☐
Human error identification methods	☐
Task analysis methods	☐
Other/s, please specify:	☐

Section 4: Your views on additional approaches or methods

Imagine that an approach or method for assisting design following the application of CWA was being developed. Think about what attributes such an approach or method should possess. Rank the following attributes in order of importance, with 1 being the most important and 14 being the least important.

Rank	Attribute	Description
☐	Creative	Facilitates creativity and/or innovation
☐	Efficient	Process is efficient and/or cost effective
☐	Holistic	Supports coordinated design of all system elements (e.g. interfaces, training, support materials, team structures)
☐	Integrated	Can integrate with existing systems engineering processes
☐	Iterative	Facilitates an iterative design process
☐	Reliable	Produces consistent results each time it is applied
☐	Stakeholder involvement	Involves project stakeholders (e.g. designers, engineers, management) in the design process
☐	Structured	Provides structure to the design process
☐	Tailorable	Can be tailored for different system types (e.g. intentional, causal, first-of-a-kind)
☐	Theoretical	Is consistent with the underpinning theory and principles of CWA
☐	Traceable	Provides a detailed record of design decisions
☐	Usable	Is usable for CWA practitioners, systems designers, engineers, etc
☐	Valid	Does what it says it will do (e.g. produces effective designs)
☐	Worker/user involvement	Involves workers/end users in the design process

Can you think of any additional attributes, not listed in the previous question, that you think would be important for such an approach or method to have?

5.2 Discussion

The aim of this chapter was to explore the synergies and connections between CWA and the sociotechnical systems theory approach to define requirements for a new design approach. The explicit combination of CWA and sociotechnical systems theory has identified a series of design requirements and evaluation criteria for the new design approach. The use of the AH has also provided a means for identifying potential design tools that could be incorporated in the approach.

5.2.1 Methodological contribution and implications

From a methodological perspective, the analysis is the first to use CWA in a self-referential manner. The development of the AH required a comprehensive consideration of CWA and what it can provide to design in a way that supports the sociotechnical systems theory principles. Potentially, future research could employ the latter phases of CWA, based on appropriate data collection activities, to provide further insights.

The analysis has also demonstrated the utility of the AH for the development of evaluation criteria for the testing of a HFE method. This may be of benefit in future research.

5.2.2 A note about the ranking of methodological attributes

The ranking of the methodological attributes produced some interesting results which warrant further discussion. For example, the finding that CWA practitioners ranked worker / user involvement and stakeholder involvement relatively low was unexpected. This suggests that when trade-offs need to be made, due to time or resource constraints, it is the participatory or collaborative activities that are more likely to be abandoned. This would appear to be in conflict with the sociotechnical systems approach which places high importance on the participation of the actors within the system because “the analysis, preparation and implementation of a sociotechnical design… belongs to the members of the organization whose working lives are being designed” (Cherns, 1976, p. 791). Methods or guidance that would support CWA practitioners to efficiently collaborate with users and stakeholders could be beneficial to resolve this potential discordance between the approaches.

Another attribute that received a relatively low ranking, and thus was not included in the set of evaluation criteria, was reliability. Reliability and validity are seen as cornerstones of methodological evaluation in HFE to ensure the scientific robustness around their use (e.g. Annett, 2002; Shorrock & Kirwan, 2002; Stanton & Stevenage, 1998; Stanton & Young, 1999).

However, whether reliability and validity requirements are the same for different types of HFE methods is questionable. Annett (2002), for example, argues that the validity of evaluative methods (i.e. tests that aim to measure a parameter, such as workload or fatigue) should be distinguished from the validity standards required of analytical methods (i.e. those that aim to understand complex systems). For evaluative methods, reliability is achieved when results from independent samples agree. For analytic methods, reliability is achieved where data collection conforms to the underlying model of the method (Annett, 2002). A design approach is neither an evaluative nor analytical method. By its nature, it intends to promote creativity and innovation. Thus, not only would it be unlikely that high levels of reliability would be achieved amongst designs created by different groups, it would actually be undesirable.

The participants in the CWA practitioner survey may have considered the issues around measuring the reliability of a design approach when ranking this attribute, leading to it being ranked relatively low. However, given that validity, which incorporates a concern for reliability (Stanton & Young, 1999), was ranked in the top five weighted scores, there is a need for reliability to be addressed over time in some manner. In contrast to traditional reliability measures, it may be more desirable to adopt an evaluation criterion that the design approach produces reliably valid outcomes (i.e. that valid outcomes are achieved each time the approach is applied). This would require a body of evidence to be built up over a period of time, similar to the action research approach embraced by researchers in the sociotechnical systems theory field.

5.3 Conclusion

In conclusion, the use of the AH model provided clear design requirements to drive the development of the design approach. The requirements included the need to support system design in an integrated manner, the need to incorporate CWA outputs in design, to incorporate the sociotechnical systems theory design principles in design and to ensure that the designed system has the property of adaptive capacity. The requirements also included the need for guidance that supports all of the functions identified within the AH (e.g. design planning, requirements specification, concept design) as well as the need to ensure that the sociotechnical systems theory process principles and general system design processes are supported in design, as necessary. The final requirement was that the design approach should provide flexibility and choice in the design tools used in design.

In the following chapter, the process and considerations influencing the development of the CWA-DT will be described as well as how Version 1 of the toolkit addressed the requirements identified in this chapter. The theoretically linked evaluation criteria identified from the AH will be used to assess the effectiveness of the CWA-DT in its application to public transport ticketing (Chapter 7) and to RLX safety (Chapter 10).

6 Developing Version 1 of the CWA Design Toolkit

6.1 Introduction

Given the clear findings in Part One of this thesis reinforcing the need for guidance to support CWA practitioners to use the framework for design, the aim of this chapter is to describe the approach taken to develop the CWA-DT and to demonstrate how it meets the requirements identified in the previous chapter.

The final version of the CWA-DT is provided in the Appendix. That version incorporates amendments based on a proof of concept application and the full application to RLX design. The toolkit is intended for use by HFE professionals who may be either experienced CWA users interested in using the CWA-DT to assist them to use CWA within a design project, or those new to CWA but are interested in exploring a system-based approach to design. The focus of the CWA-DT is to provide assistance with design thinking and the application of the sociotechnical systems theory values and principles. It is not intended to replicate or to replace guidance for conducting CWA (e.g. Jenkins, Stanton, Salmon & Walker, 2009; Vicente, 1999) or guidance that have already been provided for EID (e.g. Burns & Hajdukiewicz, 2004). Further, the CWA-DT provides guidance focussed on a participatory design process, rather than the detail of getting to a particular design outcome. It is intended for those design processes that have a wider scope than interface design. However, as interface design is often a relevant aspect within the detailed design process, use of the CWA-DT can occur in conjunction with EID and users are referred to guidance for EID to assist this process.

In contrast to some other toolkits, the target user group for the CWA-DT is design teams rather than the intended users of the final design. However, the guidance is intended to be useful to a broad audience from CWA beginners to experts.

A range of activities were undertaken to inform the development of Version 1 of the toolkit. Firstly, the CWA literature was reviewed to gain an understanding of what different tools in the CWA framework provide to assist design with a wider scope and in further detail than the analysis of means-ends links described in the AH in the previous chapter. Secondly, the findings from this review were discussed in a workshop session with experienced CWA users and supplemented with additional aspects suggested by workshop participants. Finally, literature from the field of design and innovation was considered in relation to the key themes raised by CWA practitioners in the survey (outlined previously in Chapter 4).

6.2 What information do the CWA phases and tools provide?

To gain an in-depth understanding of the information and knowledge that analysts gain from each phase or tool used, a review of the CWA literature was undertaken. The result of this was a draft description of contributions to design for each CWA tool.

Following this, a half-day workshop was held with three colleagues (two PhD students and a senior researcher all with CWA experience) to identify additional uses of the CWA tools for design. Workshop participants were provided with descriptions of what was identified in the literature and asked to provide further information based on their experiences using the framework. Participants were prompted to think specifically about how each phase and tool could support design, and how it could support the design of different aspects of a sociotechnical system such as information displays, control / input devices, alarms, equipment / tools, function allocation, job / team design, training, procedures, workplace layout and environmental factors. The additional ideas generated were incorporated into the initial descriptions.

A further outcome of this workshop was a rough structure of a process for moving from the CWA outputs to a design concept. The process involved iterations from design ideas, stemming from the CWA findings, back to the CWA outputs to evaluate and refine the ideas and to assist with decisions about the detailed design.

The final descriptions of the key contributions of each CWA phase and tool to design, incorporating the workshop feedback and additional ideas, are discussed in the following sections.

6.2.1 Work domain analysis

The WDA phase, particularly the AH, provides a representation of the functional structure of the system (Vicente, 1999). By populating the levels of abstraction for the work domain in question, it is possible to identify the purpose/s of the system, the measures of system performance, the general functions performed within the system, the physical functions required to support the general functions and the physical objects that perform functions within the system. The means-ends links connecting nodes at adjacent levels identify 'what-how-why' relationships between nodes. Thus, the AH can provide information about what should be measured, what information should be derived (e.g. via sensors) and how information should be organised (e.g. in databases) (Vicente, 1999). Importantly, the WDA phase identifies the ecological constraints of the system and all of the physical objects in the work domain that actors have available to interact with or to manipulate. The representation can be reviewed to determine the level of redundancy and flexibility in the system (e.g. where multiple physical objects provide the same physical process for the same function). Further, being a formative analysis, it can be used to determine where there is functionality in the system that is not being exploited. For example, it may uncover a physical object that is present and able to perform a physical process but that is not currently used for that purpose. Finally, the AH provides a means for tracing the effect of new or proposed physical objects on the system, such as how they might support or hinder the functions and purposes of the system.

In comparison to the AH which shows the functional structure, the part-whole decomposition represents the physical structure of the system (Naikar, 2013; Vicente, 1999). It can provide an understanding of how complicated the system is through showing the number of sub-systems and components that it comprises. It also enables the analyst to break the system down into any part-whole relationship, even at the higher levels of abstraction.

The AH and the part-whole decomposition are combined to create the ADS (Vicente, 1999). In design, this could be done to ensure that the wider system is modelled, even where a sub-system only will be subject to re-design. This could assist with ensuring coherence between the wider system and the sub-system being designed. The ADS can also be used to determine how information should be organised in interfaces or in databases (Vicente, 1999; Burns & Hajdukiewicz, 2004).

6.2.2 Control task analysis

The ConTA phase of CWA models the activity within the work domain and requires the identification of what needs to be done for the system to achieve its purposes (Vicente, 1999). Two key tools used in the control task analysis phase are the CAT (Naikar, Moylan, & Pearce, 2006) and the decision ladder (Rasmussen, Pejtersen & Schmidt, 1990; Vicente, 1999).

The CAT identifies the goals that need to be pursued and the situational constraints on these goals. It identifies different situations (in relation to geographical locations, time, phase, etc.) in which control tasks may be performed. This could assist to ensure that the design takes account of different situations. Further, the situations identified in the CAT could be used as the basis for scenarios (Carroll, 2002) to be used within a design process. Importantly, the CAT identifies in which situations control tasks currently occur and where they could occur, given the constraints of the system. The identification of these situational constraints provides an opportunity to consider whether changes to these constraints could achieve design goals as demonstrated by Stanton and colleagues (2013).

The decision ladder representation identifies the information and relations relevant to different situations (Vicente, 1999). Specifically, it identifies the information processing activities and knowledge states relevant to decisions required to carry out control tasks. The decision ladder provides insight into how the requirement for a decision is activated (i.e. through alerts), what information, data and cues are available to actors, what systems states are possible, the consequences associated with various system states, the options for action available, what goals are used to determine the selection of target states and what tasks and procedures could be conducted to reach the target state. At each of these points the analyst can identify where improvements can be made. For example, could the design of alerts be improved? Is there likely to be information overload? Could information and cues in the environment be provided in a more salient manner? Are actors aware of the consequences of selecting an option?

While the generic decision ladder models novice decision making, through the identification of shortcuts (leaps and shunts), expert decision making can be modelled. This supports design for experts through promoting skill-based and rule-based behaviour.

With the information provided by the decision ladder it is also possible to map relationships between system states, options and information and cues (Jenkins et al, 2010). It is also possible to map the location of information elements in the world (e.g. external environment, internal environment, documentation) (Jenkins, Stanton, Salmon, Walker & Rafferty, 2010). This type of approach may lead to insights about where the information might best be presented.

6.2.3 Strategies analysis

The most commonly used tool in the StrA phase is the information flow diagram. This provides the analyst with knowledge about the various ways in which control tasks can be carried out, and the order in which tasks are performed (Vicente, 1999). It is possible to differentiate between those strategies currently in use and strategies that could potentially be used. Information flow charts enable the analyst to consider the amount of behavioural flexibility possible within the existing system constraints. That is, the number of ways by which a desired end state can be achieved. The analyst could review the strategies and identify positive or optimal strategies and design to support these, while also designing to constrain strategies seen as undesirable. The analyst could also identify new strategies, which might require changes to the existing constraints. Within a design process, an analyst could use the flow charts as a form of evaluation, to consider how different objects or design configurations influence the strategies. Further, information flow charts could be combined with other methods such as hierarchical task analysis to further interrogate the desirable strategies as part of a design process.

The SAD (Cornelissen, Salmon, Jenkins & Lenné, 2013) is another tool that has been proposed for the StrA phase. It enables the analyst to formatively identify all of the possible strategies for the performance of control tasks by using verbs as prompts to apply to the physical objects in the WDA. This provides an understanding of which strategies are available for each physical object or object-related process. The SAD also identifies contextual factors (called criteria) which may lead to some strategies being chosen over others, providing additional insight into factors that influence the selection between strategies. The SAD further enables the analyst to consider the influence of different levels of the AH on strategies (e.g. how different values and priority measures affect the selection of strategies).

Similarly to information flow charts, the SAD could also be used in an evaluative sense. For example, enabling the analyst to model the impact on a strategy or strategies where a particular physical object is not available. Additionally, the analyst could trace the influence of proposed physical objects or design configurations on strategies. Finally, both information flow charts and the SAD enable the identification of errors associated with each strategy identified.

6.2.4 Social organisation and cooperation analysis

The fourth phase of CWA, SOCA, considers the communication and coordination requirements of the different actors in the system. Naikar (2006b) notes that this phase is not about determining an optimal allocation of work / tasks or organisational structure for the system, but acknowledging that flexible structures are required to enable adaption to unexpected events or demands. Criteria for the allocation or dynamic allocation of tasks across actors include actor competency, actor access to information, facilitating the communication required for coordination, workload, safety and reliability and regulatory compliance (i.e. where rules or regulations require a specific actor be responsible for a task) (Vicente, 1999).

This phase uses the tools from the latter three phases of CWA. When used for SOCA, the AH or ADS can be employed to represent which the actors (human or technical) use the physical objects or are involved in the achievement of the object-related processes and purpose-related functions (e.g. Jenkins, Stanton, Salmon & Walker, 2009).

The CAT, when used in the SOCA phase, identifies which actors can carry out control tasks in which situations, given the constraints of the system. This can highlight for each actor, how many control tasks they engage in for a given situation (providing an indication of workload or work demands, potentially with further analysis) which could be used to provide insights and solutions regarding different distributions of work demands across actors (Naikar, Pearce, Drumm & Sanderson, 2003). The representation could also be used to determine where tasks are in conflict or are clustered, resulting in a need to re-design task flow and task distribution. The SOCA-CAT can also prompt the analyst to consider whether tasks could be performed by different actors given changes to the existing system constraints.

When decision ladders are used in the SOCA phase, the system actors can be overlayed onto the ladder to show how they contribute to decision making in relation to control tasks (e.g. Jenkins, Stanton, Walker, Salmon & Young, 2008). It assists to determine how actors should communicate with one another (Vicente, 1999) and can identify responsibilities for handover activities or for sharing information with other actors (e.g. where only one actor receives the information but others require it). This could prompt design ideas around team design, physical workplace design and design of communication systems. Finally, when viewed side-by-side with the WDA, the decision ladder used for SOCA can be utilised to evaluate how information requirements are supported in the system.

In relation to StrA, when used for SOCA, the information flow chart assists to determine the responsibilities of the various actors in the system (Vicente, 1999). It shows the strategies that can be used by each actor, how strategies differ for different actors and how actors can coordinate to achieve a strategy (e.g. how humans and technology can work together to achieve a task). It can assist to understand the level of redundancy and flexibility in terms of task allocation (i.e. whether multiple actors are performing the same or overlapping tasks). It can also be used to determine which actor or actors are responsible for critical strategies or tasks. It may further be possible to connect strategies for particular actors to gain an understanding of work flows. Finally, it provides a basis for identifying potential errors that could be made by different actors for each strategy.

The SAD can also be used in the SOCA phase to identify what strategies can be used by each actor, how strategies differ for different actors and what strategies different actors use under different contextual conditions. It can also detect the interactivity and potential for conflict arising from strategies adopted by different actors and which actors have more strategies to choose from with associated implications for workload, complexity of tasks, etc. Further, due to the link to the AH, it can demonstrate how actors use different work domains objects differently and whether values and priority measures are different across different actors.

6.2.5 Worker competencies analysis

The final phase of analysis, WCA, assists the analyst to understand the skill, rule and knowledge-based competencies required by human actors operating in the system (Vicente, 1999). The SRK taxonomy (Rasmussen, 1983), enables the analyst to map, for each critical strategy, how the system supports each level of information processing. In the SRK model, skill-based behaviour is associated with sensory-motor performance which occurs in skilled activity without conscious control being required. Rule-based behaviour refers to the application of stored rules, based on past experience, to determine behaviour. Finally, knowledge-based behaviour is engaged in unfamiliar situations where it is not possible to draw upon past experience and the actor must engage in reasoning to understand the situation and select an appropriate course of action.

The SRK taxonomy provides design principles for EID which support the goal to avoid forcing cognitive control at a higher level than that required by the demands of the task, while also providing appropriate support for all SRK levels. Design principles for EID include (Vicente, 1999):

- Enabling direct manipulation of the interface (supporting skill-based behaviour).
- Providing consistent one-to-one mapping between the constraints of the work domain and the cues or signs provided by the interface (supporting rule-based behaviour).
- Representing the work domain as a hierarchy of abstraction to provide a faithful model of the work domain (supporting knowledge-based behaviour).

An additional tool that has been proposed for the WCA phase is the SRK inventory (Kilgore & St-Cyr, 2006). This can assist design by identifying how behaviour at each SRK level can be supported in relation to the information processing steps and resulting knowledge states identified in decision ladder analyses given particular situations. Further, the SRK inventory can be used to ensure that for each strategy, the system supports knowledge-based behaviour required in abnormal or emergency situations.

6.2.6 Conclusion

It is evident from the above discussion that the tools and phases of CWA have many and varied opportunities to contribute findings and insights for design. The knowledge gained from the review of the CWA literature formed a basis for the guidance provided with the CWA-DT as well as informing the development of some of the tools developed for the toolkit. The CWA-DT will be introduced and described in this chapter, subsequent to the following discussion of the various approaches to design in HFE and related disciplines, which informed the design process adopted for the CWA-DT.

6.3 Approaches to design

6.3.1 Human-centred and participatory design

Broadly, HFE design approaches subscribe to the human-centred design philosophy. Human-centred design (also known as user-centred design but arguably having a slightly broader remit) focusses design activity on understanding the needs and preferences of users, as well as their limitations, and designing to suit these. HFE knowledge and methods can be used in human-centred design approaches to uncover and understand user needs, capabilities and limitations. The international standard on user-centred design for computer-based interaction systems (ISO, 2010) incorporates the following principles (which can also be usefully applied beyond computer-based systems):

- The design is based on an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centred evaluation.
- The design process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

The ISO standard also defines a process for design. This process begins with planning the design process, followed by understanding and specifying the context of use and user requirements, producing design solutions that meet the requirements and evaluating the designs against the user requirements. The process concludes when a solution has been created that meets the user requirements.

Both CWA and the sociotechnical systems theory perspective might be considered human-centred approaches as they place humans at the centre of the design process. However, they represent an enhanced approach to the type of human-centred design processes envisaged by the ISO standard. Specifically, they explicitly take a systems perspective, not referring to users (which may narrow the remit of design) but instead considering all actors (both human and technical) and the interactions between them. Further, sociotechnical systems theory encourages more than consideration of users and stakeholders, or even their involvement. It requires decision making authority around design be bestowed upon users and stakeholders and their ownership of the outcomes of the design process (Clegg, 2000).

The principles articulated in the ISO standard, however, clearly demonstrates that a number of the sociotechnical process principles have pervaded modern design practice. For example, the principles of iteration, of the whole user experience and of multidisciplinary participation in the design process are strongly aligned with the sociotechnical systems theory perspective. Given the complementary nature of the design process set out in the ISO standard with the sociotechnical systems theory approach and its international standing, the process described in the standard was adopted as an initial starting point for developing the CWA-DT.

Another consideration for the development of the CWA-DT was the different approaches taken within the human-centred design paradigm. Eason (1991) discusses the knowledge-into-use approach where users constitute sources of data for design and may be involved as participants in requirements gathering activities and user-testing of prototypes. It has been noted that in many human-centred design processes the user is spoken for by the researcher who collects and synthesises their data (Sanders, 2002). Eason (1991) contrasts this with the user participation approach, where the user is the client and has decision making power in the design process. He explains that proponents of the former approach argue that users may not be the best judge of their needs and require experts to make design decisions for them. Supporters of the user participation approach, on the other hand, argue that it is for users to determine how values and objectives are traded-off in design. This is important as it is they who retain ongoing ownership of the system, while designers will move on to other systems.

Clearly, the sociotechnical systems theory approach is strongly associated with the user participation approach. In fact, participatory design stems from the sociotechnical tradition with the Tavistock researchers having been invited to be involved in the Norwegian Industrial Democracy project in the 1960s (Trist, 1981). Following successful case studies in Scandinavia, participatory design methods and approaches have been adopted for a range of design purposes. The movement continues to gain momentum as users are no longer willing to accept what is designed for them and are beginning to demand co-creation (Sanders, 2002). Participatory design and co-creation is about designing with people, rather than designing for people. Further, it is expected that in the future people will design for themselves. The participative approach, at least that practiced in the Scandinavian tradition, is strongly values driven and views the benefit of user involvement as stemming from three motivations (Gregory, 2003):

- Applying the knowledge of users to create better designs.
- Taking users on the design journey so they have a better understanding of reasons for decisions and will be less resistant to change.
- Respecting the rights of users / workers to have a say in decisions that will affect their work (the workplace democracy aspect).

An interesting consideration is the extent to which CWA aligns with participatory design. Few of the studies reviewed in Chapter 3 referenced the use of a participatory design approach (cf. Jansson, Olsson & Erlandsson, 2006). In fact, as noted previously, Vicente (1999) criticises participatory design processes on the basis that they represent descriptive approaches to work analysis which are unable to explore new possibilities for how work is undertaken. Further, he observes that users may have different, and incomplete or incorrect mental models of complex systems and therefore their views should not form the basis of design. Instead, the aim of CWA is to provide operators with information about the true functioning of the system to support them in problem solving (Vicente, 1999). While such criticisms may be valid, there is a case for arguing that participatory design could be beneficially applied in conjunction with CWA. For example, researchers could work collaboratively with system users and stakeholders to uncover the constraints of the system, and to then develop and refine design solutions based on an agreed, objective understanding of how the system functions. This type of approach could exploit the best aspects of both CWA and participatory design.

6.3.2 Design thinking

An approach that is increasingly being employed within the human-centred design paradigm is design thinking. This approach involves the application of design processes and skills to promote innovation within organisations. It aims to assist non-designers to think like professional designers and to focus on the needs on the users of the product, service, system being designed (Brown, 2008). Design thinking is proposed not as a method, but rather a way of making design accessible to non-professional designers. Edward De Bono introduced the term lateral thinking to clarify that one did not need to be a 'creative' person to generate novel and useful designs (De Bono, 1992). A pioneer in bringing concepts of creativity to business environments, De Bono emphasises the importance of using methods and tools to encourage lateral thinking, rather than usual, logical thinking, when attempting to solve problems.

IDEO's Human-Centred Design Toolkit (2009) takes a design thinking approach by providing guidance on design for non-government organisations working with communities in developing countries. It provides a simple process moving from 'hear', to 'create', to 'deliver', with techniques and methods that can be used by design teams to progress through each stage of that process. A key part of the hear stage is the development of empathy with users to better understand their needs.

Another design thinking publication by Liedtka and Ogilvie (2010) provides a process for use in business settings. This approach encompasses ten tools and methods structured into four questions. This follows a standard design process that begins with the existing situation (what is?), then diverges to generate a wide range of new ideas (what if?), subsequently converging to refine a selection of these ideas (what wows?) and finally, evaluating and refining the ideas further ready to test them in the market (what works?).

The Design with Intent Toolkit was created to provide design patterns that can be used in design for behaviour change (Lockton, Harrison & Stanton, 2010a). The toolkit provides cards based on eight different lenses or perspectives on design, both environmental and cognitive. The toolkit provides information about each lens and guidance on how the cards can be used to generate design ideas. Novel uses of the cards are also encouraged.

The design thinking approaches discussed above are consistent with the co-creation approach to design and their form as toolkits or 'how-to' guides was part of the inspiration for a toolkit approach to the CWA-DT.

6.3.3 Toolkit approaches to design

As noted above, toolkit approaches are a relatively popular approach in human-centred design. In addition to those described above, toolkits available include the Inclusive Design Toolkit (University of Cambridge, 2013), the Service Design Toolkit (Namahn & Design Flanders, 2014) and the Behavioural Insights Toolkit (Social Research and Evaluation Division of the Department for Transport, 2011). Further, toolkit approaches have been recommended for other areas of HFE such as error prediction (Kirwan, 1992) situation awareness (Salmon, Stanton, Walker & Green, 2006) and teamwork (Stanton, Salmon, Rafferty, Walker, Baber & Jenkins, 2013).

Specifically, a toolkit approach was considered appropriate for the CWA-DT due to the wide range of design purposes and application domains within which CWA-based design might occur. It is also consistent with the form of CWA as a framework rather than a structured methodology and with the requirement to provide flexibility and choice for designers (as identified in Chapter 5). Although there are a number of design toolkits in publication, no formal toolkits were identified as being developed for CWA, or for sociotechnical systems design.

Toolkits provide a structured, usable resource to support those undertaking a design project to gain an understanding of the theoretical underpinnings of an approach, and to plan, scope and execute their project. Toolkits generally provide information about the overall approach, a proposed process (which may vary from highly structured to unstructured / iterative), and guidance on tools, methods and techniques that can be used in various circumstances. They vary in the extent to which they provide templates or materials for use with users. Most are intended to support designers (professional or non-professional) to facilitate activities with users, as is the case with the CWA-DT, however some are intended for direct use by users themselves (e.g. Sanders, 2001; Von Hippel & Katz, 2002).

6.4 Themes from the survey of CWA practitioners

Having reviewed the design literature as relevant to the development of the CWA-DT, the following discussion turns to consideration of each of the themes raised in the survey of CWA practitioners relating to design, initially described in Chapter 4. These themes were collaboration, design skills and knowledge, insights, creativity and iteration across analysis, design and evaluation. Each theme will be examined in relation to its relevance to design and how it has influenced the development of the CWA-DT.

6.4.1 Collaboration

Some respondents to the CWA practitioner survey remarked that when designing on the basis of CWA outputs they work in a collaborative manner with users, suggesting that CWA practice may have evolved beyond what was envisaged by Vicente (1999) at the time of publishing his influential book on CWA. Respondents also discussed the need for analysts to collaborate with designers or system developers. Such responses reflected the difficulty in handing over analysis findings, insights and requirements to designers who were not involved in the initial CWA work.

To meet the principles of sociotechnical systems theory, and to further extend the use of CWA within participatory and collaborative design approaches, the CWA-DT recommends the involvement of users, SMEs (e.g. HFE professionals, designers, engineers, etc.) and system stakeholders (e.g. managers, union representatives, etc.) in design. Where possible, as many groups as possible should also be involved in the analysis process to gain the tacit knowledge that is generated through this activity.

6.4.2 Design skills and knowledge

Related to the need for collaboration were views and comments on the need for design skills and knowledge for a successful design process. For example, the concept maps shown in Chapter 4 included propositions such as ‘design is a skilled profession’, ‘design is for designers’ and ‘designers contribute design skills’.

Two of the CWA survey participants specifically raised the need for design thinking to move from the CWA analysis to design. They stated:

> *“Design thinking", typically an action-on-reflection process… This is much more time efficient and has a stronger "product focus"… I always use this approach in both industrial and scientific designs.* (Participant with 2 years’ experience using CWA, self-rated as a competent CWA user).
>
> *… there is very little advice on how the CWA outputs are transformed into design. We had experts and clever people, but there isn't really any procedure that one can go through to get from, e.g. the AH and the CAT, to a fully designed interface. You still need good design thinking!* (Competent user with 2 years’ experience).

Implicit in some of the statements was the knowledge-into-use perspective described by Eason (1991). That is, that design should be done by professional designers. The CWA-DT subscribes more to a participatory approach, but it does encourage the research team to collaborate with professional designers as much as possible, given their distinct knowledge and skills that would obviously benefit the process.

6.4.3 Insights

Another of the tensions or trade-offs arising in the literature and the survey responses was between a highly structured process (e.g. the analytic mapping of analysis findings to design requirements and features of the final design) and a more open, creative process of design, inspired by the findings of the analysis. The importance of traceability and structure have been emphasised in the literature (e.g. Elm, Gualtieri, Tittle, Potter & McKenna, 2008; Kilgore, St-Cyr & Jamieson, 2008) and it may be that this is appropriate for some design purposes, such as for well-defined interface design projects. However, the survey results showed that CWA practitioners desired both creativity and structure in a design process.

In addition, having structure does not necessarily mean that the information gained from CWA outputs must be systematically mapped to aspects of the outcome of the design process. In fact, CWA itself can be conceptualised as less an analytical tool and more a way of thinking about a system from the perspective of constraints and degrees of freedom. Rasmussen and colleagues (1994) offer this view, concluding, following a review of design processes, that:

> *It is clear… that the design process is neither a well-ordered progression from a problem formulation to the implementation of a solution, nor is it a conscious, rationally planned process*. (p. 169).

A number of respondents to the survey emphasised the use of CWA outputs as thinking tools. Moreover, they emphasised the strength of CWA as being the learnings and insight gained by being involved in the analysis process, rather than the specific outputs of the phases:

> *The biggest challenge is remembering that this analysis is the means to an end - that is, it isn't about creating the models, it is about developing a deep and appropriate understanding of the system to be controlled. Too often people get caught up in drawing the boxes, or filling out the templates, but aren't really thinking about why they are doing it, or what they are learning*. (Expert user with 20 years' experience).

> *If you get sucked into filling in all of the links and ensuring that your language is right everywhere then you'll never be able to exploit your design insight. If the insight is what you are looking for, then it is okay to stop the analysis when you're confident that you have that insight*. (Expert user with 16 years' experience).

> *The framework provides a structure for seeking and identifying information relevant to design. It is not the truth, it is just a useful way for analysts to gather and store information… Design is a creative process that is based on information… CWA can help to organise that information, but it does not substitute for the creative design process*. (Competent user with 5 years' experience).

Further, a number of survey respondents specifically noted that the design process was not a direct mapping from analysis to design. Rather, design was informed indirectly by the analysis, through the offering of insights:

> *… you can't get from any model of work or behaviour directly to a design; you just have to accept that the process of doing the model work will indirectly inform the design*. (Proficient user with 2.5 years' experience).

> *CWA offers some unique and brilliant insights that have proven very useful. At the same time it is a framework that is impossible to "implement" as a well-defined, confident, traceable practice.* (Proficient user with 15 years' experience).

> *I believe that design is largely insight… CWA is effective at generating insight because it forces the analyst to look at a problem from many (careful [sic] orchestrated) perspectives. Somewhere along the way you learn what the most profitable perspectives are and run with the insight from those*. (Expert user with 16 years' experience).

The use of the term 'insight' is also observed in the CWA literature. For example, Vicente (1999) states "… we can try to discover new possibilities for design by determining what options are feasible and useful, given the insights gained from the work analysis" (p. 125).

Insight is a core part of the creative process and it is consistent with the notion that CWA does not produce a list of requirements as some other HFE methods might do, but instead provides a unique conceptual lens that can be used to understand the functioning of a complex system in a range of ways that differ from other analysis approaches. Accordingly, the notion of insight was adopted in the CWA-DT as the key connection between the analysis process and outputs, and the resulting design ideas. The manner in which insights are used within the CWA-DT is similar to the notion of 'design seeds' proposed by Chalmers and Lamoureux (2005), although insights are used at an earlier point in the design process. Insights enable a level of structure to be achieved within the design process through the way in which insights are systematically identified, documented and used in the design process. This further ensures that the creative benefits of insights are not lost or overlooked over the design process which may extent over a period of time.

6.4.4 Creativity

In a similar vein to insight, creativity is integral to design and innovation processes. The requirement for creativity in designing on the basis of CWA has been emphasised by Rasmussen and colleagues (1990) who stated:

> *Design is a creative process which cannot be controlled by formal procedures. New ideas and concepts emerging during design have an intuitive basis, and conscious*

> *thought largely is used for evaluation and rationalization of the emerging design. For this evaluative analysis, the present framework is well suited serving systematically and explicitly to bring to the mind of a designer the various relationships influencing the match between work requirements and agent resources* (p. 135).

Creativity is a multifaceted concept which has been said to comprise of at least four main components. These are the creative process, the creative product, the creative person and the creative situation (MacKinnon, 1970).

Process

The creative process has previously been defined as "the forming of associative elements into new combinations which either meet specified requirements or are in some way useful" (Mednick, 1962, p. 221). Or as Steve Jobs is oft-quoted as saying, "creativity is just connecting things" (Henriksen, Mishra & the Deep-Play Research Group, 2014, p. 15). This associative approach to creativity underlies many of the exercises and design tools within the CWA-DT. For example, materials such as inspiration cards (e.g. Brandt & Messerter, 2004; Halskov & Dalsgård, 2006; IDEO, 2003; Lockton, Harrison & Stanton, 2013) can be particularly useful to prompt associations not previously considered. Further, the use of such tangible materials in a design situation is beneficial given the conceptualisation of design as a reflective conversation with design materials (Schön, 1992). This conceptualisation proposes that designers' knowledge is tacit and they design by doing, through the sensory appreciation of actual or virtual worlds and using the physical and tactile to make adjustments and refinements to the evolving design over time.

A further process consideration relates to the previous remarks regarding structure (see section 6.4.3). While initially the need for creativity may appear to conflict with the need for structure, research has indicated that creativity is enhanced by constraints or conditions of scarcity, rather than hindered by them (Snowden & Boone, 2007). Thus, placing constraints on the design process (such as a short time frame or limited budget) may actually increase creativity. Such strategies are applied within some of the CWA-DT design tools.

Product

The creative product is the end-goal of the CWA-DT. According to Shah and colleagues (2003), the success of creative processes can be measured based on an evaluation of what the process generates. Specifically, success can be judged by taking into account the novelty of ideas generated (i.e. how unusual or unexpected the ideas are), the variety of ideas (i.e. how well the ideas are spread across the problem space), the quantity of ideas and the quality of ideas.

The concepts of quality and usefulness are also present in the innovation literature. Creative products can be considered innovations, which can be described as the introduction of something new, or some change to an existing system, that has unique benefits or significant positive effects. It is important to consider innovation, in addition to creativity, as sociotechnical systems theory came about to improve the way in which innovations are designed and implemented within organisations. Creativity is an integral part of innovation (e.g. Valgeirsdottir, Onarheim, & Gabrielsen, 2014), but innovation also requires other practical support such as financial resources and organisational sponsorship (Sethi, Smith & Park, 2001). Further, in addition to the creative process (involving divergent thinking), innovation requires evaluation, refinement and selection processes (where the design space converges to focus on a shortlist, or single concept to move towards implementation). The CWA-DT uses the term ‘design’ as a synonym for ‘innovation’ and adopts this divergence-convergence notion through early idea generation processes followed by shortlisting and decisions that narrow the design space until a final design is produced.

Person

While the person is included in MacKinnon’s (1970) four aspects of creativity, it is clear from the design thinking movement that creativity is no longer considered the domain of the creative individual. Design thinking and related approaches are based on the notion that all people naturally engage in generative thinking and are therefore capable of creativity (De Bono, 1992; Epstein, 1996). However, there may be some attributes that make people better suited to design activities than others. Tim Brown from IDEO (2008) suggests that a good design thinkers have the following attributes:

- Empathy: the ability to see problems from multiple perspectives.
- Integrative thinking: the ability to go beyond selecting between current options to instead create novel solutions that surpass and dramatically improve on existing alternatives.
- Optimism: the belief that a new and better option than the existing is possible.
- Experimentalism: the ability to be explorative in investigating the functioning of the existing system and exploring constraints in creative ways that proceed in new directions.

- Collaboration: the ability to work in an interdisciplinary manner, preferably having varied qualifications or experience across multiple disciplines (such as being both a psychologist and designer, or engineer and urban planner).

These attributes are not innate and could be learned through experience or training, supporting the notion that any individual can produce creative products. Further, the environment or situation within which people engage in creativity activities can also influence their performance.

Situation

When engaging in design, people are influenced by situational factors including the physical and social environment. Research has found that certain aspects of the physical environment such as natural light, a connection with the natural environment (i.e. a view onto a garden), bright colours, and the availability of diverse stimuli to promote associative thinking can all enhance creativity (Imber, 2009). Further, tangible materials such as inspiration cards or modelling tools such as LEGO, can provide a means of engaging participants and encouraging their physical, rather than only cognitive, involvement in the design process.

In relation to the social environment, evidence has shown that individual performance is superior to group performance in idea generation. For example, studies have shown that groups generate significantly less ideas than the same amount of individuals working in isolation (e.g. Larey & Paulus, 1999). That is, the whole group fails to perform better than the sum of its members. This is suggested to occur because of social processes including groupthink, conformity and the tendency towards consensus (e.g. Nemeth & Nemeth-Brown, 2003).

Although there may be drawbacks of a group approach for creativity, it was important for the CWA-DT to retain a focus on group-based activities because of benefits such as the opportunity for participants to learn from one another and understand one another's perspectives, to engage in political debate, and to ensure transparency of the design process. These benefits are particularly important from a sociotechnical systems theory perspective. Furthermore, there is an argument that dialogue with others enables people to reveal and explore their own paradigms, mental models and assumptions which may otherwise act to block creativity. Dialogue is different to discussion or argument in that it is not about convincing others that one's own position is correct, but of genuinely listening to and learning from others to create synergy. This enables ideas to emerge from the interactions between people that would not have been produced by the individuals working alone (Gurteen, 1998).

The trade-off between the social influences that restrict creativity in groups and the benefits of group processes for design is addressed within the CWA-DT. While a decision was made to embrace group processes with a workshop approach to engagement with users and stakeholders envisaged for design, strategies are in place to minimise the negative effects on creativity. For example, brainstorming tools recommend the use of strategies such as individual brainstorming prior to group brainstorming (similar to the nominal group technique originally proposed by Delbecq & Van de Ven, 1971). Further, a number of tools involve the encouragement of debate and dissent. Dissent is a key strategy for combating conformity and group think (Nemeth & Nemeth-Brown, 2003). One of the ways in which dissent is encouraged within the CWA-DT is through the 'assumption crushing' exercise which asks participants to take commonly accepted assumptions underlying the existing design and to turn them on their head. This sets up a social environment that not only accepts dissent and alternative thinking but encourages it.

6.4.5 Iteration across analysis, design and evaluation

The importance of iteration in design is well recognised. Methods from the cognitive systems engineering field, including CWA, are generally intended to facilitate ongoing re-evaluation and re-consideration of the problem being investigated as new information arises, or as the analyst progressively builds their understanding of the system (Militello, Dominguez, Lintern & Klein, 2010). The need for iteration is also evident for task analysis methods (e.g. Stanton, 2006). Within design, iteration enables the re-framing of the design problem itself as well as the design solutions being explored. Iteration is required because of the complexity of the domains being analysed and in recognition of the systemic nature of design (Clegg, 2000). Vicente (1999) notes that the distinction between the terms analysis and design is an artificial one, and that in practice these processes are interrelated and mutually informing.

Participants in the CWA practitioner survey suggested that a benefit of utilising the CWA outputs within a design process is the ability to evaluate design ideas using the outputs, to gain an understanding of the impact of proposed changes on the system. This could provide assistance for selecting or shortlisting those design solutions that could provide the most benefit, and could also assist in the process of refining design ideas. The process adopted for the CWA-DT encourages iteration both from within and between analysis, design and evaluation activities. The notion of using the CWA outputs for evaluation is an important aspect of this process. An overview of the CWA-DT, incorporating these processes is provided in the following section.

6.5 Version 1 content

Influenced by the approaches and literature discussed in Section 6.3 (i.e. human-centred and participatory design, design thinking and toolkit approaches to design), Version 1 of the toolkit was developed to meet the design requirements identified in Chapter 5. A diagram showing the process and the tools developed is presented in Figure 6.1. The CWA-DT encompasses the functions required for CWA-based design, being analysis planning, the analysis process, requirements specification, design planning, concept design, high level evaluation and design concept/s selection, detailed design, formal evaluation and design refinement, implementation and testing and verification.

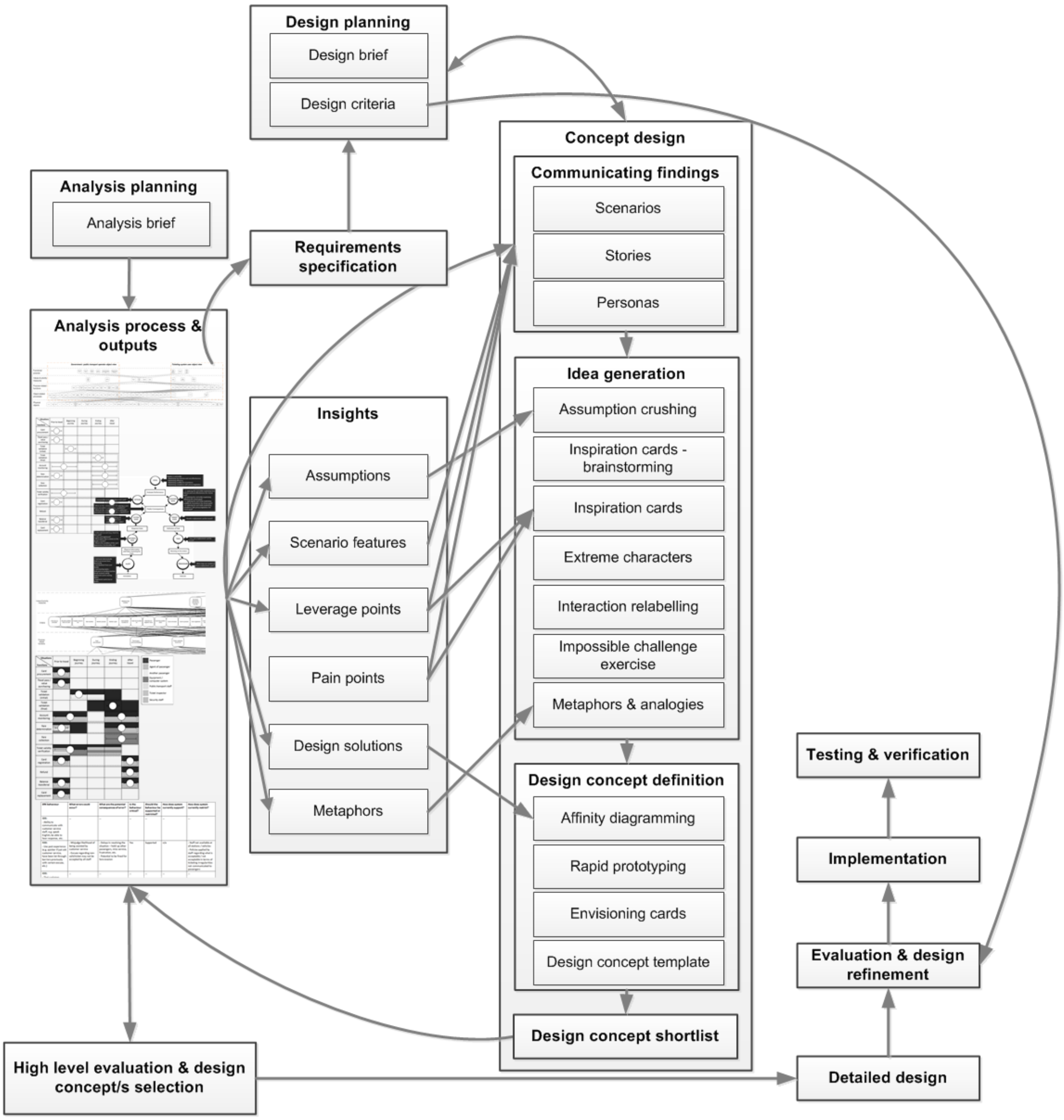

Figure 6.1. Overview of the CWA-DT process and tools.

Figure 6.1 intends to convey, through the use of arrows, how information from one function or tool is, or can be, used to inform other steps in the design process. For example, insights about scenario features can be used in the development of scenarios. Further, it should be noted that the process flow is not necessarily linear, and that iteration back and forth is expected and encouraged. An example of where this may occur is illustrated by a double-headed arrow between the Design planning and Concept design functions indicating that during the concept design process, the scope of the design or the design requirements may be reviewed and amended in light of the explorations occurring with the use of the design tools.

Within each of the functions in Figure 6.1, a number of tools and templates are provided. A description of each component (function, tool and template) of the CWA-DT is provided in Table 6.1. Again, it is emphasised that it is not envisaged that users of the toolkit would necessarily go through all stages nor utilise all tools, rather, they would select that which is most useful based on the scope of their design work. However, the key aspects of the toolkit that are recommended for any application are the use of the Analysis brief, the application of CWA (at minimum the WDA phase), the use of the Design brief and Design criteria documentation, as well as at least one tool to communicate the findings of the research, to generate design ideas and to define design concepts.

Table 6.1. Components of the CWA-DT (Version 1).

Steps & tools	Description
1. Analysis planning	Guidance for planning the analysis process is provided in the CWA-DT to assist research teams to consider the scope of the analysis and how it will be resourced.
Analysis brief	The key document for the analysis planning stage is the analysis brief, adapted from Liedtka & Ogilvie (2010), to suit CWA projects. The analysis brief prompts the research team to consider the issue or need that has motivated the work, the end deliverable or product expected from the entire process, stakeholders and target users, research settings and situations, the project dependencies and constraints, and, importantly the CWA phases that are likely to be of most benefit.
2. Analysis process	While the CWA-DT provides some guidance to assist the analysis process, it does not intend to replace authoritative texts on CWA (e.g.Jenkins, Stanton, Salmon & Walker, 2009; Naikar, 2013; Vicente, 1999). Instead, it refers readers to such guidance available for completing the analysis phases. It does provide some guidance on particular aspects of CWA that are not as commonly found in the literature, such as stakeholder object worlds (Rasmussen, Pejtersen & Schmidt, 1990; Naikar, 2013) as this analysis can provide an understanding of stakeholders which is useful in planning the design process.
Insights	Guidance and templates for recording insights derived by the analysts is provided. Insights in this context include both non-obvious inferences from the evidence provided in the analysis (Klein & Jarosz, 2011), as well as more obvious findings about the system that the analyst considers important for the design process. The insights template prompts the analyst to provide a description of the insight identified and how it was identified (i.e. which phase of CWA was being undertaken and the thought process surrounding the insight development). This enables an explicit linking between the analysis, the insight, and any proposed design subsequently stemming from the insight. When documented, insights are categorised into assumptions, leverage points, metaphors, scenario features or design solutions.
3. Requirements specification	A template to assist the identification of high level design requirements from the WDA phase is provided.
4. Design planning	Planning for the design stage, once the team has gained what they require from the analysis stage, is important for ensuring that the project is adequately resourced and that contingencies have been considered. It also assists to ensure that an appropriate design process is adopted.
Design brief	A design brief (adapted from Liedtka & Ogilvie, 2010), is developed to drive the design process. This document defines the scope of the design process (which may have changed due to findings of the analysis), project planning for the design process, as well as the key goals of the design process. These key goals relate to the design requirements derived during the requirements specification process. It is encouraged that the values and principles underpinning sociotechnical systems theory are also incorporated into the design brief as part of the process of achieving agreed values and purposes amongst those involved in design.
Design criteria	The design criteria template prompts the team to consider the criteria that will be used to determine whether or not the outcomes of the process adequately meet the design requirements. The criteria can be based on the values and priority measures of the WDA or can be drawn from other sources.
5. Concept design	The CWA-DT places considerable focus on the creative process of concept design. Tools are provided to assist users to communicate the findings of CWA, to generate novel designs (encouraging divergent thinking) and to define design concepts (through convergent thinking).
Scenarios	Scenarios are narratives describing use situations relevant to the design process. They are used in the CWA-DT to enable information discovered in the analysis to be communicated efficiently and effectively to design participants (Carroll, 2002). They can promote understanding of user goals, experiences and challenges to prompt design solution ideas and to evaluate proposed designs by considering how the scenario might be different if that design was implemented. The analysis can provide many inputs to scenarios, including user goals, the presence of conflicting goals, different types of situations and circumstances, different strategies that can be employed and the different competencies of users.

Stories	Stories are different to scenarios in that they are real-life cases describing people's interactions within the system that can be used to demonstrate a particular finding or perspective that is illustrative to discuss. Stories can be used for communicating information uncovered during the analysis in a concrete, specific way (Erickson, 1995). They can also assist to promote empathy with users or other stakeholders within the system.
Personas	Personas are descriptions of people (real or fictional) within the system. They provide information about the person's particular circumstances, capabilities and limitations, motivations, values, etc. to develop empathy with various users and stakeholders of the system. Analysts have the opportunity to develop empathy and understanding during data collection activities however design participants may not experience this directly. Empathy is important for achieving designs that align with sociotechnical values.
Assumption crushing	This tool outlines a process for considering assumptions associated with the existing system, then challenging these assumptions and creating alternative statements that change the boundaries of the design space (Imber, 2012). This enables the design team to transcend the traditional design solutions and promote innovation. The alternative statements developed can be used to brainstorm design ideas.
Inspiration cards	Cards and card sorting techniques are commonly used within participatory design activities. As noted previously, the physical interaction with the cards assists the design process. In the CWA-DT, cards can include those drawn from the Design with Intent Toolkit (Lockton, Harrison & Stanton, 2010a) as well as those developed to reflect insights such as leverage points and pain points. The exercise encourages the participants to explore combinations of design cards to promote associative creativity.
Extreme characters	While personas and scenarios tend to be based around prototypical users, extreme characters have exaggerated emotional attitudes and goals. Exploring design ideas for extreme characters is analogous to the crushing of assumptions. It assists to uncover undesirable or antisocial emotions and goals and thus expand the design space. Role-playing each character within the workshop is recommended to provide richness and bring the character to life (Djajadiningrat, Gaver & Frens, 2000).
Interaction relabelling	Interaction relabelling draws upon associative creativity through the introduction of an unrelated product to prompt ideas about interaction with the product to be designed. Design participants work in small groups to brainstorm ideas and physically role-play interactions with the unrelated product to explore possibilities. The activity draws upon metaphorical design and can be used to assist designers to move away from prototypical interaction styles (Djajadiningrat, Gaver & Frens, 2000).
Impossible challenge exercise	Most people are unaccustomed to thinking laterally as most activity involved in work and study requires analytical, rational thinking. However, lateral thinking is important for generating novel ideas. Based on the idea that failure can promote creativity, as our brain tries to generate a range of solutions to try and solve very challenging problems (Epstein, 1996), this exercise asks participants to solve a problem which is impossible to resolve using standard rational processes (Imber, 2009).
Metaphors and analogies	Metaphors and analogies can assist designers to take inspiration from an area or domain that is similar but has some difference, and apply this in design. Metaphors provide a means of seeing familiar things in a new way. For example, Norman's (2007) metaphor of the horse and rider used to explore approaches to vehicle automation. The metaphors identified as insights during the analysis can be provided on inspiration cards, or used in group brainstorming.
Affinity diagramming	Again related to associative creativity, the idea of affinity diagramming or combinatorial play is a process of drawing together diverse ideas to create novel solutions. This guidance for affinity diagramming in the CWA-DT aims to prompt further creative combinations of design ideas, including the introduction of ideas recommended by previous research, by other stakeholders, or implemented elsewhere. It can also be used to ensure that interventions are proposed across different levels of the system, and are holistic concepts that support integrated system design (i.e. are not focused on one aspect of the system alone).
Rapid prototyping	Design ideas can be given form early in the design process to prompt further ideas and to test assumptions about how people will interact with the finished design.

	Asking small groups to develop prototypes given the same design requirements provides diverse solutions of which the best aspects can be combined.
Envisioning cards	The importance of human values in design is emphasised in sociotechnical systems theory and the CWA-DT. Design often requires values to be traded-off and it is preferable for this to occur explicitly and that it involves those who may be affected by such trade-offs. The envisioning cards can provide a prompt for considering the implications of the design concepts identified in relation to the themes of stakeholders, time, values, and pervasiveness (Friedman & Hendry, 2012).
Design concept template	Design concept templates are A3-sized sheets which are provided for the documentation of design concepts. The sheets incorporate prompts to give the concept a name, provide a drawing or sketch of the design, indicate the sociotechnical systems theory values incorporated in the design, the design hypothesis underlying the concept, other system changes that would be required for the concept to be successful and any foreseeable unintentional consequences of the design.
6. High level evaluation and design concept selection	The CWA-DT provides guidance for the desktop evaluation of concepts using the CWA outputs. For example, new physical objects can be inserted into the WDA and the impact on the nodes at the higher level of abstraction can be assessed. Further, impacts on other outputs such as the CAT, decision ladders and information flowcharts can be identified. Following the evaluation process, which should involve the participation of users and stakeholders where possible, refinements can be made to the design concepts, and a shortlist or single concept can be selected for further design effort.
7. Detailed design	Given the broad range of design purposes for which the CWA-DT might be applied, there is little specific guidance on detailed design in the CWA-DT. However, reference to useful guidance such as HFE standards for interface design, workstation design, etc. are provided.
8. Evaluation and design refinement	This stage of the design process refers to a more thorough evaluation of concepts through processes such as user testing, computer-based simulation and modelling and safe-to-fail experiments. Such activities can lead to refinement of the designs to ensure they are effective, prior to full roll-out. The design criteria determined in Step 4 can be used to determine measures of success for the evaluation. Further, the CWA outputs can be used to inform the evaluation activities. For example, the WDA can be used to design simulation studies (Jenkins, Stanton, Salmon & Walker, 2011a).
9. Implementation	Implementation of innovations is an important part of the design process that can benefit from the application of sociotechnical systems theory principles. The CWA-DT provides guidance for the development of an implementation plan that emphasises the importance of monitoring the impact of the change both in the initial stages and in the longer-term.
10. Testing and verification	This stage refers to the testing that would be undertaken to ensure that the design concept was implemented as planned. This could involve standard processes such as testing of software components or engineering tests, but should also involve initial monitoring to ensure that no unanticipated negative effects of implementation are identified. A design verification template is provided to assist in this process.

6.6 How Version 1 meets the design requirements

Having described the components of the CWA-DT, it is important to discuss the aspects or features of the CWA-DT that address the design requirements identified in Chapter 5.

Requirement 1: The approach should aim to support system design

The CWA-DT was developed specifically to support system design. This is achieved through the iterative process of analysis, design and evaluation shown in Figure 6.1.

The design process model used within the CWA-DT is compatible with systems engineering models such as the V Model (Department of Transportation, 2007) and it provides guidance to holistically consider different aspects of the system (including the design of interfaces, training, procedures, the physical environment, etc.).

Requirement 2: The approach should ensure adaptive capacity of the designed system

The design of a sociotechnical system exhibiting the property of adaptive capacity is promoted by the CWA-DT in a number of ways. For example, the application of the values of sociotechnical systems theory encourages design participants to think about humans as adaptive decision makers within the system and to accept the need for performance variability. Further, evaluation of design concepts through the CWA outputs will identify where constraints are undesirably restricting behaviour or system functioning and provide the design team with the opportunity to consider the effect on the adaptive capacity of the system.

Requirement 3: The approach should provide guidance for supporting all of the purpose-related functions identified in the AH

The first purpose-related function was that CWA outputs are incorporated in design. The CWA-DT process begins with the application of the CWA framework and uses the insights to provide a connection between the findings of CWA and idea generation activities. The toolkit also recommends using the CWA outputs as a resource for high-level evaluation and for design refinement. In this way, CWA outputs can potentially inform all design stages.

The second function was that sociotechnical systems theory design principles were incorporated in design. This occurs in the CWA-DT by the alignment between the tools and the sociotechnical systems principles.

The third function related to the provision of guidance for each of the system design functions (e.g. design planning, requirements specification, concept design, detailed design, etc.). A description of how these functions are incorporated within the CWA-DT is available in Table 6.1.

Requirement 4: The approach should incorporate sociotechnical systems theory design principles in design

The sociotechnical systems theory design principles were incorporated into the object-related process level of the AH. A commentary on how they were incorporated into the CWA-DT is provided in Part 1 of Table 6.2 below.

Requirement 5: The approach should support all of the object related processes in the AH

The CWA-DT incorporates guidance and tools for supporting each of the object-related processes identified in the AH presented in Chapter 5. These included the sociotechnical process principles as well as more general system design processes that may be undertaken within a design process. Table 6.2 presents the object-related processes identified in the AH and identifies how they are supported by the CWA-DT.

Table 6.2. Tools from Version 1 of the CWA-DT that support each object-related process.

Object related process	**Supporting tools / guidance**
Part 1. Sociotechnical systems theory process principles	
Adoption of agreed values and purposes	- Analysis brief. - Design brief. - Guidance to introduce and communicate sociotechnical systems values and principles. - Sociotechnical values cards. - Stories for communication. - Assumption crushing. - Design goal inspiration cards.
Provision of resources and support	- Analysis brief. - Design brief.
Adoption of appropriate design process	- Guidance on design process selection based on system type. - Written information on each design tool and the circumstances under which it would best be utilised.
Context / problem analysis	- Analysis brief. - Stakeholder needs analysis template.
Design and planning for the transition period	- Analysis brief. - Design brief.
Documentation of how choices constrain subsequent choices	- Guidance for using the AH to evaluate the impact of choices. - Design concept template requiring documentation of effects on other parts of the system.
User participation	- Guidance recommends participation of users within the design process and provides tools to facilitate this.
Constraints are questioned	- Agreed values and purposes (documented in analysis brief and design brief) would include this. - Assumption crushing.
Representation of interconnectedness of	- The AH provides this representation.

system elements	
Joint design of social and technical elements	- Use of the sociotechnical systems values and principles to drive design (through incorporation of them in the design brief). - Guidance on how CWA can support function allocation.
Multidisciplinary participation and learning	- Guidance recommends multidisciplinary participation. - The design brief and project planning should incorporate time for sharing and learning to occur.
Political debate	- Design brief and project planning should incorporate time for this to occur. - Guidance on facilitation notes the need to encourage debate and document issues and concerns. - Assumption crushing helps to draw out debates and areas where participants might disagree. - Stories or extreme characters could be used to raise issues known to be controversial. - Envisioning cards for exploring design concepts (e.g. the values tension card or non-targeted use card).
Design driven by good solutions – not fashion	- Design brief. - Design with Intent Toolkit cards. - Assumption crushing could be used to change mindsets about fashionable design solutions. - Envisioning cards for exploring design concepts.
Iteration and planning for ongoing evaluation and re-design	- Incorporated in the analysis brief and design brief. - Scenarios or stories that explore or uncover future needs. - Guidance recommends multiple workshops to provide design participants with the opportunity to iterate and refine design ideas.
Part 2. System design processes	
Stakeholder needs analysis	- Guidance on stakeholder object world representations. - Stakeholder needs analysis template. - Envisioning cards for exploring design concepts (stakeholders card).
Function allocation	- Guidance for how CWA can support function allocation, including reference to HFE standards and guidelines.
Information systems / interface design	- Guidance for how CWA can support interface design, including reference to HFE standards and guidelines and guidance for EID.
Job / task design	- Guidance for how CWA can support job / task design, including reference to HFE standards and guidelines.
Team design	- Guidance for how CWA can support team design, including reference to HFE standards and guidelines.
Physical environment design	- Guidance for how CWA can support the design of the physical environment, including reference to HFE standards and guidelines.
Support materials / procedures / rules design	- Guidance for how CWA can support the design of procedures / rules / support materials, etc., including reference to HFE standards and guidelines.
Management system design	- Guidance for how CWA can support management system design, including reference to HFE standards and guidelines.

Requirement 6: The design approach should provide flexibility and choice in the physical objects used for design

The CWA-DT provides a range of tools which can be selected based on the purposes and scope of the design project. As noted previously, the toolkit structure was chosen specifically to provide flexibility and choice, acknowledging the vast diversity in design projects that may seek to utilise CWA.

6.7 Conclusion

Version 1 of the CWA-DT was developed based on the theory and practice of CWA and the sociotechnical systems theory approach. It was further influenced by design approaches such as human-centred design, participatory design, the design thinking movement and toolkit approaches within the literature. Finally, the development of the toolkit drew from the views and experiences shared by CWA practitioners gathered during a workshop and an online survey. During the development of the toolkit, decisions were made to resolve key trade-offs such as between creativity and structure, and between individual and group processes for design activities.

Following the development of the CWA-DT, the next step involved testing it using an application within a relatively simple sociotechnical system. This initial testing was conducted to provide a proof of concept demonstration of its effectiveness and to learn from the application to make refinements to the CWA-DT. The proof of concept application will be described in Chapter 7.

7 Applying the CWA-DT to design a transport ticketing system

Read, G. J. M., Salmon, P. M., Lenné, M. G. & Jenkins, D. P. (2015). Designing a ticket to ride with cognitive work analysis. *Ergonomics.* Advance online publication.

7.1 Introduction

Following the development of Version 1 of the CWA-DT, there was a need to test the design process in a proof of concept manner prior to putting it into practice to inform the design of a complex, safety-critical system. A non-safety critical system was selected as the application domain for the proof of concept. The domain selected was public transport ticketing. This was considered a useful candidate domain for the test as it is a sociotechnical system with a reasonable level of complexity, however, it is not so complex that the CWA application would be overly onerous. Further, while the domain is very different to RLXs, with the key inputs and outputs being associated with funds transfer and authority to travel rather than the movement of people and vehicles, there is also some key areas of overlap between the domains. For example, many pedestrian users of RLXs are also public transport passengers who are using the RLX to access train station platforms. Thus, this domain provided the potential to explore design ideas that might integrate or coordinate the user experience associated with using the RLX and using the ticketing system.

The aim of this chapter is to present and discuss the findings of a proof of concept test of the effectiveness of Version 1 of the CWA-DT. In line with the flexible use of the toolkit, all aspects were not applied, but selected based on the purposes of the design activity with its limited scope. Further, participation in the design process was restricted to the involvement of a small group of users, rather than a full-scale application involving all key stakeholders. The following paper provides the results of the proof of concept test including evaluation results gained from participants, reflections on the process and outcomes, and recommendations for improvement.

Declaration for Thesis Chapter 7

Declaration by candidate

In the case of Chapter 7, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Primary author responsible for the concept, design, data collection activities and the CWA analysis. Developed the CWA-DT and planned and conducted the design workshops. Responsible for initial drafting of the paper and subsequent editing.	85%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Paul M. Salmon	Review of CWA analysis and input to planning of design workshops. Provided critical reviews of draft versions of the paper.	n/a
Michael G. Lenné	Provided critical review of draft versions of the paper.	n/a
Daniel P. Jenkins	Provided critical review of draft versions of the paper.	n/a

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's Signature	[redacted]	**Date** 2 July 2015
Main Supervisor's Signature	[redacted]	**Date** 2 July 2015

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Designing a ticket to ride with the Cognitive Work Analysis Design Toolkit

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Cognitive work analysis has been applied in the design of numerous sociotechnical systems. The process used to translate analysis outputs into design concepts, however, is not always clear. Moreover, structured processes for translating the outputs of ergonomics methods into concrete designs are lacking. This paper introduces the Cognitive Work Analysis Design Toolkit (CWA-DT), a design approach which has been developed specifically to provide a structured means of incorporating cognitive work analysis outputs in design using design principles and values derived from sociotechnical systems theory. This paper outlines the CWA-DT and describes its application in a public transport ticketing design case study. Qualitative and quantitative evaluations of the process provide promising early evidence that the toolkit fulfils the evaluation criteria identified for its success, with opportunities for improvement also highlighted.

Practitioner summary: The Cognitive Work Analysis Design Toolkit has been developed to provide ergonomics practitioners with a structured approach for translating the outputs of cognitive work analysis into design solutions. This paper demonstrates an application of the toolkit and provides evaluation findings.

Keywords: cognitive work analysis; sociotechnical systems theory; system design; ticketing system design; participatory design

1. Introduction

In recent times, the discipline of human factors/ergonomics (HFE) has seen a rise in the use of systems analysis methods (e.g. Waterson 2009; Jenkins et al. 2010; Walker et al. 2010; Stanton and Bessell 2014). Cognitive work analysis (CWA) is one such framework that supports the analysis of complex sociotechnical systems with the aim of improving system design (Vicente 1999). It is unique in that it takes a formative approach, identifying the possibilities for behaviour within the system's constraints, rather than describing actual behaviour (i.e. how behaviour is), or prescribing normative behaviour (i.e. how behaviour should be). CWA has been used to analyse various types of complex sociotechnical systems including nuclear power generation (e.g. Burns et al. 2008), military command and control (e.g. Jenkins et al. 2008), air traffic control (e.g. Ahlstrom 2005), disaster management (e.g. Jenkins et al. 2010), healthcare (e.g. Miller 2004), road transport (e.g. Cornelissen, Salmon, McClure, et al. 2013), rail transport (e.g. Stanton et al. 2013) and submarine systems (Stanton and Bessell 2014).

A significant challenge faced by HFE practitioners is how to take the outputs from system analysis methods, and indeed other ergonomics methods, and create design concepts that will solve the issues identified. While CWA has been applied in numerous design applications (e.g. Bisantz et al. 2003; Naikar et al. 2003; Jenkins et al. 2010; Stanton and McIlroy 2012), like all HFE analysis methods, the outputs of CWA provide information to support design rather than doing the design. The analysis outputs provide recommendations for various types of interventions, rather than design specifications (Lintern 2005). To better support the use of CWA outputs in design, a design approach for use with CWA has been developed to exploit the synergies between the framework and the sociotechnical systems theory approach. This design approach has been titled the Cognitive Work Analysis Design Toolkit (CWA-DT).

Sociotechnical systems theory provides design principles for developing work systems, stemming from the work of the Tavistock Institute in the 1950s (Trist and Bamforth 1951). The approach is underpinned by humanist values and aligns with ideas of participative democracy in the workplace. Importantly, sociotechnical systems theory is geared towards the joint optimisation of the social (human) and technical (machine) aspects of a system (Walker et al. 2008).

While CWA and sociotechnical systems theory evolved independently, they share an underpinning in systems theory and both emphasise the importance of system adaptability to enable resilience in the face of external disturbances. Further, both support equifinality – the principle that an end state can be reached via different means. They support this by

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advocating for flexibility within systems such that people are given choice and control around how work is performed enabling them to deal with events unanticipated by system designers. Importantly, the CWA framework provides a means to jointly analyse and optimise the social and technical system (Stanton and McIlroy 2012), thus having potential to support efforts towards joint optimisation. Whereas these synergies in approach ensure that many of the design principles of sociotechnical systems theory are implicitly incorporated in CWA and the designs underpinned by CWA, through the use of the CWA-DT it is hoped that this connection will be more structured and explicit.

The aim of this paper is to introduce the CWA-DT and demonstrate its use within a case study design application to develop design concepts for a public transport ticketing system. The case study was intended as a proof of concept application of the toolkit, providing preliminary evaluation results and identifying improvements required to enhance the effectiveness of the toolkit.

2. The CWA design toolkit

2.1. Development

The CWA-DT was developed to support design activities that incorporate both CWA and the principles of sociotechnical systems theory. Goals and evaluation criteria for the CWA-DT were identified prior to its development (Read et al., in press). The goals included that the approach should aim to support system design, ensure adaptive capacity of the designed system, incorporate CWA outputs in design and incorporate sociotechnical systems theory design principles in design. Furthermore, a goal was that the design approach should provide flexibility and choice in the objects used for design, for example, it should provide information and guidance for the selection and use of analysis and design tools including CWA tools, scenarios, inspiration cards and stakeholder analysis documentation.

Evaluation criteria defined for the CWA-DT included both methodological criteria and criteria relating to sociotechnical systems theory. The methodological criteria included that the approach facilitates creativity and/or innovation, provides structure to the design process, supports coordinated design of all system elements (e.g. interfaces, training, support materials, team structures), can integrate with existing systems engineering processes, provides a process that is efficient and/or cost effective, is valid and facilitates an iterative design process. The criteria relating to sociotechnical systems theory included those relating to sociotechnical values: humans as assets, technology as a tool to assist humans, promote quality of life, respect for individual differences, and responsibility to all stakeholders, as well as sociotechnical design principles such as that the approach produces designs that incorporate useful, meaningful and whole tasks, the needs of business, managers and users, and that system elements are congruent.

As a toolkit to assist those conducting the design process, the CWA-DT provides a suggested process and guidance about design activities and existing design tools (i.e. scenarios, prototypes, mock-ups) that support a sociotechnical approach to design. What sets it apart from other toolkits such as the IDEO User-Centred Design Toolkit (IDEO 2009) is that it is based specifically around the use of CWA to understand the existing system, providing guidance and commentary about how information from CWA outputs can be used during design activities. A toolkit approach providing information and guidance was chosen for the CWA-DT as opposed to a pre-defined method as this enhances flexibility and autonomy for designers to choose how they undertake design for particular design briefs. Users of the toolkit are encouraged to take from the toolkit that which they find useful.

2.2. Overview of the CWA-DT

The CWA-DT provides guidance for the various functions associated with designing sociotechnical systems. These functions include: analysis planning, the analysis process, requirements specification, design planning, concept design, detailed design, evaluation and design refinement, implementation, and testing and verification. The CWA-DT suggests a process for achieving these functions, outlined as 10 steps shown in Figure 1. As can be seen in the figure, the functions need not necessarily be undertaken in sequence and iteration is encouraged throughout the process.

The process illustrated in Figure 1 is able to align with the V model commonly often used in systems engineering (Department of Transportation 2007). For example, the concept design step in the CWA-DT aligns with the high-level design step in the V model. The potential for outputs developed during various steps of the CWA-DT to be integrated into systems engineering activities is important as stakeholders are likely to have requirements that such models are followed. However, the V model does not acknowledge the iteration that occurs in real-world design practice and does not necessarily facilitate a human-centred approach to design. The process outlined in ISO 9241-2010: 010 – *Human Centred Design for Interactive Systems* describes an interdependent and iterative process such that design activities use the outputs from previous activities or can provide an input to other activities. This sort of iteration is also represented in Figure 1. Further,

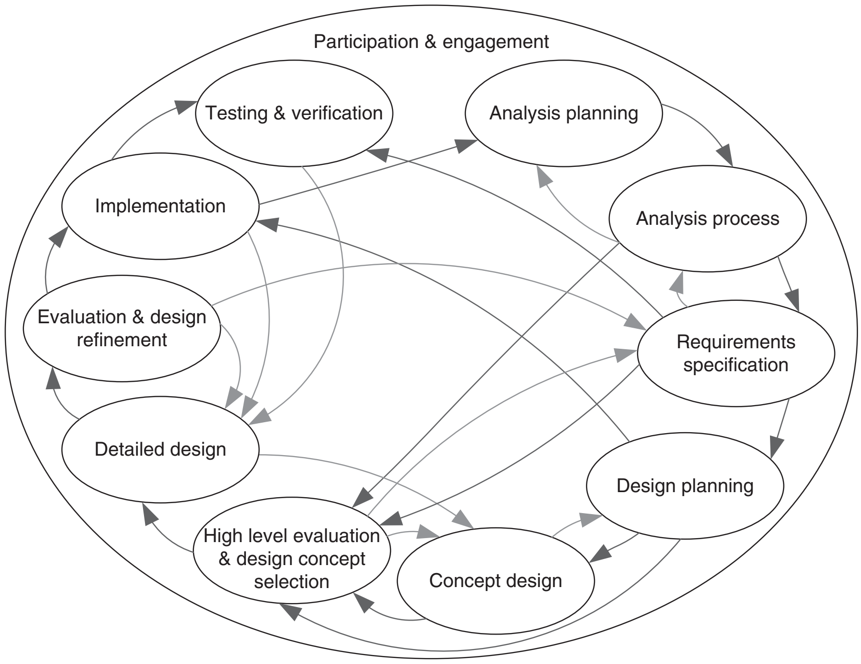

Figure 1. Functions supported by the CWA-DT.

the CWA-DT and the ISO standard are similar in that they both place importance on planning to support the successful completion of the design process.

Where the CWA-DT differs from those models of design described above is that the steps are underpinned by the principle of participation and engagement, following sociotechnical researchers such as Clegg (2000) who implores that 'systems and their design should be owned by their managers and their users' (472). To achieve ownership requires more than just consultation or participation and there is a need for genuine engagement and empowerment of stakeholders and users (e.g. Baxter and Sommerville 2011). This mirrors the shift from user-centred design processes (where data are gathered about users to determine their needs and requirements) to participatory design or co-design where users participate and cooperate directly with researchers and designs (Sanders and Stappers 2008).

Table 1 presents further detail about the steps illustrated in Figure 1 that contribute to the development and refinement of design concepts (i.e. from analysis planning to high-level evaluation and concept selection) as these are the steps that were applied in the case study described in this article. Being a simulated design process, the process did not extend to the latter steps such as detailed design, implementation and testing and verification. It should also be noted that while Table 1 describes opportunities for the engagement and participation of users and stakeholders relevant to each step, this level of participation was not always able to be achieved in the case study application.

A key contribution of the CWA-DT is the guidance and templates provided for recording insights derived by the analysts regarding the system under investigation. Insights can be used by designers to synthesise observations or other data into a more in-depth understanding as part of the sensemaking process. Insights are inferences from the data in the form of hypotheses or best guess explanations that assist the creative problem-solving process (Kolko 2010). In some cases, insights are limited to non-obvious inferences from evidence and radical shifts in understanding that lead to more accurate mental models (Klein and Jarosz 2011). In the CWA-DT, the term incorporates these types of insights as well as more obvious findings about the system that the analyst considers an important contribution to the design process (such as scenario features that are captured to provide depth and realism to scenarios). It should be noted that insights developed during the analysis stage may be inaccurate or incorrect as they are likely to be hypotheses rather than facts. Analysts are encouraged to seek research evidence to confirm or refute the insight where possible; however, it may be the case that their accuracy remains unknown until the latter stages of design evaluation and testing.

The CWA-DT provides guidance on how insights (including assumptions, leverage points, metaphors, scenario features and design solutions) can be used within a design process. This guidance enables the communication of insights usually only available to the analysts to those not directly involved and immersed in the analysis. This can be achieved through tools

Table 1. Overview of steps recommended by the CWA-DT and tools and templates provided.

Step	Description/key activities	Tools, templates and guidance provided	Engagement and participation opportunities
Analysis planning	The analysis process should be planned to ensure there is clarity for the design team and stakeholders about the purpose of the project and to ensure appropriate boundaries are drawn for the analysis. The key activity is the development of an *analysis brief*.	– Analysis brief (adapted from Liedtka and Ogilvie 2010) that identifies project need, analysis deliverables, key stakeholders, target users, project constraints, etc. – Guidance on selection of appropriate CWA phases.	– Review and/or acceptance of analysis brief by stakeholders.
Analysis process	The analysis process begins with data collection activities (e.g. document review, subject matter expert interviews, observation, 'think-aloud protocols', etc.). Following this the appropriate CWA phases would be applied and outputs developed, reviewed and refined. During the analysis process 'insights' about the functioning of the system are recorded by those conducting the analysis. Insights include: assumptions, potential leverage points, metaphors, scenario features and design solutions.	– Guidance about insights and their use in design. – Insights template that enables documentation of the insight, the thought processes leading to its identification, and how it might be used in the design process.	– Participation of users and stakeholders in data collection activities. – Participation of users and stakeholders in development and/or verification of CWA outputs. – Participation in the identification of insights.
Requirements specification	Requirements can be identified from the CWA outputs, particularly the first phase, work domain analysis which identifies the overall purposes of the existing sociotechnical system and the measures that are used to determine its effectiveness. The design team may choose to use the purposes of the existing system or to change/amend these if it is considered that this would improve the system's effectiveness. However, if the design is focussed on a very specific part of the system, the latter phases of analysis may also be used to determine requirements.	– Guidance on identifying requirements from CWA outputs.	
Design planning	Design planning involves the development of documentation to drive and scope the design process. This step also includes the design team determining the most appropriate design activities to undertake for sharing the analysis findings with users/stakeholders, for idea generation and for design concept definition (e.g. synthesising ideas into more holistic concepts). Development of design materials such as scenarios, inspiration cards, etc., based on the insights documented. Planning for events such as workshops, meetings, etc.	– Design brief template that identifies the design scope, project planning for design, design requirements identified from the CWA outputs and relevant design requirements from sociotechnical systems theory. – Design criteria template that identifies criteria for success from the measures of effectiveness identified in the work domain analysis of CWA. – Design tool selection template. – One-page guides for tools to communicate results, generate ideas and synthesis ideas (e.g. scenarios, personas, inspiration card exercises, lateral thinking exercises, affinity diagramming, etc.). – Sample workshop plans	– Review and/or acceptance of design documentation by stakeholders. – Participation of stakeholders in selecting design activities.

TABLE 1 – *continued*

Step	Description/key activities	Tools, templates and guidance provided	Engagement and participation opportunities
Concept design	The purpose of this step is to use creative and divergent thinking to identify many design ideas which are then synthesised into one or more design concepts. The CWA-DT encourages involvement of users and stakeholders in this step through the use of workshops using design activities that promote creativity and innovation.	– Guidance on workshop delivery.	– Participation of users and stakeholders in idea generation activities. – Participation of users and stakeholders in design concept definition.
High-level evaluation and concept selection	Design concepts can be evaluated at a high level using the CWA outputs enabling the design team to determine the effects of the change on the system. Changes could be benefits or unanticipated negative effects. The results of the evaluation provide a basis for the selection, rejection or refinement of design concepts.	– Guidance for using CWA outputs for evaluating design concepts. – Design concept summary template.	– Participation of stakeholders in the evaluation process. – Participation of users and stakeholders selecting, rejecting or refining design concepts.

such as scenarios and stories. This is important for participatory design processes where it may be impracticable for stakeholders and users to be involved in the analysis process itself, but it is the insights arising from the analysis process that make CWA such a unique and valuable analysis framework for design.

3. Case study: the public transport ticketing domain

In the discussed case study, the CWA-DT was applied to redesign a public transport ticketing system within an Australian city. Public transport systems are generally funded by public revenue (i.e. taxes) as well as contributions by the user. The user contribution is collected through the sale of tickets, with various means employed to enforce the requirement to hold a valid ticket for travel. Internationally, the trend in ticketing systems has been a move towards smartcards rather than paper tickets in line with a general trend towards a cashless society (Tourism and Transport Forum 2010).

The ticketing system chosen for analysis was a smartcard-based ticketing system. The smartcard system is used on multiple modes of public transport with fares associated with two geographically based zones of travel. The durable plastic card is required to be purchased, and value (a monetary amount) or a travel pass (a product that enables travel for a set period of time) to be loaded prior to travel. Purchasing and loading facilities are provided at many, but not all, locations at which passengers might begin their journey. The ticketing system in question has been subject to criticism from its users and the media regarding aspects such as the speed of processing, usability and convenience of ticket purchasing. As such, this system was chosen for this case study demonstration. It represents a sociotechnical system that contains some elements of complexity, but is simple enough to be comprehensively analysed in a case study format.

Public transport ticketing has previously been analysed as an aspect of the passenger experience of rail transport using CWA (Stanton et al. 2013). This case study will focus specifically on the ticketing sub-system of the overall public transport passenger domain (including rail as well as other modes of public transport). The purpose of the case study application was to evaluate the CWA-DT in relation to whether it could be applied to produce design concepts that satisfied the evaluation criteria described in Table 1.

Figure 2 provides an overview of the case study process based on the CWA-DT. This process was conducted by the project team established for the case study. The project team constituted three human factors researchers (the first three authors of this paper).

The process began with the analysis planning stage (top left of Figure 2) and concluded with concept selection (bottom left of Figure 2). Broadly the process involved producing an analysis brief, applying CWA to assess the system of interest, deriving insights from the CWA outputs, creating a design brief and design criteria, and then using workshops to communicate the CWA outputs and insights and to develop and evaluate design concepts based on these outputs and insights.

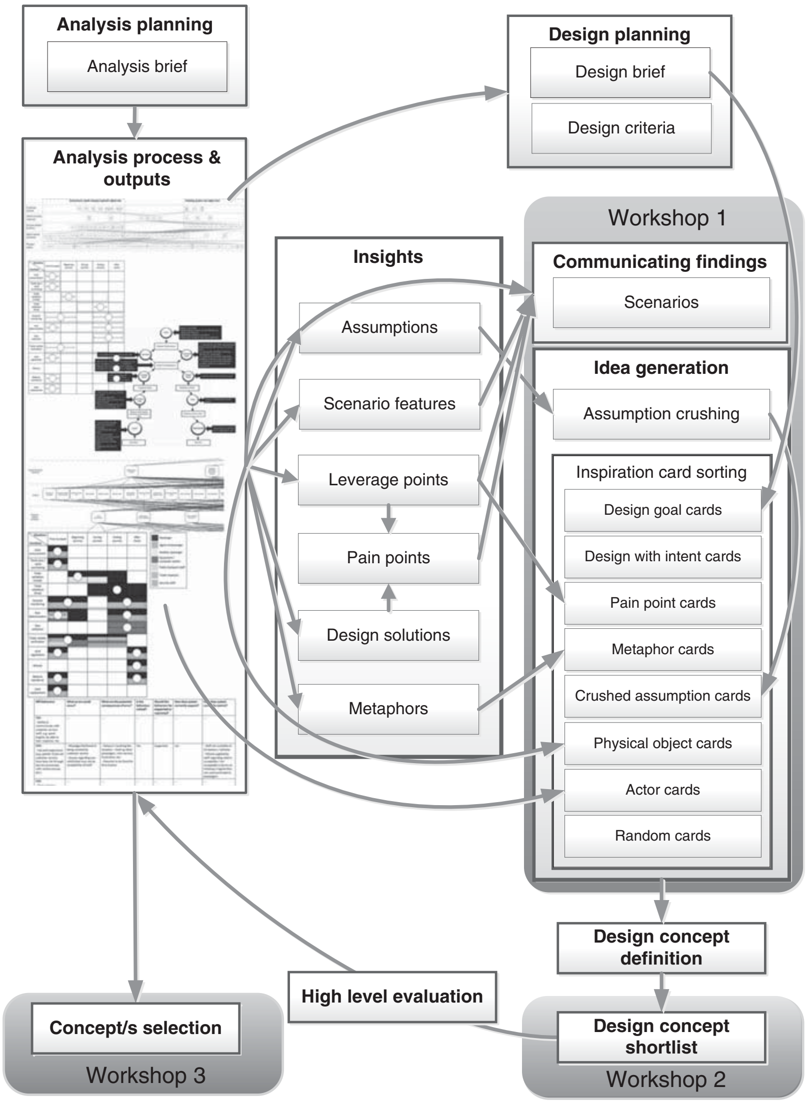

Figure 2. Overview of the case study analysis and design process based on the CWA-DT.

3.1. *Analysis planning*

The first step in applying the CWA-DT was the development of an analysis brief to provide a background and scope to guide the case study. The analysis brief described the background to the project as:

> An election is held and a new government, not involved in any past decisions about the system, is elected to power. The new Minister for Transport has tasked this project team with reviewing the ticketing system and designing the next generation system for implementation in 5–10 years' time. The team is to identify and learn from the issues with the current system and design a new system that meets the goals of government and users.

The analysis brief documented the deliverable of the project as a proposed design solution for a ticketing system appropriate for a metropolitan public transport system in 5–10 years' time. Other key points from the analysis brief included that data should be collected about both regular and irregular users, and that the project is constrained to the design of a ticketing system, rather than exploring alternative means of gaining funds to cover the costs of public transport operations.

3.2. Analysis process

All five phases of CWA were applied to the ticketing system case study. Some extracts of the analysis outputs have been published previously (see Read et al. 2014). A summary is provided in Section 3.2.2.

3.2.1. Data collection activities

A review of publicly available documentation about the ticketing system was undertaken and interviews were held with two ticketing system subject matter experts to elicit information and rich pictures describing the functioning of the technical system. Interviews were also conducted with six users of the public transport ticketing system (three regular users and three irregular users). These interviews included a critical decision method interview (Klein, Calderwood, and Macgregor 1989), focussing on a challenging experience that the user had encountered when using the ticketing system as well as a structured interview where users generated strategies for certain situations and tasks associated with ticketing. As the primary analyst was a regular user of the ticketing system, the analysis was also informed by their experiences and everyday observations.

3.2.2. Analysis outputs

Work domain analysis. An abstraction hierarchy (AH) was developed to represent the ticketing work domain (see Figure 3). We use the CWA terminology of ‘work domain’ in this paper even though ticketing system users are members of the public, rather than ‘workers’ within this domain. The AH describes the constraints of a work domain within which behaviour is possible. It represents the domain from five levels of abstraction (reading from the bottom of Figure 3 up): the physical resources available within the system, the processes afforded by those resources, the functions supported by the processes, the values and priorities of the system and finally the overall purpose/s of the goal-directed work domain (Vicente 1999). Means–ends links are present between nodes at adjacent levels. For example, although the links are not visible in Figure 3 due to the complexity of the diagram, the ticket barrier/gate (a physical object) provides a means of obstructing access (an object-related process) which, in turn, is a means to enforce ticketing regulations (a purpose-related function). The enforcement of ticketing regulations enables the system to collect revenue from public transport users (a functional purpose) and this can be measured through the extent to which fare evasion occurs (a value and priority measure).

During the development of the AH, it emerged that there were discrepancies in how the work domain is viewed by the government stakeholders of the system and the users of the system. Consequently, the AH was delineated according to different stakeholders’ object worlds (Naikar 2013). Object worlds refer to the views that different stakeholders have of the system, recognising that not all stakeholders will share the same purposes, values, etc. The nodes belonging to the government or public transport operator’s view of the domain are presented on the left-hand side of the AH, while the nodes relevant to the user’s view of the domain are presented on the right-hand side. The physical objects are shared amongst both stakeholders. Selected nodes have been enlarged within Figure 3 to highlight indicative examples at each level of abstraction.

Since the remainder of the analysis is concerned with the functions performed by users in the system, as opposed to organisational functions such as customer service and enforcement, the remaining phases of analysis drew from the user object world.

Control task analysis. The second phase of CWA, control task analysis, identifies the activities and tasks that need to be carried out within the work domain. The tools used in this phase include the contextual activity template (CAT) which analyses activities in work domain terms, as well as the decision ladder which analyses activities in decision-making terms (Naikar, Moylan, and Pearce 2006).

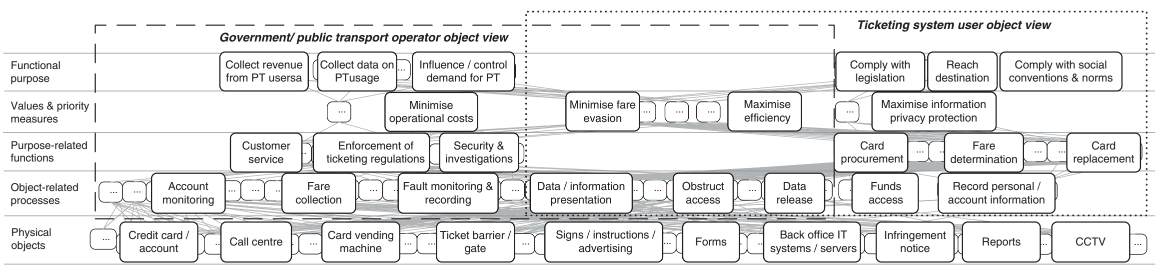

Figure 3. Work domain analysis for the public transport ticketing system, with example nodes enlarged. Note: in the figure, public transport is abbreviated to PT.

The CAT developed for the ticketing system case study is shown in Figure 4. The template is a matrix with the situations encountered (defined as phases of a public transport journey) represented by the columns and the functions occurring within the work domain (transposed from the AH) shown in the rows. The circles with the attached bars in the matrix represent situations in which the functions typically occur. The dotted line boxes in the matrix indicate situations in which the functions could occur, although they may not typically occur there (Naikar, Moylan, and Pearce 2006).

A series of decision ladders were also developed to describe the constraints on decision-making when using the ticketing system to achieve the different functions specified in the AH. Decision ladders outline the information processing activities and resultant knowledge states that if followed from the bottom left to the bottom right of the ladder represent the process of novice decision-making (Vicente 1999). As expertise develops, shortcuts (called leaps or shunts) can occur where, for example, an alert is directly associated with a system state or the diagnosis of a system state leads to the selection and execution of a task without any intervening information processing steps. An example decision ladder, for the function of *travel pass/value purchasing*, is shown in Figure 5. This figure shows, moving up the left-hand side of the ladder, what can alert the user that they need to purchase a travel pass or value for their smartcard (i.e. the card is being used for the first

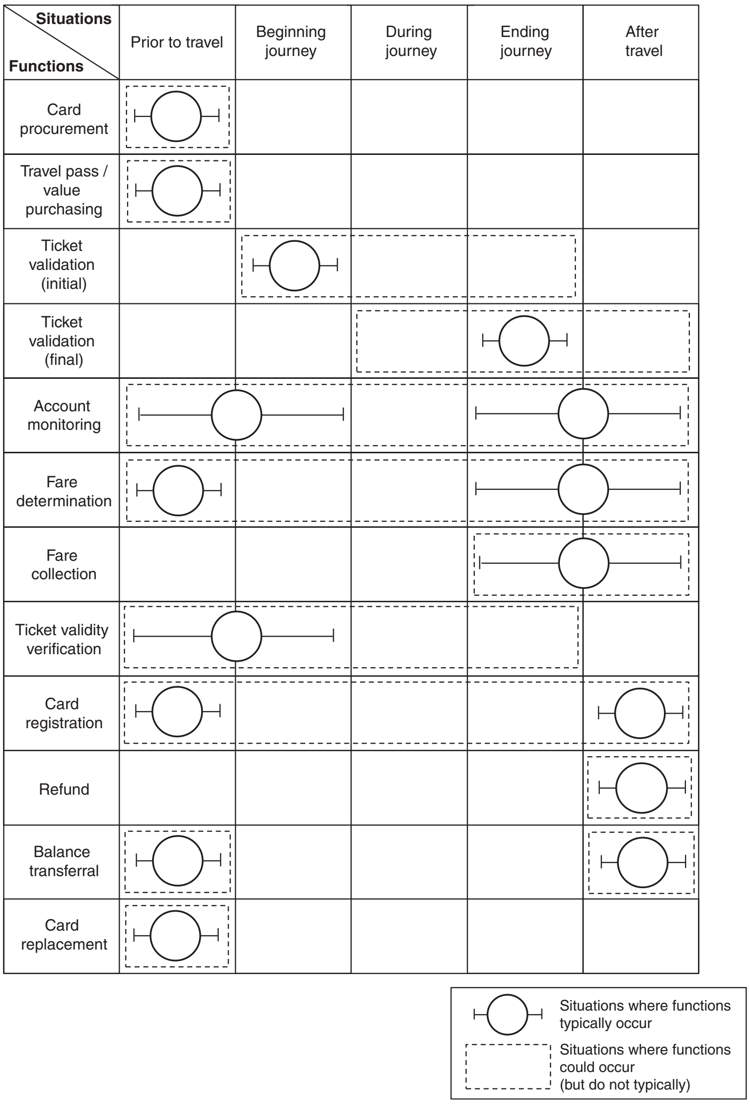

Figure 4. Contextual activity template.

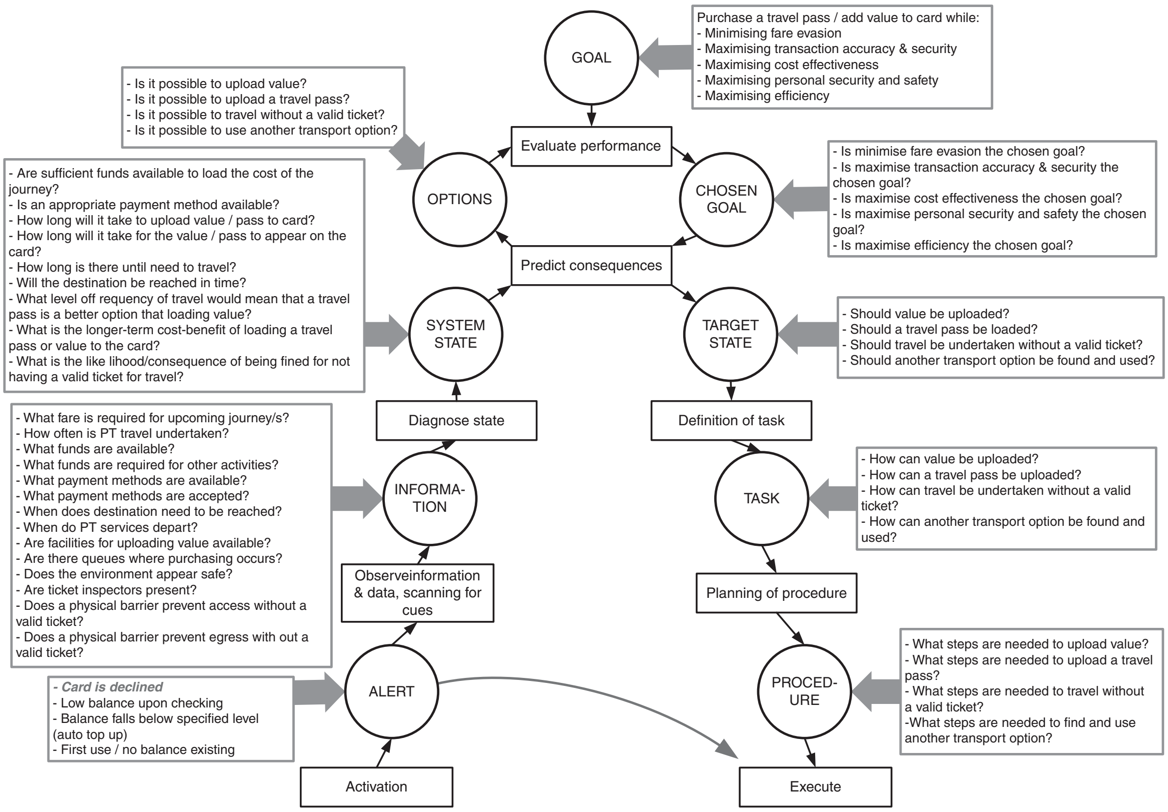

Figure 5. Decision ladder for the function *travel pass/value purchasing*.

time), the information a user may use to make a decision (i.e. are facilities for uploading value available?), the relevant system states that a user might diagnose based on the information available (i.e. how long will it take to upload value to the card?) and the options available (such as upload value, upload travel pass, travel without a ticket or use another transport option). At the top of the ladder are the goals that a user might trade off in making their decision (such as minimising fare evasion, maximising transaction and accuracy security, maximising cost effectiveness, maximising personal safety and security and maximising efficiency). The right-hand side of the ladder then represents the processes associated with selecting an option and how it will be executed.

The arrow in Figure 5 between *Alert* and *Execution* illustrates a shortcut described by a participant who was an experienced user. The participant, on having their card declined by a card reader, immediately disembarked from the public transport vehicle to avoid being on the vehicle without a valid ticket. The participant explained that this was an action they had taken previously when faced with the same circumstances.

Strategies analysis. The strategies analysis phase identifies the range of strategies that can be employed to perform the activities and tasks in the system (Vicente 1999). A common tool used for strategies analysis is the information flow chart. These flow charts identify the steps that can be used to move from a start state to an end state. Flow charts were developed for the key purpose-related functions identified in the user object view of the AH.

In addition to information flow charts, a Strategies Analysis Diagram (SAD; Cornelissen, Salmon, Jenkins, et al. 2013) was developed for the ticketing system. The SAD builds on the AH developed in the work domain analysis phase and involves the addition of two levels to the diagram: verbs and criteria. The verbs are used to specify how the physical objects can be used. For example, for the physical object ‘ticketing barriers’ the following verbs were identified: locate, look at, check, stand at, move through and jump. The criteria are then used to specify the circumstances under which different strategies might be chosen. For example, the strategy ‘jump ticketing barriers’ is possible or more likely when the following criteria apply: barriers are present, smartcard has no/negative value, smartcard misplaced/lost/forgotten, smartcard not owned, equipment not working, under time pressure and staff not present.

Social organisation and cooperation analysis. The social organisation and cooperation analysis (SOCA) phase analyses how tasks and activities are distributed across actors within the system. SOCA can be performed on those CWA outputs already developed by overlaying the actors (human and technical) that could be involved in different aspects of the system's functioning. For the case study, SOCA was performed using the CAT.

Seven actors were identified within the SOCA phase: passengers, agents of passengers (e.g. parents or carers who perform functions to assist passengers), other passengers, technology (i.e. automation), public transport staff (e.g. customer service personnel, drivers), ticket inspectors and security staff. The SOCA highlighted that although more technologically advanced than previous paper ticket systems, the ticketing system required most functions to be performed by humans. For example, fare collection was the only automated function. Further, it was noted that while ticket inspectors were able to check the validity of tickets during the journey using handheld card readers, passengers themselves were unable to perform this function after they had initially validated their ticket, as ticket vending machines or card check devices were not available on public transport vehicles.

Worker competencies analysis. The final phase of CWA, worker competencies analysis, identifies the cognitive skills and processes required to perform tasks within the system. The skill, rule and knowledge taxonomy (SRK taxonomy) is generally applied in this phase. The taxonomy relates to three levels of cognitive performance: skill-based behaviour (SBB), rule-based behaviour (RBB) and knowledge-based behaviour (KBB) (Rasmussen 1983). In this case study, the aim was to support integrated systems design, rather than only the design of interfaces or information systems. Accordingly, the SRK inventory was completed in relation to the strategies identified within the strategies analysis phase. Strategies were drawn from the SAD by reviewing the relationships between the verbs and physical objects and transposing the strategies into a table identifying the SBB, RBB and KBB required to execute each strategy.

Considering the function *travel pass/value purchasing*, the SRK analysis highlighted that fine motor control is required for strategies such as placing the smartcard on the vending machine card cradle. Further, knowledge was required about different fare products and zone-based pricing that was not always provided for users at the time and place of purchase.

3.2.3. *Documenting insights*

Insights were documented by the analyst performing the CWA as they arose during the analysis process. In the documentation, each insight was described (e.g. that the system is designed on the assumption that users do not want to pay for transport and cannot be trusted to voluntarily comply with regulations), as was the analysis activity that provided or prompted the insight (e.g. development of AH). Implications for the design process were also documented (e.g. that this assumption be incorporated in an 'assumption crushing' exercise – see Section 3.5.3 for a description of this activity).

In total, 34 insights were documented from the analysis: 26 by the primary analyst and the remainder (8) by another member of the project team, a CWA expert, who reviewed the analysis outputs. Insights were categorised into the following types: assumptions, potential leverage points, metaphors, scenario features and design solutions.

For the idea generation stage, the leverage points and design solutions were re-phrased into pain points. Pain points (e.g. Clatworthy 2011) refer to aspects of the system that cause frustration for users or that hinder the achievement of user goals. The purpose of phrasing these insights in this manner was to avoid leading design participants in the idea generation workshop (described in Section 3.5.3) to particular solutions or constraining their thinking to certain types of solutions. The original insights can then be introduced in the evaluation stage of the design process.

3.3. *Requirements specification*

Requirements for the design were derived from the functional purposes identified in the AH, including those from the government/public transport operator perspective and the user perspective. The requirements were intentionally specified at a high level so as to enable the design process to introduce radical changes, as opposed to making evolutionary modifications to the existing design. The requirements were incorporated into the design brief as discussed in Section 3.4.1.

3.4. Design planning

Planning for the design process involved the use of the analysis findings and insights to populate the design documents and to develop workshop materials for three workshops with ticketing system users.

3.4.1. Design documentation

A design brief was developed by the primary analyst to document the scope, project plan and key goals of the design process. The goals were identified from the requirements specification process (described in Section 3.3) as well as from the values proposed by sociotechnical systems theory as the design philosophy.

The design criteria document outlined the criteria for evaluating the effectiveness or success of the design. The criteria were taken from the values and priority measures identified in the AH and also from sociotechnical systems theory. The design requirements, values and evaluation criteria from the design brief and design criteria documentation are outlined in Table 2. These documents were reviewed and accepted by the design team.

Table 2. Design goals and evaluation criteria identified in the design documentation (design brief and design criteria).

High-level design requirements	The system should: – collect revenue – promote respect of the system by its users – collect data (journey details) on public transport usage – be able to be used to influence demand for public transport – support the user in their purpose to reach their destination – support the user to comply with the transport ticketing legislation – support the user to comply with accepted social conventions and norms – operate within its allocated budget – operate within its legislative mandate – comply with relevant legislation (including the promotion of social and economic inclusion, economic prosperity, environmental sustainability, personal privacy, etc.)
Sociotechnical systems values	The design process will be driven by the following values: – humans are viewed as assets – technology is viewed as a tool to assist humans – quality of life is promoted – individual differences are respected – responsibility to all stakeholders is acknowledged
System-specific evaluation criteria	The design concept: – minimises intentional and unintentional fare evasion – operates hardware and software with a high level of technical reliability – minimises operational costs – supports a high level of transaction accuracy and security – does not collect, use or release any personal information that the owner of the information does not wish to be collected, used or released – does not introduce risks to the safety or security of users, employees or members of the public – supports efficient use by users and efficient operation of public transport services – ensures on-going usability and convenience for users – ensures on-going cost effectiveness for users
Sociotechnical systems theory principles evaluation criteria	Within the design concept: – tasks are allocated appropriately between and amongst humans and technology – useful, meaningful and whole tasks are designed – boundary locations are appropriate – boundaries are managed – problems are controlled at their source – the needs of the business, users and managers are incorporated – intimate units and environments are designed – the design is appropriate to the particular context – adaptability is achieved through multifunctionalism – system elements are congruent – the means for undertaking tasks are flexibly specified – authority and responsibility are allocated appropriately – adaptability is achieved through flexible structures and mechanisms – information is provided where action is needed

3.4.2. Workshop material preparation

Insights and other information gained directly from the analysis were used to develop materials for the design workshops. Figure 2 shows how the various types of insights contributed to design activities, particularly for the idea generation workshop (Workshop 1). Table 3 provides some specific examples of insights and how they were translated into design materials.

For the main idea generation activity, a set of Design with Intent cards (Lockton, Harrison, and Stanton 2010) were selected for use with the design participants. The purpose of the Design with Intent cards is to assist designers tasked with behaviour change design briefs to generate ideas. Each card contains a behaviour change technique or principle which the designer can use to prompt or inspire ideas relevant to their design brief. For example, the 'Angles' card asks 'Can you slant or angle things so some actions are easier than others?' A small number of cards were excluded from the selection as they appeared inconsistent with sociotechnical systems theory values. For example, the card titled 'First one free' was not selected. It asks 'Can you give something away which gets people interested or addicted, so they come back and pay for more?' This type of influencing technique was judged to violate the value of viewing people as assets, and designing to improve quality of life.

In addition to the Design with Intent cards, seven sets of bespoke inspiration cards were developed to inspire design ideas. These sets of cards recorded:

- the design goals (derived from the design brief);
- pain points (derived from the leverage points and design solutions);
- metaphors (pictures and symbols to represent objects, domains and brands, derived from metaphor insights);
- physical objects (identified from the bottom level of the AH);
- actors (identified from the SOCA);
- cards with pictures of random objects (representing diverse stimuli which can prompt creativity); and
- blank cards for recording crushed assumptions (derived from another workshop exercise, based on insights about assumptions).

Table 3. Examples of insights derived from the analysis, and how they were used to develop design materials.

Type of insight	Example insight	Analysis output that prompted the insight	How the insight was translated into design process materials
Assumption: an underlying assumption upon which the system, or a part of the system is based. Includes hypotheses and beliefs underlying how the system functions.	The system is designed on the assumption that users do not want to pay for transport and are not trusted to voluntarily comply with regulations.	Work domain analysis – AH	Added to list of assumptions for *Assumption crushing* exercise.
Leverage point: an aspect within a system which if changed in a small way, could produce big changes across the system (Meadows 1999) or any other opportunity for system improvement.	Most functions occur either before or after the journey, with no functions typically occurring during the journey. During the journey users potentially have more time to undertake functions.	Control task analysis – CAT	*Pain point card* developed noting the lack of support for completing tasks during the journey.
Metaphor: a subject that can be substituted for, or compared with, the existing system or an aspect of the system, on a symbolic level.	Airlines provide facilities for passengers to check in prior to arrival at the airport. Potentially public transport could provide an option for early validation of a ticket.	Control task analysis – CAT	*Metaphor cards* developed with symbol of an airplane and logo of a well-recognised airline company.
Scenario feature: a feature of a potential scenario that the analyst feels is important to capture. Examples include a type of actor, attributes of an actor, a type of task, an environmental disturbance or influence, etc.	Poor weather conditions – heavy rain and wind.	Decision ladder analysis (when overlaying interview data)	*Scenario* One scenario presented in idea generation workshop incorporated situation of heavy rain leading to rushing and crowding with umbrellas at train station entry.
Design solution: a proposed design or feature of a design identified by the analyst/s.	Enable people may no longer requiring their smartcard and balance to transfer it to assist others who have difficulty affording public transport travel via charitable organisations.	Decision ladder analysis for 'balance transfer'	*Design synthesis* Idea proposed to participants when synthesising and selecting design concepts.

Some cards (e.g. the metaphors) were informed by the insights identified. Others were informed directly by the analysis. For example, the physical objects identified in the AH were used to inform physical object cards which intended to prompt design participants to explore new ways to use existing objects in the system. Further, the actors identified in the SOCA were used as the basis for actor cards which intended to prompt participants to consider whether actors might adopt new roles or perform tasks differently.

3.5. Concept design

3.5.1. Participants

Four ticketing system users (two male, two female) were recruited from those that had participated in the interviews that informed the analysis. Participants had a mean age of 33.3 years and represented both regular and irregular users. All design workshop participants were PhD students. Two participants were from the field of HFE, one was from civil engineering and one from the field of exercise physiology.

3.5.2. Process overview

As shown in Figure 2, participants took part in three workshops: an idea generation workshop (Workshop 1), a concept review workshop (Workshop 2) and a concept selection workshop (Workshop 3). Accordingly, the concept design process began with a focus on divergent and creative thinking which subsequently converged with the combining of ideas into specific concepts, followed by evaluation using the CWA outputs.

3.5.3. Workshop 1: communicating the findings and idea generation

The idea generation workshop ran for two and a half hours. Following an exercise to promote lateral thinking, participants were presented with an overview of the design brief and asked in particular to consider the sociotechnical systems values. Participants were asked to brainstorm their understanding of each value (e.g. humans as assets) to assist participants to reflect upon the values. An overview of the design goals was also provided to participants.

To communicate the key findings of the analysis and to facilitate the development of empathy with other transport ticketing users, participants read through scenarios that identified pain points identified within the insights.

Next, the key assumptions identified within the insights were presented to the group. During the assumption crushing exercise participants were asked to brainstorm, for each assumption, what the opposite assumption would be. For example, the assumption that users would not voluntarily comply with ticketing rules became that users will voluntarily comply. The new crushed assumption statements were written onto blank inspiration cards for incorporation into the subsequent exercise.

Participants then worked in pairs to brainstorm design ideas using the inspiration cards. Groups documented their ideas on templates and were encouraged to attach the cards that had inspired each idea on the templates. The cards were introduced over time rather than all at once to avoid confusion. Thirty design ideas were generated through this process. These ideas included giving passengers the opportunity of paying within 24 hours of their journey rather than requiring pre-payment (following the crushing of the assumption that tickets must be pre-paid), the use of celebrities in advertising and to model desirable behaviour (based on a metaphor card that included the logo of a supermarket chain that uses celebrities in its advertising), the provision of ticket machines on public transport vehicles to provide users with more flexibility (based on the Design with Intent card titled Positioning) and rewards such as pens, maps and smartcard wallets to promote voluntary compliance (based on the Design with Intent card titled Unpredictable Reinforcement combined with an object card ‘network map’).

3.5.4. Design concept definition

The ideas generated during Workshop 1 were combined into five distinct design concepts by the primary analyst through the use of processes such as combinatorial play (Liedtka and Ogilvie 2010) and affinity diagramming. This was done by the analyst outside of the workshop process due to constraints of design participants’ time.

For each concept, a summary document was developed that included a name for the concept and the features of the design associated with five system element categories: interfaces or interaction design, function allocation or automation, workplace or environment design, organisation design (e.g. policy, communication, business planning) and socio-political environment design (e.g. legislation, government activities, industry body activities). This was done to ensure that the development of design concepts considered the integration and coordination of these aspects of the system and avoided proposing a design that would be incoherent or inconsistent across aspects or levels of the system. A brief description of each of the five concepts is provided in Table 4.

Table 4. An overview of the five design concepts developed.

Concept	Description/key features
Concept 1: the smarter smartcard	– Users present a smartcard to a card reader – Each card reader has a unique personality, using characters that engage with the user. – Card readers engage with users through use of icons (such as smiley faces) and audio speech to promote respect. For registered cards, the system uses the person's name – e.g. 'thank-you < name > for contributing to the operation of our public transport system'. Variable messages would be used to avoid becoming annoying to users. – When the card is held to the reader the user can access informative and meaningful information about the status of their card (i.e. information relevant to the fare structure). – Registered users are automatically entered into prize draws each time they validate their ticket at the beginning and completion of the journey to encourage compliance and supports the collection of data.
Concept 2: a short-term option	Similar to Concept 1, but with the following additions: – Users can present a short term (paper) ticket to card readers. – Tourist packs are provided on-board the airport link bus and at tourist information centres containing a short-term ticket, a network map, and brochures about ticketing.
Concept 3: the smartcard becomes a smartphone	– Users wave their smart phone near a reader and an application on the phone communicates with the reader. – The application displays informative messages and includes the ability to recharge, provides push notifications if the balance is low, and enables direct debit / credit card secure payment before, during or within 24 hours after travel. – The smart phone application collects optional personal information in return for entry into prize draws or rewards. – Transport for low-income passengers is subsidised through enabling passengers to donate winnings from prize draws that are turned into travel money for people in need. – Random surveys are available via the application covering topics such as customer experience / feedback on public transport services, particular reasons for travel and travel patterns, feedback on marketing strategies, etc. – A reporting system is integrated within the smart phone application enabling the reporting of issues around disrespectful behaviour, vandalism, faulty equipment, safety hazards, etc. Users are rewarded for reporting issues and feedback is provided about the action taken in response to the report. The reporting system is also available through a website enabling those without the application to report issues/concerns.
Concept 4: an automatic ticketing system	Similar to Concept 3, but instead of waving the smartphone near the reader a GPS tracker / sensor is provided at railway stations and on other vehicles (e.g. buses) which communicates with a smartphone application without need for user to take any action. Further, as with Concept 2, short term (paper) tickets can be used as an alternative to the smart phone application.
Concept 5: a more sociable ticketing system	Similar to Concept 3, but with the following additions: – An educational game is available via the smartphone application which assists users to learn about the public transport network, ticketing rules, how to reach popular destinations, etc. The game is linked to rewards via points that can be exchanged for travel money or as vouchers for tourist attractions, restaurants, etc. – Points are also gathered by travelling on the network when the smartphone is used for ticketing. – The game is linked to a social media site enabling users to 'check themselves in' at different destinations, leave travel tips for other users, or engage in discussion forums. Users are encouraged to identify themselves on social media to promote ownership and respect. – Celebrities roam the system providing random rewards to users who have valid tickets or who are seen performing other desirable actions such as assisting other passengers with luggage or prams, stepping back to allow passengers off the vehicle before attempting to board, giving up their seat others, etc. – Short term (paper) tickets can be used as an alternative to the smart phone application.

3.5.5. Workshop 2: design concept shortlist

In Workshop 2, the five concept summaries were presented to the participants. The concept summaries left some aspects blank where the original ideas had been underspecified and participants began by brainstorming how these underspecified areas should be addressed. This led to refinement of the concepts followed by participants being asked to select two to three concepts for evaluation. Rather than selecting particular concepts, the participants instead combined various aspects from all five of the concept summaries and created two new concepts.

The first concept created by the participants (Refined Concept 1) involved a combination of durable smartcards, short-term tickets (associated with a small levy to discourage regular use) and a software application for smartphones which could be validated at ticket readers. This involved combining aspects of the initial concepts 1, 2 and 3. The design participants felt that choice was important for different user groups. For example, a smartphone application alone was seen as potentially disadvantaging those who cannot afford or do not wish to own a smartphone. The concept also incorporated ideas from various concepts in Table 4 such as ticket readers that would engage with users through different personas using variable messages, and users being entered into prize draws when they validate their tickets. Further, the concept included the removal of ticket readers and barriers at train stations with readers instead located on trains.

Refined Concept 1 was seen as a baseline concept, with Refined Concept 2 building upon it to incorporate a more sophisticated smartphone application with additional features. This would include the game (proposed in Initial Concept 5, Table 4) to educate users about the city's public transport system, the ticketing and fare rules and social conventions and desirable behaviour on public transport. It would also include a reporting system where users could provide feedback about system performance and safety. Points or prizes would be awarded for reporting. Further, there would be an integrated social media forum.

3.5.6. Evaluation and design refinement

A key component of the CWA-DT is the preliminary evaluation of design concepts via inserting them into the original CWA outputs. The purpose of this is to examine the effects of introducing new technologies/artefacts/information within the wider sociotechnical system. This process was undertaken to conduct a high-level evaluation of the two design concepts that were created in Workshop 2. First, the design changes associated with each concept were inserted into each of the CWA outputs to identify the effects the changes would have on the system. Figure 6 provides an example of how this was achieved with the CAT representation. The shapes overlaid on the CAT indicate how Refined Concept 1 would introduce flexibility into the system by enabling journey payment to occur at any time in the journey cycle, even following travel, through the use of a smartphone application. Customers could also use the application to check the validity of their ticketing product, and to monitor their account. No negative effects were identified in the CAT evaluation.

The evaluation of Refined Concept 1 with the SAD analysis found that some criteria (such as the presence and status of ticket barriers) would be removed and that this might have a negative effect on minimising fare evasion. However, the proposed smartphone application would provide users with the ability to check to their balance and the ability to purchase a travel pass or value during or after the journey and this added flexibility would have a positive effect on minimising fare evasion.

Based on evaluations of both concepts across all CWA outputs, a concept evaluation summary was developed for each concept which summarised the:

- elements of the design concept;
- extent to which it met the design criteria (both the system-specific and sociotechnical values criteria);
- extent to which it addressed the pain points (i.e. whether these were removed in the design concept);
- benefits in terms of the extent to which the concept met the goals (predominantly through tracing the effects through the AH);
- estimated costs and cost savings associated with implementing and operating the design
- potential undesired / emergent effects identified;
- assumptions that the design concept relied upon for its success; and
- areas requiring further investigation to inform further design activities.

3.5.7. Workshop 3: concept selection

Participants returned for Workshop 3 where they were presented with the outcomes of the evaluation. The participants provided feedback and comments on the evaluation, including areas where potential costs or benefits were missed in the

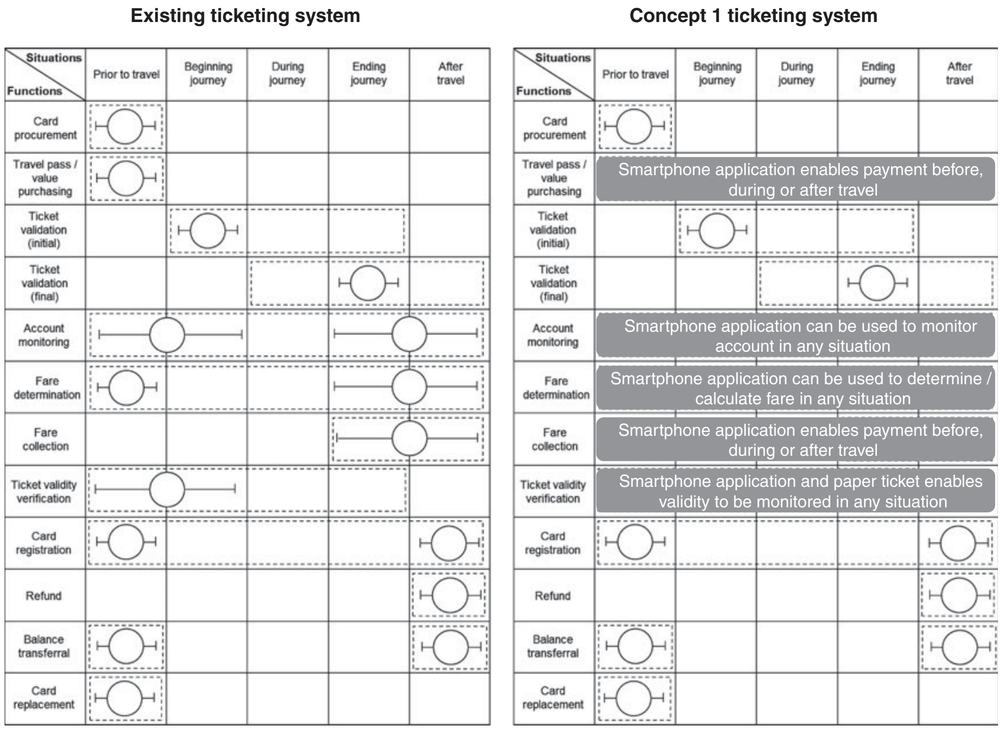

Figure 6. Evaluation of Refined Concept 1 using the CAT.

summary. The concept evaluation summaries raised a number of areas where further investigation would be required before participants felt comfortable to commit to selecting a final concept for further development. For example, would the removal of ticket barriers potentially lead to higher levels of anti-social / criminal behaviour? Would the costs of developing and maintaining a sophisticated smartphone application be reasonable?

In general, it was agreed that Refined Concept 1 would provide a more flexible system for users while promoting user engagement and respect for the system which was expected to reduce costs associated with vandalism, anti-social behaviour and property damage. Ideas for reducing the additional costs of Refined Concept 2 included advertising and partnerships with commercial organisations, such as those relying on the tourist market.

4. Evaluation of the CWA-DT

Feedback from participants and a reflective process undertaken by the primary analyst were used to evaluate the performance of the CWA-DT according to the evaluation criteria outlined in Section 2.1. These criteria can be categorised as relating to methodological considerations (whether the process facilitated creativity, was structured, valid, etc.) and to sociotechnical systems theory considerations (whether the process aligned with the values and principles of sociotechnical systems theory).

The participant feedback was gathered through in two ways. Qualitative feedback was gathered through verbal feedback from participants following the idea generation session as well as from open-ended questions in a questionnaire completed by participants at the final workshop. The questionnaire asked participants to document the best part of the design process and their suggestions for how the process could be improved. The questionnaire also gathered quantitative data through participant ratings, on a five-point scale from strongly agree to strongly disagree, regarding the extent to which the process met the seven methodological criteria discussed in Section 2.1. The criteria relating to sociotechnical systems theory were considered not conducive to participant ratings.

The analyst reflection focussed on the extent to which the overall process (from analysis planning to concept selection) met the methodological evaluation criteria and the sociotechnical systems theory evaluation criteria.

Table 5. Participant ratings and analyst reflections on the application of the CWA-DT and the extent to which it achieved the evaluation criteria.

Criteria	Participant ratings	Analyst reflections
Creative	Strongly agree ($n = 3$) Agree ($n = 1$)	Many ideas were generated that, to the authors' knowledge, are not currently used in ticketing systems. This would suggest that the process stimulated creativity. Anecdotally, participants suggested to the researcher that they had not realised they could be creative prior to the workshop.
Structured	Strongly agree ($n = 1$) Agree ($n = 3$)	The translation of insights to design materials was straightforward using the toolkit. The design documentation helped to drive the process, and the workshop activities were well-structured and were effective in producing design ideas.
Efficient	Strongly agree ($n = 1$) Agree ($n = 1$) Neutral ($n = 2$)	Workshop time was under four hours, and the researcher spent approximately 40 hours on preparation for, facilitating and documenting the design workshops. Considering the comprehensiveness of the design concepts and evaluation findings, this can be considered an effective use of time.
Holistic	Strongly agree ($n = 1$) Agree ($n = 1$) Neutral ($n = 1$) Disagree ($n = 1$)	The concept summaries assisted to ensure that the design concepts took into account all elements of the system and varying system levels. However, in idea generation, the participants tended to focus on the physical level of the system. Potentially, this was influenced by the use of the inspiration cards which tended to focus on the physical interaction. Further, the workshop participants were ostensibly users of the system and a process involving more various stakeholders would potentially bring the discussions up to the wider system view.
Iterative	Strongly agree ($n = 1$) Neutral ($n = 2$) Disagree ($n = 1$)	The workshops enabled some iteration to occur in relation to changing and refining aspects of the concepts each time they were considered. However, the time constraints of the case study process limited a truly iterative process. For example, the refined concepts were created through the merging of the components of the initial concepts developed.
Integrated	Strongly agree ($n = 1$) Agree ($n = 3$)	As a case study process, involving postgraduate student participants, the success of the case study in relation to integration with real world processes could not be determined. However, it is interesting that all participants agreed or strongly agreed that this criterion was met.
Valid	Strongly agree ($n = 1$) Agree ($n = 3$)	The process has demonstrated the ability to translate findings from CWA into a participatory design process. The process generated a number of innovative ideas that were refined over workshop sessions to develop two refined concepts. Participants responded positively to the process indicating that it at least had face validity. Further, the design concepts selected by the participants increased the flexibility of the system. This would suggest that their implementation would increase the system's adaptive capacity.

4.1. Methodological criteria

Participant ratings against the methodological evaluation criteria are shown in Table 5. Participants generally agreed or strongly agreed that the process met the evaluation criteria. However, in the case of the iterative and holistic criteria, at least one participant in each case disagreed that they were achieved.

The analyst reflections against each criterion are also provided in Table 5. They show that, in general, the evaluation criteria appear to have been met successfully. Consistently, with the views of participants, areas of improvement were identified in relation to iteration and holism, as well as integration, which was difficult to determine in a case study application.

4.2. Sociotechnical systems theory criteria

Analyst reflections on the extent to which the two sociotechnical systems theory evaluation criteria were met are provided in Table 6. The first set of criteria related to alignment with sociotechnical values. This applies to both the design process and the outcome of that process. During the workshops, the participants readily accepted these values and appeared to embrace them. As noted in the table, discussion points during the workshops related to the values and many were incorporated in the design concepts selected. However, additional time for participants to discuss and agree upon the values and a structured process for doing this would be beneficial in future.

The second criterion relates to the extent to which the proposed concepts met the sociotechnical content principles. Some general comments on a sub-set of the content principles are provided in Table 6.

4.3. Additional participant reflections

In response to the open-ended questions posed to participants at the conclusion of Workshop 3, the participants generally provided positive feedback about the idea generation session and the inspiration cards, particularly the Design with Intent

Table 6. Analyst reflections on sociotechnical systems theory criteria.

Criteria	Analyst reflections
The design approach facilitates a process that aligns with the sociotechnical values	
Humans as assets	Being users themselves, the design participants expressed their empathy for users described in the scenarios that were used to communicate the pain points uncovered in the analysis. Further, design ideas generated tended to focus on the needs of users.
Technology as a tool to assist humans	The design concepts promoted choice between more technologically sophisticated options (such as the smartphone application and smartcard) as well as a less sophisticated options being the paper tickets. These technologies were seen by the participants as being convenient and useful for users, as well as meeting system goals.
Promote quality of life	The idea of introducing a social media platform was related to promoting a sense of community and inclusiveness amongst public transport users. Further, the design concepts were focussed on engaging users and rewarding desired behaviour as opposed to punishing undesired behaviour.
Respect for individual differences	The participants focussed on flexibility and options for users who may have different requirements. Further, the project team was cognisant of the need to respect different working styles and preferences of the design participants. Accordingly, participants were given freedom and flexibility in the way they generated ideas and came to consensus regarding design decisions.
Responsibility to all stakeholders	In relation to the value of responsibility to all stakeholders, there were some discussions that aligned with this. For example, sustainability was raised during the workshops as a reason to avoid short term paper-based tickets and their inclusion in the final design concepts was only agreed where a disincentive was applied via a surcharge for using this ticket type.
The design approach produces designs that align with sociotechnical content principles	
Tasks are allocated appropriately between and amongst humans and technology	Participants rejected the design concept incorporating a fully automated ticketing system as they, as users, felt it important to retain control over their account and an awareness of what was happening with it. The concept selected maintained the majority of current user tasks and the enhanced concept extended the amount of tasks that could be undertaken by users by introducing means to report issues and to interact socially via smartphone applications.
Useful, meaningful and whole tasks are designed	As noted previously, the design participants thought that users would want to retain control over their account. Accordingly, they did not recommend automating user tasks or aspects of them. Further, meaningfulness was illustrated by attempts to improve how the system communicates with users with ideas to provide messages in words rather than through the use of beeps or alarms and through engagement such as via the smartphone 'game' or giving card readers different personas.
Design incorporates the needs of the business, users and managers	The high-level design requirements and the criteria for success were identified from the ticketing system AH which incorporated the needs of users as well as the government and transport operators. Through the evaluations it was therefore possible to ensure that the proposed design concepts would align with these needs.
System elements are congruent	The design concepts were formally documented in concept summaries which included areas to document the aspects of the concept that related to different elements within the system such as interfaces / interaction design, workplace / environment design and the organisation (policy, communication, business planning). Accordingly, any inconsistencies would be identified in the development of this summary and could be subject to change and refinement.
Means for undertaking tasks are flexibly specified	The design concepts promoted flexibility and choice in the type of ticket used (e.g. smartcard, smartphone application, paper ticket) as well as flexibility in when the payment for a trip can be made. These proposed changes would greatly contribute to the system's flexibility to respond to different needs and to problems and disturbances.
Intimate units and environments are designed	The proposals around social media and more human interaction with ticketing technology were intended to promote feelings of inclusivity and a more intimate environment for public transport generally. It was expected that this would promote pride and respect for the system in comparison to the current environment which has a less personal and more disciplinary character.

and the metaphor cards. Participants suggested the addition of an initial period of brainstorming with no prompts, enabling them to document their existing ideas for improving the system. Participants also responded positively to the group working and discussions but suggested that larger groups would be useful for generating more ideas.

In the questionnaire feedback, one participant who had some previous experience with CWA suggested that the best thing about the process was that the raw CWA materials were not presented in the workshop. This validated the decision to extract the design-relevant information from CWA and communicate it to design participants through other means. However, given more time to conduct the workshops and depending upon the backgrounds of those participating, use of the outputs in a participative manner within design workshops could be valuable.

Areas for improvement suggested in the questionnaire results were associated with the need for incubation time for ideas and a method for capturing ideas that arise outside of the workshops. Further, one participant raised the need for more time to consider and debate the sociotechnical values as well as the involvement of participants in the design concept definition process. Finally, it was suggested that a wider range of expertise represented within the design participants would enhance creativity for idea generation and enhance the evaluation component through providing a broader knowledge of potential costs, issues and effects of changes.

5. Conclusion

Effectively using the outputs of HFE methods to support system design in a manner that is consistent with contemporary theories of sociotechnical system performance represents a significant challenge to our discipline. The aim of this paper was to describe a case study application of the CWA-DT which aims to support the use of CWA outputs in design, given that there is currently insufficient support for this process. In addition, the study described aimed to provide some preliminary evaluation of the CWA-DT's effectiveness and to identify areas for improvement.

The ticketing system case study demonstrated that the CWA-DT was able to generate a range of design concepts using insights derived from CWA outputs developed for the existing ticketing system. Further, the CWA-DT was used to refine these concepts, evaluate them for their system-wide effects and identify the most suitable concept in line with sociotechnical systems theory.

The CWA-DT was evaluated by assessing the subjective ratings of design participants and reflections by the design team. The results of this evaluation indicate that the process was generally successful. The design process was well received by the design participants who responded positively within the workshops and through the feedback processes. Accordingly, it is concluded that this early evidence indicates that the CWA-DT can provide a suitable and theoretically appropriate design approach for ergonomics applications.

Many of the areas of improvement for the CWA-DT raised by participants were a consequence of them participating within a case study rather than a real-life design activity. For example, time limitations meant that some activities were allocated less time than they would in a real-world design process. Further, participants were postgraduate students rather than ticketing system stakeholders with expertise in this area.

It should be acknowledged that given the design of the study, it has not been possible to measure the contribution of the CWA analysis to the design outcomes directly. The creative nature of the design task would make it difficult to compare the impact of the CWA-DT, as opposed to using CWA alone, with a between-participants study. Likewise, the impact of introducing the findings of CWA analysis into alternative design processes has not been formally assessed. As such, it is not possible to ascertain the requirement for a toolkit like the CWA-DT with structured guidance and tools to assist the design process as opposed to a less structured introduction. Given that CWA is not familiar to many design teams, some form of structured guidance, such as the CWA-DT, is expected to be of use particularly for the first time CWA is used in design. Individual design teams would then be expected to select those aspects of the CWA-DT that can be best integrated into existing design processes.

Improvements suggested by participants and the analysts own reflections have been used to refine the CWA-DT. Future applications will incorporate a more robust process for introducing and discussing the sociotechnical system values as well as additional idea generation activities to promote consideration of interventions beyond the level of physical interaction. Further, the CWA-DT will recommend the participation of a broader range of stakeholders who should be involved in the design concept definition process, rather than the analyst conducting this activity.

The CWA-DT requires further evaluation using a full-scale application on a complex system. This will provide additional refinements to the toolkit and should improve its ability to effectively assist the translation of CWA outputs into valuable design concepts. In turn, this should extend the reach of CWA to improve the design of real-life complex sociotechnical systems. The toolkit, or aspects of it, could potentially also be beneficially applied in conjunction with other system-based analysis methods where analysis findings need to be translated into design concepts.

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7.2 Discussion

7.2.1 Implications for the CWA-DT

The proof of concept application of the CWA-DT provided initial positive findings regarding the effectiveness of the toolkit. Participants were highly engaged with the process and provided positive evaluation ratings against the methodological criteria. Further, the authors conducted a review of the extent to which the sociotechnical systems theory values were addressed within the design process as well as the extent to which the sociotechnical principles were represented in the design concepts. Again, this resulted in positive evaluations.

While the results are reassuring, there is a need to apply more objective measures to determine the extent to which the values and principles are embraced in the final design concepts. This could be achieved through the development of more concrete indicators for each of the values and principles. Such indicators will be developed and applied in Part Three of this thesis.

Due to its limited scope as a proof of concept test of the design approach, the outcomes of this design activity could be criticised for failing to consider in detail the activities conducted by actors such as bus drivers (who answer ticketing queries), customer service staff (who process refunds, deal with defective cards and respond to queries and complaints) and judges and court staff (who process fines, hear appeals, etc.). While the design concepts were predominantly user-centric, there was consideration of the wider aims of the system. This wider system perspective was informed by the interviews with two SMES who had previous involvement in ticketing system design.

Importantly, the proof of concept application led to the identification of potential improvements to the CWA-DT. In terms of the methodological criteria, these related to better supporting holistic thinking and better supporting iteration within the design process. Further, practical areas for improvement identified included an additional brainstorming activity, larger groups for idea generation activities, a method for capturing ideas that arise outside of the sessions, additional opportunity to consider the sociotechnical values, and finally, the involvement of a broader range of expertise including system stakeholders. The use of these recommendations to improve the CWA-DT will be discussed in Chapter 8.

7.2.2 Implications for ticketing system design

The sociotechnical systems theory approach has previously been discussed in relation to smartcard design and implementation, including for ticketing systems (Cooper, Gencturk & Lindley, 1996). However, the present study represented the first known attempt to design a smartcard system using the sociotechnical systems approach. Furthermore, no previous research has applied CWA to analyse a transport ticketing system.

The application of CWA in this context demonstrated the complexity of ticketing systems. This was an unexpected finding which has important implications for future ticketing system design. For example, although on initial consideration the purpose of the system is simple: to sell tickets to public transport passengers, on deeper consideration there are multiple purposes associated with the domain, and these purposes may conflict (especially across the domains of passengers and system administrators). Further, it is also a system that has shifted over time from a customer service setting where employees, such as conductors and drivers, are involved in ticket sales, to a self-serve paradigm with increasing levels of automation. The implications of this shift have not previously been considered from a systems perspective.

The trend towards technological innovations in ticketing systems, such as the introduction of smartcard systems, is based on a number of expected benefits. These benefits include improved personal security for users and public transport staff as cash is not required to be carried, the ability to cancel a lost or stolen card (where it has been registered by the user), better data about public transport use through better tracking of journeys and the opportunity to better understand and manage demand (e.g. through discounts for off-peak travel or regular use) (Tourism & Transport Forum, 2010). However, with the removal of employees involved in transactions the system loses potential emergent properties such as the crime deterrent influence provided by staff members on public transport vehicles and railway station platforms, the customer service value of an employee available to answer questions and provide ticketing and travel advice, and the additional capacity for response to emergencies and unforeseen events on public transport. Further, with poor design and implementation of the smartcard system, the espoused benefits are unlikely to be realised. For example, users may not register their card because of concerns about surveillance linked to a general mistrust of government to handle the personal information of private citizens (Cooper, Gencturk & Lindley, 1996). This reduces the expected benefits in relation to security (as non-registered cards may still be stolen and re-used) and in relation to the recovery of funds when cards are lost or stolen. Fewer registered cards also limits the type of data that transport operators can collect about users to use for planning public transport services and managing demand. Thinking broadly, a poorly designed ticketing system could reinforce negative attitudes towards public transport and lead potential users to choose less sustainable transport modes such as private vehicles.

The CWA provided valuable insights into the constraints affecting passenger interaction with the ticketing system. Further, the application of the CWA-DT led to the creation of design concepts that would potentially mean greater optimisation of the human and technological aspects of this system. The design concepts appear to embrace the sociotechnical systems theory values and principles more so than the existing design. For example, the final designs focussed on providing flexibility and choice for users such as through the implementation of a smartcard with additional options such as short-term paper tickets for tourists or occasional users, as well as mobile phone applications for those who prefer the convenience of using an existing technology instead of needing to purchase a separate smartcard for their public transport travel. The final design concepts were also heavily influenced by a concern to support the social aspects of the ticketing system and potentially to use the ticketing system to promote social connection amongst transport users (i.e. through an integrated social media forum). This may assist to promote the quality of life of public transport users and also supports the sociotechnical principle of designing intimate units and environments.

7.2.3 Implications for sociotechnical systems theory

This proof of concept application of the CWA-DT has provided further support for the utility of sociotechnical systems thinking to non-employment contexts and demonstrates the benefit of expanding systems thinking beyond traditional domains as advocated by Davis and colleagues (2014). In fact, the increasingly routine uptake of technological solutions by government authorities to keep pace with international practice and to obtain promised cost savings makes the need for sociotechnical design more urgent. Modern society risks becoming overly technocentric, with little consideration of the impact of new technologies on the overall purposes of the system and on human quality of life. The sociotechnical systems theory approach represents an opportunity to redress this imbalance.

It is not the stifling of progress that is being advocated, but careful consideration being given to ensure that systems, especially public services such as the public transport, are designed to meet not only short-term economic goals, but also the longer-term social and environmental needs of society.

7.3 Conclusion

Based on the feedback from participants and the reflections on the design process and outcome, it can be concluded that the proof of concept application was successful. The process of developing insights from the analysis was straightforward for the analyst, participants were highly engaged with the design activities, the outcomes were innovative and practical and, with further refinement, could provide a valuable contribution to improve future ticketing systems. The exercise also led to the recommendation of important refinements to the CWA-DT. In the following chapter, a description will be provided regarding how these recommendations were implemented in Version 2 of the CWA-DT. Subsequently, in Part Three of this thesis, the results of more rigorous testing of Version 2 of the toolkit, based on the full scale application to the design of RLXs, will be presented.

8 Refining the design approach – Version 2 of the CWA-DT

8.1 Introduction

While the proof of concept application of the CWA-DT to the design of a public transport ticketing system yielded positive findings, areas for improvement were identified and these were a focus for the second iteration of the CWA-DT. Based on the findings, changes were made to the toolkit to improve its effectiveness prior to its application in the RLX domain, and to increase its utility for future applications more generally.

The aim of this chapter is to describe the activities undertaken to refine and improve the CWA-DT and to provide an outline of Version 2 of the toolkit. Detail is provided about the key changes to the CWA-DT made in Version 2 and a description is provided of a review and validation process held with SMEs to provide feedback on the amendments.

8.2 Amendments to the CWA-DT

Participant feedback from the proof of concept application, provided either verbally during the session or through written responses to the evaluation questionnaires, was reviewed and recommendations for improvement were identified (see Chapter 7). Further, a reflective process was adopted following the proof of concept study which identified additional recommendations for improvement. One additional area for improvement realised through the reflective process was the need to ensure the utility of the toolkit when used by analysts other than the developer. Consideration was given to how unfamiliar users of the CWA-DT could be guided to easily identify insights and to select appropriate design tools for their design purposes. Table 8.1 describes refinements made to the toolkit based on each recommendation for improvement and includes references to relevant parts of the final version of the CWA-DT provided in the Appendix.

Table 8.1. Recommendations arising from the proof of concept application and associated refinements to the CWA-DT.

Recommendation	Refinement	Reference in the Appendix (final version of the CWA-DT)
Participant recommendations		
1. Addition of an initial period of brainstorming with no prompts – enabling design participants to document their existing ideas for improving the system.	CWA-DT guidance on idea generation updated to suggest this activity.	'Selecting design tools' (p. 61).
2. Use of larger groups for idea generation (e.g. larger than groups of two) to help in generating more ideas.	The CWA-DT guidance for workshop planning now refers to an optimal small group size of 5-7, based on good practice in facilitation.	'Create an appropriate environment' (p. 20).
3. Need for incubation time and capturing of ideas that occur outside of the workshop.	Addition of suggestions for capturing ideas away from the workshop (where it extends over multiple sessions). For example, providing participants with notepads, asking them to photograph inspirations, etc.	'Prepare participants for creativity' (p. 22).
4. Additional time to consider and debate the sociotechnical values.	A more robust process for introducing and discussing the sociotechnical systems theory values through the addition of values cards, rather than just a discussion of the values.	'Adopt agreed values' (p. 22-24).
5. Involvement of participants in the design concept definition process.	Recommendation that design participants be involved in the design concept definition process, rather than the analyst conducting this activity.	'Design concept definition' tools (p. 139-145).
6. Involvement of participants with a wider range of expertise to enhance creativity in idea generation and also to provide expertise in the evaluation phase.	No refinement, Version 1 already incorporated this idea however it was not implemented in the proof of concept application due to the limited scope.	See guidance on 'Involve the right participants' (p. 21).
Analyst recommendations		
7. Encouragement of holistic thinking - not just the physical design of the system.	Additional focus on other aspects of the system where this is within the design scope. The affinity diagramming tool provided in Version 1 could provide this however it was not selected for use in the proof of concept study.	'Affinity Diagramming' tool (p. 140).
8. Allow appropriate time and support for iteration.	Guidance for planning the design process acknowledges the need to provide sufficient time and support for iteration throughout the analysis, design and evaluation stages	'Complete the analysis brief' (page 39) and 'Complete the design brief' (p. 69).
9. The use of 'prompts' to assist in developing insights - to improve ease of insight development.	Development of CWA prompts and organisational metaphor prompts to assist analysts to identify insights about the system's functioning.	'Prompting for insights' (p. 53).
10. Guidance for design tool selection.	Addition of the Design tool selection matrix to assist teams to select appropriate design tools for their design purposes and scope.	'Selecting design tools' (p. 61-68).

The key amendments arising from the proof of concept study were the addition of insight prompts to assist analysts to identify insights (Recommendation 9 in Table 8.1) and the additional of a matrix document to assist design teams to select appropriate tools for their design brief (Recommendation 10 in Table 8.1). The development of these additions to the CWA-DT are discussed in detail in the following sections.

8.3 Prompting for insights

The use of prompts to assist in building analysis outputs and interrogating them for the purposes of evaluation or design has previously been applied for other methods, such as hierarchical task analysis (Stanton, 2006). These questions or prompts can be specific to the problem domain. For example, for job design, a question to assist in the process of developing a hierarchical task analysis might be 'how does information flow in the task?' (Bruseberg & Shepherd, 1997).

Adopting this idea for the CWA-DT resulted in the development of two sets of prompt questions that aim to assist research teams to thoroughly interrogate the CWA outputs for insights, particularly where all team members may not have been involved in developing all outputs. The prompts are intended to be used following the application of CWA (although their use may lead to iterations to the analysis), within a facilitated group setting.

8.3.1 CWA prompts

The first set of prompts relate to the different phases of CWA. A sample of prompts is provided in Table 8.2 (see page 103 of the Appendix for the complete set). The CWA prompts aim to draw out relevant findings and insights based on the CWA literature (e.g. based on descriptions by Vicente, 1999; Jenkins, Stanton, Salmon & Walker, 2009) as well as to pose questions drawn from the sociotechnical systems theory literature, particularly those offered by Appelbaum (1997). It is intended that analysts would apply prompts appropriate for the phases of analysis they have selected for the CWA and not necessarily apply the whole list. Over time, analysts might begin to consider these prompts tacitly while conducting the analysis or may add new prompts that they find useful.

Table 8.2. Sample of CWA prompts.

CWA phase / tool	Prompt questions
Overall context	- What are the major factors in the organisation's environment that influence the system's functioning? - Considering the inputs to the system: Where do they come from? Are there any potential issues with their supply? - Considering the outputs of the system: Where do they go? What wider purpose do they serve? What might happen if they were not produced?
Work domain analysis	- Are there multiple purposes specified for the system? Do these conflict? Could they potentially conflict? Under what circumstances? - Are there conflicting values & priority measures within the system? - Are there any unexpected or unusual functions? - Which object-related processes are poorly supported by the physical objects? - Which physical objects have the most influence / support the most object-related processes?
Stakeholder object worlds	- What are the key differences amongst stakeholder object worlds? - Can differences lead to issues relevant to achieving the purpose/s of the system?
Contextual activity template	- Was it straightforward to define the situations for the CAT? - Do the situations have clear boundaries, or do they overlap? - For what situations is it possible to complete tasks, although they are not typically undertaken? Why are they not typically undertaken?
Decision ladders	- Are the alerts for key decisions clear and unambiguous? - What leaps or shunts should be supported? - Should any leaps or shunts be restricted?
Information flowcharts	- Which flowcharts showed the most flexibility for completing tasks? - Did any flowcharts have limited options for completing the task? - Are certain strategies used more often than others? Why?
Strategies analysis diagram and flowchart	- Which physical objects have the most interaction with actors in the system? - Can any interactions between actors and physical objects be improved? - Were any interesting or unusual strategies identified? Should these strategies be supported? Should these strategies be constrained?
Social organisation and cooperation analysis	- To what extent are tasks currently completed by: Humans? Technology? - Would any tasks completed by humans be better completed by technology? - Would any tasks completed by technology be better completed by humans? - Do bottlenecks exist in relation to task or communication flow?
Skills, rules, knowledge taxonomy	- What are the routine tasks? Does the system support these tasks through direct perception and action? - Does the system support problem solving activities for non-routine / unforeseen tasks and situations? - What high-consequence errors could occur? How does the system prevent errors? How does the system support error detection? How does the system support error recovery? How does the system support the mitigation of the consequences of error? - Do those responsible for tasks have the necessary knowledge and skills for the task (including in non-routine / unforeseen circumstances)?

8.3.2 Organisational metaphor prompts

The second set of prompts is derived from a sociological approach consisting of four paradigms through which organisational functioning can be viewed (Morgan, 1980). The aim of this set of prompts is to promote innovative or ‘out of the box’ thinking about the system under consideration. The four paradigms are: functionalist, interpretive, radical humanist and radical structuralist. Figure 8.1 (adapted from Morgan, 1980) shows how these paradigms vary on the extent to which they align with views of the need to control and regulate systems versus openness to radical change (vertical axis). They also vary with the extent to which they are concerned with objective views of a system or subjective views (horizontal axis).

CWA fits within the functionalist paradigm. Within CWA, systems are viewed as performing a function, they have a purpose and the analytical tools can be used to understand how the system meets its purpose. CWA also takes an objective view of the system in that it assumes that there is an objective truth about the way the system functions, rather than focussing on the subjective experience and understanding of humans within the system. Sociotechnical systems theory takes into account the subjective experience of those within the system slightly more so but could still be classified as falling within the functionalist paradigm due to its focus on the optimisation of human and technological aspects of a system to achieve a common goal. Therefore, when applying CWA and the sociotechnical systems theory approach, it may be possible to fail to consider the other paradigms, especially those aligned with perspectives on radical change. Prompts to consider questions relating to the other quadrants of the matrix can enable research teams to think outside of their usual paradigms and might provide a greater insight into system functioning. This is based on the notion that there is no single correct or optimal paradigm from which to understand the world (Meadows, 1999; Morgan, 1980) and that looking through multiple lenses could enhance generative thinking and creativity. Morgan (1980) suggests that within each paradigm, metaphors for organisational functioning can be used to expand thinking about organisations and systems.

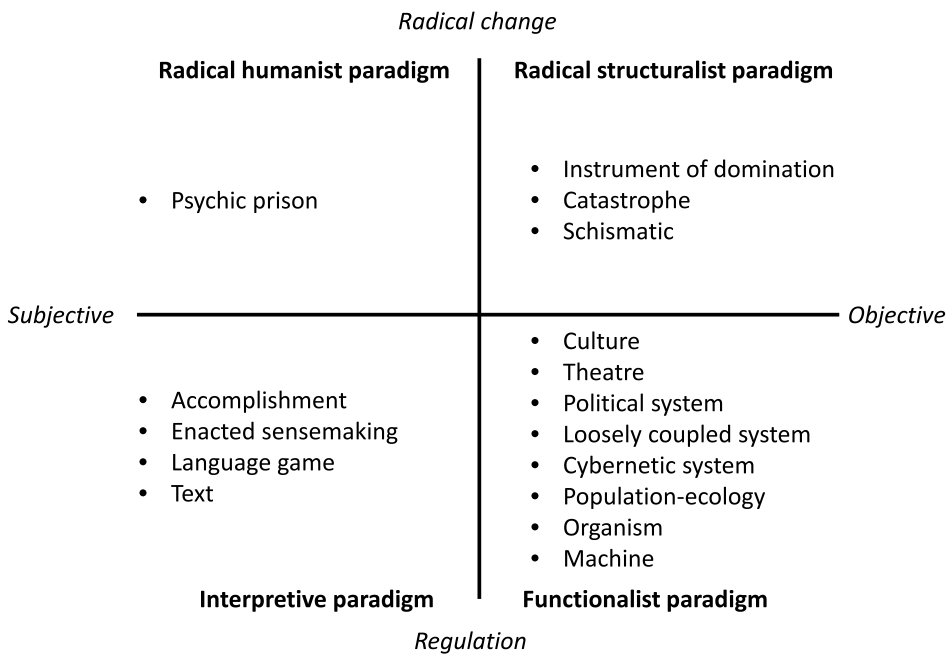

Figure 8.1. Paradigms for understanding organisational functioning (adapted from Morgan, 1980).

Interestingly, while the functionalist paradigm is most familiar in relation to systems theory, the radical structuralist paradigm also contains ideas arising from systems theory. For example, the schismatic metaphor of organisations focuses attention upon how organisations have a tendency to fragment and disintegrate as a result of internally generated strains and tensions. Morgan (1980) notes that this view counters the functionalist premise that organisations are unified entities seeking to adapt and survive, by focusing upon processes through which organisations factionalise as a result of schismogenesis (Bateson, 1936) and the development of patterns of functional autonomy (Gouldner, 1959, as cited in Morgan, 1980). This is relevant to the principle of entropy in general systems theory. Another metaphor in this paradigm, catastrophe theory, relates to the mathematical theory proposed by Thom (1975) which enables the modelling of changes to equilibrium. This theory posits that small changes in certain parameters of a nonlinear system can cause equilibria to appear or disappear, or to change from attracting to repelling and vice versa, leading to large and sudden changes of the behaviour of the system. This is akin to the idea of 'tipping points' which has become a popular notion about system change since the release of Malcolm Gladwell's (2000) book.

Based on Morgan's descriptions of the metaphors shown in Figure 8.1, a number of prompt questions were identified for application to CWA outputs. Table 8.3 provides a sample of these (for the complete list, see page 107 of the Appendix). These prompts enable researchers to explore different organisational metaphors and paradigms. This is particularly beneficial for systems thinking and aligns with Meadows' (1999) proposal that the most effective leverage point in a system is the ability to transcend paradigms.

Table 8.3. Sample of organisational metaphor prompts.

Metaphor	Prompt questions
Functionalist paradigm	
Cybernetic metaphor	- How does information flow through the system? - Are feedback loops in place?
Loosely coupled systems metaphor	- In what aspects is the system inefficient? - Where is coordination between system components, actors or groups of actors unsuccessful or lacking? - Are there situations where any one of several means will produce the same end?
Population-ecology metaphor	- What are the system's main competitors? - What other options are available to users / customers / clients to achieve their goals? - What activities are intentionally undertaken to maintain the system's niche?
Theatre	- What are the official roles of actors within the system? - What unofficial roles do actors undertake?
Culture	- What rituals are undertaken by actors? How did these arise? What meanings can be identified from rituals? - What stories and myths are shared between actors? How did these arise? What meanings can be identified from the stories and myths?
Political systems	- When is coercive power exercised? Who is the target of coercive power? Who exercises coercive power? - When is legitimate power exercised? Who is the target of legitimate power? Who exercises legitimate power? - Who (individual or group) holds a weak position of power?
Interpretative paradigm	
Language games	- What terminology is used by actors when talking about the system? - Is terminology or language common to particular actor groups?
Texts	- What terminology or language is used in official texts? - Are there contrasts or differences between the language used in official and unofficial texts? - Who authors texts used within the system?
Accomplishments	- What are the social rules or patterns that assist actors to successfully interact within the system? - What are the consequences if the rules are violated?
Enacted sense-making	- How do actors make sense of key situations? - Does the system support sensemaking?
Radical humanist paradigm	
Psychic prisons	- What is the ideology behind the design of the system? - Is there conflict between the goals or needs of the system, and that of actors or stakeholders of the system? - Do actors perceive the system to enable them to enact their own will and action?
Radical structuralist paradigm	
Instruments of domination	- Do processes or aspects of the system dominate or control actors within the system? - What forms does domination take? - What are the consequences of domination?
Schismatic systems	- Where are points of tension or conflict within the system? - To what extent do the parts of the system work in a coordinated manner?

	-	Is there evidence of fragmentation or disintegration within the system?
Catastrophes	-	How is the system influenced by the politics?
	-	How does the system influence politics?
	-	How is the system influenced by the local, national and international economy?
Catastrophe theory	-	Did the analysis uncover any variables for which a small change led or could lead to large or sudden changes in the system's behaviour (i.e. a tipping point)?

8.4 Developing of the design tool selection matrix

The CWA-DT identifies a range of design tools that could be useful in a design process, but Version 1 of the toolkit did not provide specific guidance on which tool should be selected for a particular design need or scope. To address this, a matrix was created to provide users of the CWA-DT with a comparative summary of the tools available to assist them to make a selection. The original version of the design tool selection matrix (which was later amended following SME input) incorporated information such as the name of the tool, a short description of the activity and its rationale and the types of design projects or issues for which it is recommended. The matrix also included a section for the research team to record their decision about whether each tool was selected for use (yes, no or maybe) and any comments on its use or potential use in the project. A sample of the original matrix is presented in Figure 8.2. The matrix intends to assist CWA-DT users to consider each of the tools and to select a combination that best meets the requirements and constraints of the project.

Design tool selection matrix

Tool	Description	Materials	Time requirements	Recommended for	Use? Y / N / maybe	Comments
Sharing the analysis findings						
Personas	Personas can be used to develop empathy with the users and stakeholders of the system. Analysts may develop this empathy through data collection activities however design participants may not experience this directly. Empathy is important for achieving designs that align with sociotechnical values.	- Pre-prepared descriptions of different actors in the system with prompting questions - Whiteboard for recording group insights	Approx 1.5 hours	All design projects (personas can also be communicated through scenarios and stories)		
Scenarios	Scenarios are a commonly used design tool. They involve documenting key situations of use in narrative form. Scenarios can be used to describe typical activities or to highlight problematic activities identified during the analysis. The length of the narratives will depend on the level of detail needed to communicate the key points and issues, and to develop a sense of empathy with the individual/s in the scenario.	- Pre-prepared scenarios with gaps for participants to complete - Photos / pictures / videos to enrich the scenarios - Whiteboard for recording group insights	Approx 1.5 hours	All design projects		
Stories	Stories can be used for communicating information uncovered during the analysis in a concrete, specific way.	- Pre-prepared short stories collected during the analysis. The stories should be real, personal stories that highlight key information - Photos / pictures / videos to enrich the stories - Whiteboard for recording group insights	Approx 1 hour	All design projects		

Figure 8.2. A sample from the initial version of the design tool selection matrix.

8.5 Subject matter expert review and input

To gain expert feedback on the amendments made to the CWA-DT, a three-hour workshop was held with five HFE experts who had knowledge or expertise in CWA and sociotechnical systems approaches. The workshop was held to gather feedback on the CWA prompts, the organisational metaphor prompts and on the design tool selection matrix.

In the workshop, the SMEs were introduced to the CWA prompts and organisational metaphor prompts and were asked to apply a selection of prompts to CWA analysis outputs they had previously developed. The experts provided anecdotal feedback that the prompts would be a useful resource to apply to the analysis outputs to identify key findings and insights. The review process led to some amendments to the prompts to improve understanding and usability as well as the addition of a number of new prompts that the experts suggested they would regularly consider tacitly when reviewing their own CWA outputs. One of the suggestions arising from the expert review was to provide the organisational prompts in the form of cards to enable a design team to randomly select one or two from the pack and use them to brainstorm insights and findings. Alternatively, design teams could select the metaphors that most contrast the current system paradigm or their personal background and training to expand their thinking as much as possible. The final versions of the prompts are shown in the Appendix (from page 103 and page 107). The card format for the organisational metaphor prompts is available from page 113.

The SMEs were subsequently introduced to an initial version of the design tool selection matrix and asked to conduct an exercise to imagine selecting tools to use for a particular design activity. This exercise resulted in suggestions to provide detail about the inputs required for each design tool and the outputs that would be achieved from conducting it. It also led to the addition of information about time requirements for each exercise. Apart from these minor additions, it was generally suggested that the matrix would be useful to assist design teams to select from the range of tools and activities recommended by the CWA-DT. The final design tool selection matrix is provided in the Appendix (from page 63).

8.6 The refined CWA-DT

The refined process for the CWA-DT is shown in Figure 8.3. The key differences from Version 1 (Figure 6.1, Chapter 6), is the addition of analysis prompts to assist users to identify insights, as well as the design tool selection matrix within the design planning stage.

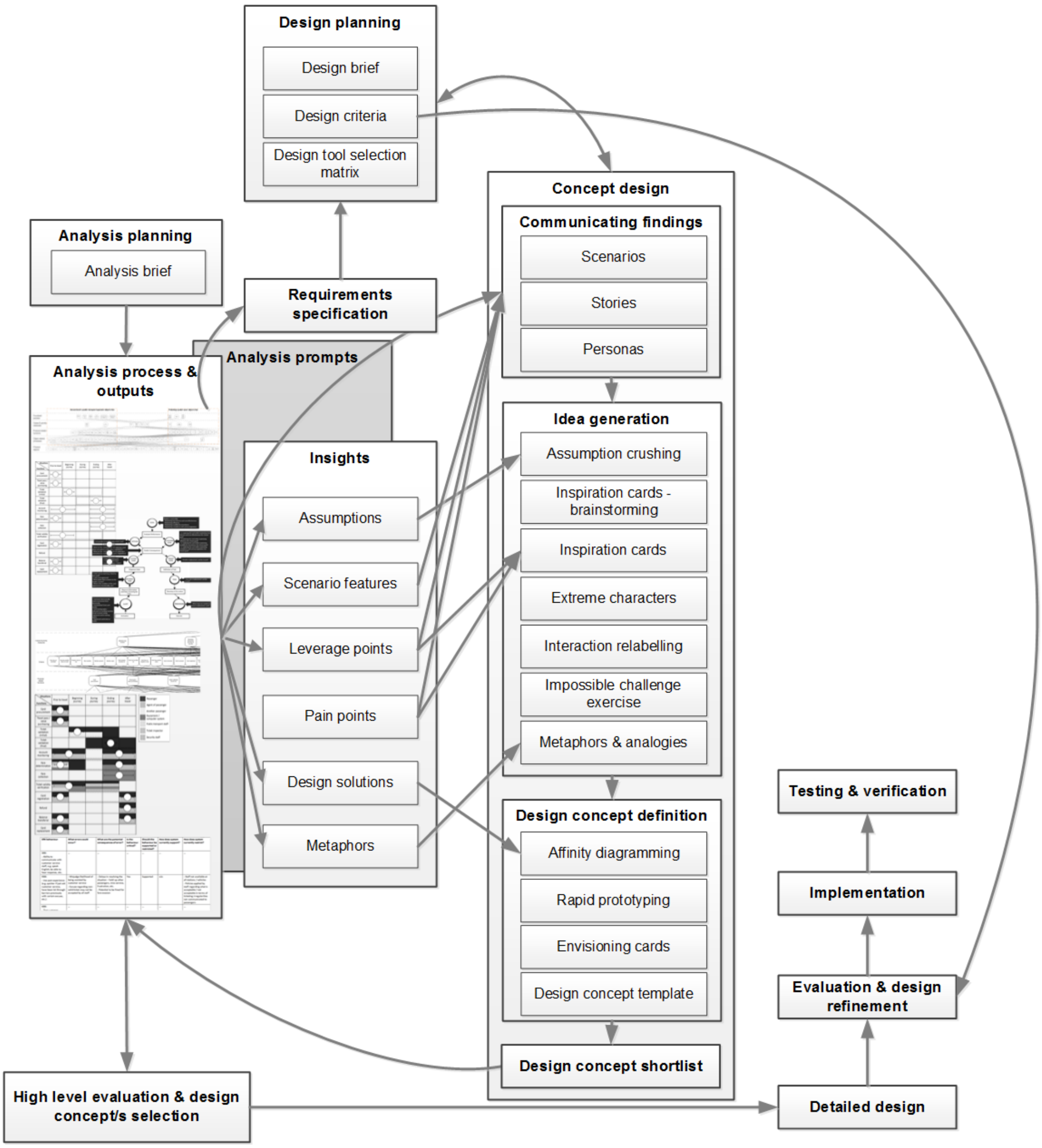

Figure 8.3. Version 2 of the CWA-DT.

8.7 Conclusion

This chapter described how the CWA-DT was refined based on the outcomes of the initial proof of concept application. These refinements included additional guidance and tools for the toolkit. Major changes included the addition of prompts to assist CWA-DT users to identify insights, and the addition of the design tool selection matrix to assist selection between different tools.

The refinement of the CWA-DT based on the findings from the initial testing of the toolkit within the transport ticketing domain was the final aspect of the methodological development which has been the subject of Part Two of this thesis. Following these amendments, Version 2 of the toolkit was considered suitable for application in the safety-critical RLX domain. In the final part of this thesis, Part Three, this design application will be detailed as will implications for pedestrian safety at RLXs.

Part Three

Application of the CWA-DT to derive recommendations for improving pedestrian safety at RLXs

9 Understanding pedestrian behaviour and risk at RLXs with CWA

Read, G. J. M., Salmon, P. M., Lenné, M. G., & Stanton, N. A. (Under review). Walking the line: Understanding pedestrian behaviour and risk at rail level crossings with cognitive work analysis. *Applied Ergonomics, submitted 23 December 2014, reviews received 11 March 2015, revised manuscript submitted 2 June 2015.*

9.1 Introduction

Pedestrian deaths at RLXs have been a long-standing public safety issue in Melbourne, Australia. On the 3rd of November 1924, under the headline "Between two trains: Boy killed at Pascoevale", the Argus newspaper in Melbourne ran the following story:

> *The level crossing near the Pascoevale railway station was the scene of a distressing accident at half-past 7 o'clock on Saturday evening, when George Alcorn, aged 16 years, of Glenroy, was run down and killed by a goods train travelling towards Essendon. Alcorn, who had been to Pascoevale on a message for his parents, was attempting to cross over the tracks in front of a passenger train going to Broadmeadows. He avoided this train but did not see the goods train approaching, and it struck him before he could jump clear. People in the vicinity say that Alcorn became confused when he saw two trains approaching him from different directions, and that he hesitated for several seconds before making up his mind as to what to do. The body, which was terribly mutilated, was removed to the morgue by the Coburg police.* ('Between two trains', 1924, p. 9).

Advances in the design of RLXs to improve pedestrian safety have occurred in the intervening 91 years since the incident reported above. For example, automatic gates are provided at many RLXs which close the pedestrian pathway when trains are approaching. However, pedestrian deaths still occur, with 17 deaths occurring in the state of Victoria over the five year period between 2009 and 2013 (Transport Safety Victoria, 2014). These deaths even occur at locations with automatic gates as pedestrians retain the ability to access the tracks either through the use of unlocked emergency escape gates or by traversing the RLX using an adjacent roadway, bypassing the road boom barriers. Further, the issue of pedestrians being unaware of a second or subsequent trains approaching an RLX remains important.

It is argued in this thesis that a systems approach is required to solve the longstanding problem of pedestrian deaths at RLXs. In particular, the literature review described in Chapter 2 found that no existing RLX research has taken a systems approach and identified CWA as an appropriate tool to apply to better understand pedestrian behaviour in the RLX context to inform design processes.

It has also been established in this thesis that there is a gap between CWA and design which was the impetus for the development of the CWA-DT. An early step in applying the CWA-DT is the use of CWA to understand the problem domain. Consequently, the aim of this chapter is to provide the results of the application of CWA to pedestrian behaviour at RLXs in metropolitan Melbourne. All five phases of CWA were used to provide a comprehensive understanding of behaviour, from the ecological functional structure (provided by the WDA), through each of the phases to the cognitive constraints (identified in the WCA phase).

Declaration for Thesis Chapter 9

Declaration by candidate

In the case of Chapter 9, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Primary author responsible for the concept, design, data collection activities, the CWA analysis and interpretation. Responsible for initial drafting of the paper and subsequent editing.	85%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	Nature of contribution	Extent of contribution (%) for student co-authors only
Paul M. Salmon	Contributed to the design of the study, reviewed the CWA analysis and provided critical review of draft versions of the paper.	n/a
Michael G. Lenné	Contributed to the design of the study and provided critical review of draft versions of the paper.	n/a
Neville A. Stanton	Reviewed the CWA analysis and provided critical review of draft versions of the paper.	n/a

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's Signature	[redacted]	**Date** 2 July 2015
Main Supervisor's Signature	[redacted]	**Date** 2 July 2015

Walking the Line: Understanding pedestrian behaviour and risk at rail level crossings with cognitive work analysis

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Abstract

Pedestrian fatalities at rail level crossings (RLXs) are a public safety concern for governments worldwide. There is little literature examining pedestrian behaviour at RLXs and no previous studies have adopted a formative approach to understanding behaviour in this context. In this article, cognitive work analysis is applied to understand the constraints that shape pedestrian behaviour at RLXs in Melbourne, Australia. The five phases of cognitive work analysis were developed using data gathered via document analysis, behavioural observation, walk-throughs and critical decision method interviews. The analysis demonstrates the complex nature of pedestrian decision making at RLXs and the findings are synthesised to provide a model illustrating the influences on pedestrian decision making in this context (i.e. time, effort and social pressures). Further, the CWA outputs are used to inform an analysis of the risks to safety associated with pedestrian behaviour at RLXs and the identification of potential interventions to reduce risk.

Keywords: rail level crossings, pedestrians, cognitive work analysis, constraints, systems approach, risk

1. Introduction

1.1 Rail level crossings

Across Australia, over the ten years between June 2002 and July 2012, there were 92 collisions between trains and pedestrians at rail level crossings (RLXs, Australian Transport Safety Bureau, 2012). In the state of Victoria, 17 fatalities and six serious injuries resulted from pedestrians having been struck by trains over five years between 2009 and 2013 (Transport Safety Victoria, 2014). Pedestrian fatalities at RLXs represent close to three times those of road vehicle occupants.

In Melbourne, Australia, RLX infrastructure operates in one of three ways. The first type of design provides static warning signs and indications to inform users that a rail crossing is present, but provides no indication of whether a train is approaching. The second type of RLX provides an alert that a train is approaching (through active warnings such as flashing lights and bells), whilst the third type provides active warnings and physical barriers (such as pedestrian gates and boom barriers, and road boom barriers) intended to prevent road users accessing and traversing the crossing while a train is approaching. The latter types of risk controls are generally considered to be the most effective in minimising collisions, at least for road vehicles (e.g. Wigglesworth & Uber, 1991). However, even with the widespread use of physical barriers, collisions still occur.

Modern safety science advocates a systems approach to the analysis and design of complex safety-critical domains (Leveson, 2004; Rasmussen, 1997; Salmon & Lenné, 2015; Wilson, 2014). Such an approach views accidents as emergent properties of the interactions within a system, rather than focusing on individual components which, even if addressed well, may not prevent future occurrences due to the variability in performance within modern complex systems and their dynamic nature. A review of the existing RLX literature found that no previous research has taken a systems approach to RLX safety based on criteria derived from a review of systems theory (Read, Salmon, & Lenné, 2013).

Within the peer reviewed literature studies focussing on pedestrian behaviour at RLXs are sparse. Those available have tended to take a normative approach to understanding behaviour by focusing on the tasks pedestrians should perform to be safe, and comparing actual behaviour to this optimal performance. For example, studies have examined the effects of installing new safety measures through statistical analyses to determine the effects on pedestrian behaviour (e.g. Farradyne & Sabra Wang and Associates., 2002; Siques, 2002). An exception to this is recent work by Stefanova and colleagues (2015) who used focus group data to identify factors contributing to pedestrian errors and violations at RLXs. They used Accimap (Rasmussen, 1997) to represent the systemic factors influencing behaviour in two violation scenarios. While this work took a systems approach, to date the majority of studies have employed survey, interview or focus group methods, rather than collecting naturalistic data. Further, no published studies have taken a formative approach to understanding pedestrian behaviour at RLXs meaning that our understanding is limited to describing existing behaviour rather than all of the possibilities for behaviour available.

This article is a direct response to this key knowledge gap, describing an application of the cognitive work analysis (CWA) framework undertaken to investigate pedestrian behaviour at RLXs. CWA enables analysts to identify and represent the constraints of a complex system, capturing the breadth of potential system functioning and the possibilities for action available to decision makers (Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999). It is proposed that utilising this framework will provide an innovative perspective on pedestrian behaviour in the RLX context.

CWA has been applied to many varied complex systems including nuclear power generation (e.g. Burns et al., 2008), military command and control (e.g. Jenkins, Stanton, Walker, Salmon, & Young, 2008), air traffic control (e.g. Ahlstrom, 2005) and submarine systems (Stanton & Bessell, 2014). CWA has also been applied to road transport (e.g. Birrell, Young, Jenkins, & Stanton, 2012; Cornelissen, Salmon, & Young, 2012) and rail transport (e.g. Olsson & Jansson, 2005; Roth, 2008; Stanton et al., 2013) and has recently been applied in the RLX domain (Salmon, Lenné, Read, Walker, & Stanton, 2014; Salmon et al., Revision under review). CWA has also been recently applied in the pedestrian footpath context (Stevens & Salmon, 2014); however, this did not consider pedestrian behaviour at RLXs specifically. CWA is growing in popularity as means for understanding sociotechnical systems and was chosen for application to this area due its unique constraints-based approach, its maturity as a systems analysis and design framework and its previous application in related areas.

2. Data collection

Multiple methods of data collection were used to inform the CWA including document analysis, input from subject matter experts, naturalistic covert observations of behaviour, elicitation of verbal protocols during a naturalistic walking study and critical decision method interviews. The verbal protocols were used to derive data about the content and outcome of thinking processes undertaken by participants, a purpose for which this method is considered reliable and valid (Walker, 2004) and the critical decision method interviews elicited retrospective data about participants' decision making processes. The reliability of the critical decision method has also been previously established (Plant & Stanton, 2013).

Approval for the research and all associated data collection activities was obtained from the Monash University Human Research Ethics Committee and other relevant ethics committees prior to data collection commencing. Approval for access to coronial records was obtained from the Justice Human Research Ethics Committee prior to these records being accessed.

2.1 Document analysis

Publicly available documentation regarding RLX infrastructure design and operation were sourced and analysed including the Australian standard for traffic control devices at RLXs and the Victorian rail industry standard for pedestrian infrastructure at RLXs. Further, 37 coronial inquest reports of non-intentional pedestrian deaths occurring at RLXs in Victoria between 2000 and 2012 were sourced from the National Coronial Information System managed by the Victorian Department of Justice and analysed.

2.2 Familiarisation activities

In order to observe RLXs from a train driver's perspective and gain familiarisation with the train driving task at RLXs a familiarisation ride was undertaken in a train cab for approximately four hours. Further, a number of RLXs in metropolitan Melbourne were visited to gain familiarisation with RLX functioning and the various physical layouts and features present.

2.3 Observations

Site selection

Seven RLX sites located in metropolitan Melbourne were selected for naturalistic observations. The sites were selected based on the features of the crossing (e.g. infrastructure, equipment, types of warnings present) as well as incident history. The features of each site are described in Table 1. The site selection process ensured that a range of RLX features were represented including automatic gates, automatic gates with locked emergency gates, pedestrian boom barriers, pedestrian mazes, RLXs adjacent to stations and crossings adjacent to road RLX (exposing pedestrians to features such as flashing lights and road boom barriers, etc.). At three RLX locations (sites 2, 3 and 6), two sets of pedestrian gates operated independently enabling users to access an adjacent train station with an island or center platform when a train is approaching from the far track (i.e. a track that they need not cross to reach the train station). These RLXs were all adjacent to a road RLX. One RLX (site 3) had additional countermeasures implemented including a latch on the emergency gate to prevent pedestrians being able to open the gate from the approach side of the RLX, a 'red man standing' (RMS) display (similar to a road pedestrian signal however instead of showing green it extinguishes when no train is approaching), and an 'another train coming' (ATC) display (to indicate to waiting pedestrians that the gates remain closed because another train is approaching).

All sites had been identified within a list of the top 20 unsafe RLXs in Victoria, ranked according to the total number of incidents (collisions and near misses between pedestrians and trains) that had occurred since 2005 (G. Sheppard, personal communication, May 10, 2013). The ranking for each RLX is shown in Table 1. This data is collated by the agency that owns the railway land and infrastructure in Victoria.

All observations occurred on weekdays and were planned to occur in the mornings and early afternoon, based on an analysis of occurrence data that indicated the time of day when the majority of collisions and near misses occur. At some locations the planned observations were unable to be undertaken due to operational requirements restricting access to some rail signal boxes and other unforeseen delays.

Table 1

Features and incident history at RLX observation sites

Site location and incident history	Automatic gates	Independent gate operation	Locked emergency gates	Pedestrian boom barriers	Pedestrian mazes	RMS / ATC displays	Adjacent to train station	Adjacent to road RLX
Site 1: Main Road, St Albans - 2 collisions, 54 near misses - Ranked 1 of 20	X						X	X
Site 2: Old Geelong Road, Hoppers Crossing - 3 collisions, 51 near misses - Ranked 2 of 20	X	X					X	X
Site 3: Centre Road, Bentleigh - 1 collision, 20 near misses - Ranked 4 of 20	X	X	X			X	X	X
Site 4: Beach Street, Frankston - 1 collision, 12 near misses - Ranked 8 of 20				X				
Site 5: Eel Race Road, Carrum - No collisions, 10 near misses - Ranked 14 of 20					X			X
Site 6: Glenhuntly Road, Glenhuntly - No collisions, 10 near misses - Ranked 15 of 20	X	X					X	X
Site 7: Cherry Street, Werribee - No collisions, 8 near misses - Ranked 20 of 20	X							X

Materials

A structured, paper-based form was used to record the behaviour of each user observed. The form enabled recording of the following items: date and time of the observation, system state encountered by the user (e.g. warnings not activated, warnings activated as the user approached, warnings activated as traversing crossing, etc.), the behaviour of the user in relation to each physical object present at the RLX (e.g. the fence, gate, boom barrier, etc), a description of the path taken by the user and their behaviour, including information about the person if it may have affected their behaviour (such as a mobility impairment) and a representation of the user's path through the RLX, including the starting point and destination, overlaid on an aerial map of the crossing.

Observation protocol

The observations were conducted in a covert manner to avoid influencing the behaviour of RLX users. Observations were undertaken from signal boxes with windows overlooking the RLX in question, or from a vehicle parked close to the RLX. Users to be observed were selected using a convenience sampling method. That is, not all users were observed as it was not possible to record the behaviour of all users. Further, due to the unpredictable flow of users through the crossing it was thought to be overly restrictive to limit the observations by using a random process of, for example, selecting one in five users that approached the crossing. Instead, once the behaviour of the previous pedestrian was fully documented, the next pedestrian approaching was selected for observation.

The protocol required that the user be selected when approaching the RLX, but not yet on the RLX. The person was then observed while they crossed and until they exited the crossing and moved away from the area. Where a group of people were approaching the RLX, one person in the group was selected to observe (based on which person within the group could be viewed most clearly when the observation was begun) with the effect of other pedestrians on their behaviour documented. In addition to pedestrians, cyclists who chose to use the designated pedestrian crossing were observed.

For reliability analysis purposes, an independent observer, trained in the observation protocol concurrently recorded user (pedestrian or cyclist) behaviour over three hours (approximately 10% of total observation time) at the first observation site. Ratings of 28 pedestrian crossing users were gathered during that period. Inter-rater reliability calculations were performed on two aspects of the observations for each of the 28 users observed: the classification of the system state and the classification of behaviour in relation to each physical object present. Between the raters there were 1264 agreements (e.g. both raters recorded that the user *walked within the fencing / enclosure* or both raters did not check the box that the user *walked within the fencing / enclosure*) and 93 disagreements (e.g. one observer recorded that the *user walked within the fencing / enclosure* however the other observer did not). A percentage agreement score of 93.15% was obtained. The calculations took into account situations where the physical object was not present during the observation providing no opportunity for behaviour in relation to the object. This was achieved by excluding ratings of objects not available from the analysis (i.e. was not counted as an agreement nor disagreement). This avoided calculations being biased towards agreements. Once the satisfactory level of inter-rater agreement was obtained, the remaining observations were conducted by a single observer alone.

In total, 370 crossing users were observed over approximately 30 hours of observations at the seven sites. Table 2 shows that state of the RLX warnings and the position of the user. In the majority of cases the warnings were not activated during the time the observed user traversed the RLX.

Table 2.

RLX warning state during observations

System state	**No of users observed**
Warnings not activated	200
Warnings activated as the user approached	85
Warnings activated during the whole time of approach	77
Warnings activated as the user was traversing crossing	2
Warnings activated after the user exited the crossing	3
Warnings stopped just as the user approached	2
Other	1
Total	*370*

2.4 Walking study

Participants

Participants were recruited through a weekly online university newsletter, through pamphlets distributed at local community centres and businesses and via advertisements on social media platforms. Fifteen participants (6 males, 9 females) were recruited to take part in the study (five at each study location). Participants were aged between 19 years and 62 years (M = 34.2 years, SD = 14.2 years).

Participants' experience with using RLXs generally and at the specific study location at which they participated varied across participants. The majority of participants (10) had moderate experience using RLXs (using them 'often' or 'sometimes'), while four participants reported that they used RLXs 'always'. One participant stated that they used RLXs 'rarely' but no participant reported having no prior experience using RLXs. In relation to experience with the particular RLX site, only two participants had traversed the route more than 20 times, two reported walking the route between two and 10 times previously, five participants had traversed the route only once and six participants had never previously traversed the route. In summary, the majority of participants were experienced users of RLXs but did not have particular experience using the RLX at the study location that they attended.

Materials

A paper-based demographic questionnaire was completed by participants. A laptop computer was used to display a video showing a forward facing view of a pedestrian walking on a footpath in an urban area to enable the researcher to demonstrate the verbal protocol methodology and enable participants to practice and gain feedback from the researcher.

Three RLX locations in the south-eastern suburbs of Melbourne were selected by the researchers and for each, a pre-determined route that incorporated two RLXs (once on each side of the road). The locations were Centre Road in Bentleigh (site 3 from the observation study), McKinnon Road in McKinnon and Murrumbeena Road in Murrumbeena. All sites had automatic gates and were adjacent to train stations and road RLXs.

The routes were designed to be completed in approximately 20 minutes, given differences in normal walking speeds. Route completion times for Bentleigh were between 10:35 and 15:46; for McKinnon were between 14:05 and 23:54; and for Murrumbeena were between 9:51 and 15:05. All participants wore Imging HD video recording glasses and a microphone and dictaphone to record the forward view and the verbal protocols.

A structured form was used to conduct post-walk critical decision method interviews with participants. This was used by the researcher to conduct the semi-structured interview and to record participants' responses. The interviews were audio recorded.

Protocol

Participants met the researcher at a public place near to the study site for which they had been recruited. Participants were provided with an information sheet broadly describing the aims of the research and completed a consent form. Participants were told that the research was investigating pedestrian behaviour in urban environments to avoid participants focussing more attention on RLX than they would in their everyday walking behaviour. Next, participants were provided with instructions on how to provide concurrent verbal protocols and they were subsequently asked to practise providing verbal protocols while watching a video recording of a pedestrian's perspective while walking in an urban environment. The researcher provided feedback to the participant regarding the quality of their verbal protocols until it was felt they were able to provide protocols of sufficient quality for the study. Participants were then shown the pre-determined route and were asked to memorise it. When participants were comfortable with the verbal protocol procedure and the route the recording equipment was fitted and activated. Participants were then asked to negotiate the study route whilst providing a continuous verbal protocol.

Once participants had completed the route they met the researcher at the point of origin and were asked to engage in a critical decision method interview (Klein, Calderwood, & McGregor, 1989). At this point, participants were informed that the research was focussed on the RLXs and were asked to select a decision associated with encountering an RLX during the walk that they found to be challenging, difficult or unusual. Once a decision was selected, the researcher and participant developed a timeline of the events associated with the decision and the researcher used prompt questions to gain a deep understanding of how the decision-making process undertaken by the participant including, for example, the information they used, their goals, the options they considered and how they selected or rejected various options.

The verbal protocols and critical decision method interviews were transcribed verbatim in Microsoft Word.

3. Developing the CWA outputs

3.1 Analytical considerations

To provide some further context about the RLX environment, Figure 1 provides a labelled still image taken from the forward facing camera worn by a participant in the walk-through study while traversing the RLX at Centre Road, Bentleigh (site 3 in Table 1). The RLX is adjacent to a road RLX and to a train station (with access to the station available via a path on the left in the middle of the two sets of gates). The figure shows part of the flashing light assembly on the right hand side, as well as the fencing used to direct pedestrians towards the footpath. It also shows the holding line which is delineated through the application of tactile ground surface indicators (TGSIs). The emergency escape gate, with signage indicating it is not to be used for access onto the crossing, is also shown. Although not shown in the figure because no train is approaching, this RLX incorporates automatic gates and active displays that show a red man standing symbol (when warnings activate) and / or an indication of another train approaching when gates remain closed between trains.

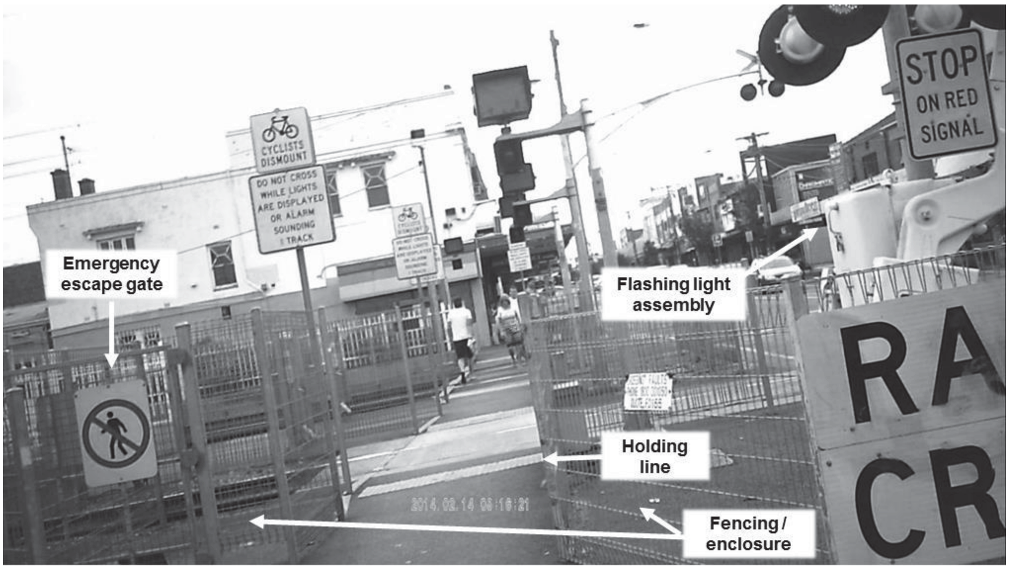

Figure 1. Still image from video of RLX with automatic gates with RLX features labelled (site 3 in Table 1).

Figure 2 is a photograph of the RLXs at Eel Race Road, Carrum (site 5 in Table 1). This RLX has no automatic gates. The 'maze' fencing configuration is intended to slow user speed on approach and to encourage them to look both ways along the track before crossing. Within the holding line is text advising pedestrians to 'wait here'. Here the holding line and markings to delineate the crossing pathway are provided as painted lines rather than TGSIs. This RLX is adjacent to a road RLX, meaning that audible bells, flashing lights and boom barriers activate when a train is approaching.

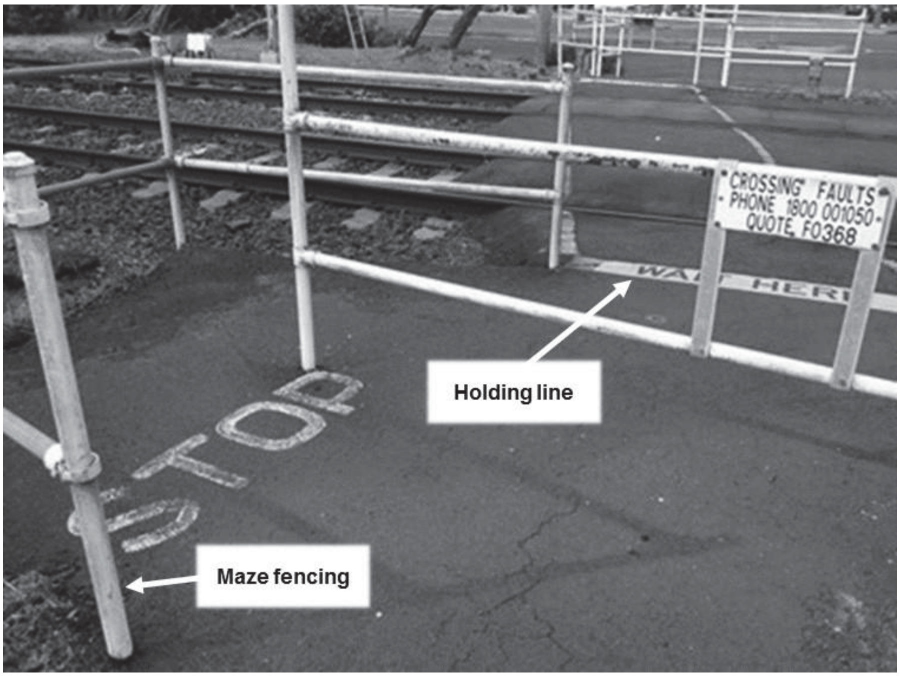

Figure 2. Photograph of maze RLX with RLX features labelled (site 5 in Table 1).

As CWA is a framework, rather than a standardised methodology, it is important to consider how it would be best applied to address safety issues at RLXs such as those identified in Figures 1 and 2. Furthermore, following the guidance of Rasmussen and colleagues (1994) and Naikar (2013) the attributes of the system under investigation should be considered, such as the extent to which the constraints on behaviour can be considered to be intentional (i.e. rely on formal and informal rules enforced by society) or causal (i.e. rely on the laws of physics).

While both types of constraints are present at RLXs, the constraints on pedestrian behaviour in this context are primarily intentional with behaviour tending to be governed by actors' personal intentions, shaped by formal rules (legislation) and social norms. The majority of the rules are intended to restrict users from traversing of the RLX while warning devices are activated. While gates are often used to physically restrict pedestrians, pedestrians retain considerable flexibility in the way in which they can approach, traverse and exit the crossing. For example, pedestrians can choose to cross on the roadway walking around or ducking under the road boom barrier to avoid stopping at the pedestrian gate.

In contrast to most other domains where CWA has been applied, pedestrians are members of the public, rather than workers or employees of an organisation. There are no barriers or restrictions to entry (i.e. licensing) for pedestrians and there is little control over behaviour, beyond the RLX infrastructure and limited supervision and enforcement activities undertaken by rail staff and the police. It has been noted, for example, that enforcement of road rules at RLXs does not occur regularly or is not perceived to occur consistently (Davey, Wallace, Stenson, & Freeman, 2008; Lobb, Harre, & Suddendorf, 2001).

Having noted that the constraints on pedestrian behaviour are primarily intentional, the engineered and physical environmental aspects of the RLX system (barriers, warnings, etc.) could be categorised as primarily casual. When these aspects of the RLX are considered alone it could be classified as an automated system governed by the laws of nature. Electrical processes are used to detect trains and provide warnings, and mechanical processes are used to operate barriers to control pedestrian (and road user) access onto the RLX.

There are also key causal constraints operating on the functioning of the train. Of particular influence is the interface between the train wheel and the rail which constrains the braking and acceleration capacity of the train. Further, trains cannot deviate laterally from the tracks. Given these constraints, in an emergency situation such as a pedestrian on the track when the train is approaching, train drivers often cannot take evasive action through sudden braking or turning to avoid a collision. This limitation, and the fact that the RLX is railway property upon which road users are given permission to cross, are the underlying reasons for legislation and rules that give right of way to trains. The behaviour of train drivers is also constrained by organisational rules and processes. As employees they are subject to procedures, performance monitoring, and are given professional training, etc. According to Rasmussen's continuum of work domains, the work domain of the train driver could be categorised as a mechanised system governed by instructive rules of conduct. However, unlike the description of that type of domain provided by Rasmussen and colleagues (1994), the casual constraints affecting braking mean that the system is tightly coupled where there is risk of collision, because there is little opportunity for recovery.

An additional consideration for the analysis was its overall purpose. The context of the analysis was to identify and understand the risks to safety associated with pedestrian behaviour at RLXs and to identify potential design solutions that could be implemented at a relatively low cost in the short-term. Many CWA design applications aim to design computer-based interfaces to support decision making using the CWA-based design approach of ecological interface design. For this work, such an approach was determined to be beyond scope as such an interface would require the development and adoption of personal devices by pedestrians. Specifically, a display showing pedestrians their field of safe travel, personalised to their particular abilities and circumstances would potentially be very effective. Such an approach may be valuable in the future if wearable technology becomes widespread and there can be integration with more general walking navigation software.

3.2 Defining the boundaries of the analysis

Spatially, the boundaries of the analysis were drawn in relation to both the rail line and the footpath / road. For the rail line, consideration was given to the approach to the RLX prior to the whistle board (a sign indicating to train drivers that they must sound their whistle as they are approaching an RLX) being visible to the train driver on each approach. For the road and footpath, consideration was given from the point just prior to where the RLX is visible to pedestrians. Although this geographical area would encompass many functions and tasks (e.g. pedestrians negotiating road intersections on approach to the RLX, train drivers responding to rail signals, etc.), only functions relevant to the RLX itself were analysed in detail.

3.3 Development of the outputs & review process

All five phases of CWA were used to investigate the constraints influencing pedestrian behaviour at RLXs. Table 3 describes the key data sources used to undertake each phase. However, it should be noted that developing the CWA outputs is an iterative process meaning that the earlier phases were often updated based on the findings of the latter phases of analysis.

The work domain analysis described in this article was informed by a broader abstraction hierarchy representation developed for all road users at RLXs (Salmon, et al., Revision under review). The current analysis incorporates more detail about the infrastructure available to pedestrians and the functions associated with pedestrian traversal of the RLX. The outputs of all latter phases were developed by a single analyst and reviewed by another analyst for accuracy and completion. Given that reliability and validity of CWA outputs have been found to be improved with input from multiple analysts (Cornelissen, McClure, Salmon, & Stanton, 2014), key elements of the outputs were also reviewed in a focus group session involving six road and rail industry subject matter experts to ensure accuracy and completeness of the analysis. The comments offered were generally minor (e.g. relating to terminology, level of detail for the description of objects, functions and tasks and minor omissions). In addition, the subject matter experts provided valuable comments and insights into what they considered to be higher risk situations, tasks and contextual factors affecting pedestrian safety at RLXs. The comments were incorporated into the analysis outputs.

Table 3.

Data sources used to develop CWA outputs

Phase	**Outputs**	**Key data sources**
Work domain analysis	- Abstraction hierarchy	- Documentation review (RLX standards) - Site visits and familiarisation activities
Control task analysis	- Contextual activity template - Decision ladders	- Verbal protocol analysis transcripts - Critical decision method transcripts

		- Review of Coroner's reports
Strategies analysis	- Strategies analysis diagram - Strategies analysis flowcharts	- Verbal protocol analysis transcripts - Critical decision method transcripts - Coroner's reports - Covert observations of behaviour
Social organisation & cooperation analysis	- SOCA-decision ladder	- Verbal protocol analysis transcripts - Critical decision method transcripts - Coroner's reports - Covert observations of behaviour
Worker competencies analysis	- Extension to strategies analysis flowcharts	- Verbal protocol analysis transcripts - Critical decision method transcripts - Coroner's reports - Covert observations of behaviour

4. CWA results

4.1 Work domain analysis

In the work domain analysis phase of CWA the system is described according to various levels of abstraction and decomposition. The resulting system representation identifies the constraints on behaviour within the work domain of interest. As part of the work domain analysis phase of this research an abstraction hierarchy (AH) was developed to identify the system constraints on pedestrian behaviour at RLXs. Given the different sources of regularity within the domains making up the overall RLX system (as discussed in section 3.1), and following the guidance for representing the AH for intentional systems (Burns, Bryant, & Chalmers, 2005; Hajdukiewicz, Burns, Vicente, & Eggleston, 1999), consideration was given to the type of system being described and how it should be represented. Given the presence of multiple purposes that are not necessarily shared across the system (e.g. pedestrian purpose versus RLX purposes), the fact that collisions may result from conflicting purposes, and the open boundary of the RLX system, the use of multiple hierarchies to model the system was considered appropriate (Burns, et al., 2005). For example, the purposes of both pedestrians and trains involve traversing the RLX to reach their specific destination, while the purpose of the engineered infrastructure and physical environment is to control this interaction.

Accordingly, the AH was modelled according to the three key domains present: the pedestrian domain, the infrastructure / physical environment domain, and the train domain (see Figure 3). The multiple hierarchies acknowledge differences at the first four levels of abstraction but they interact at the physical objects level.

One of the benefits of the AH is that is makes explicit the conflicts and trade-offs occurring at the more abstract levels of the system as well as at the physical level. For example, within the infrastructure / physical environment domain there are protective purposes which are in conflict with other functional purposes such as to ‘provide access across rail tracks’ (which is important as otherwise the railway would isolate communities or parts of communities and inhibit social and economic growth). The ongoing problem of crashes at RLXs suggests that the infrastructure domain is not always successful and is sometimes surpassed by the ‘reach destination’ purpose of the pedestrian domain.

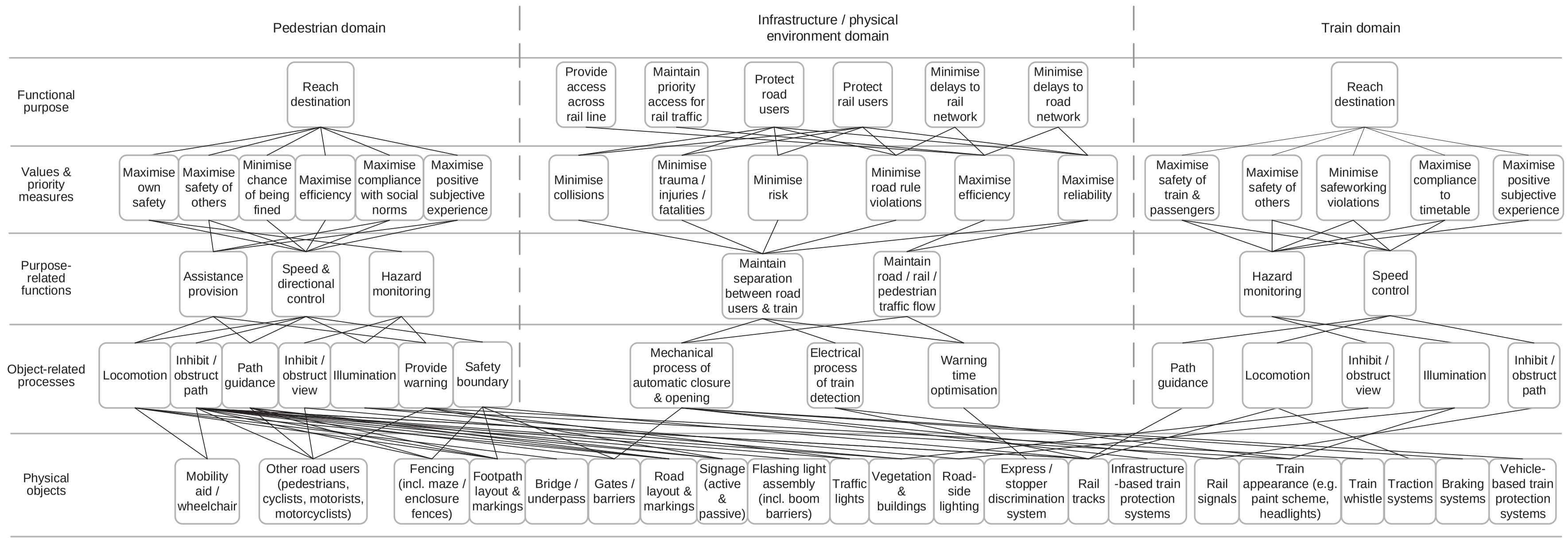

Figure 3. Abstraction hierarchy of the RLX domain showing multiple hierarchies, interacting at the physical objects level.

At the values and priority measures level of abstraction the nodes are relatively similar across the three domains but there a differences in their meaning. For example, the pedestrian and train domain share the value of maximise positive subject experience. However, this may be quite different across and within domains. For example, some pedestrians may find it a positive experience to walk around a barrier and cross the RLX as they were able to make their own decision and did not have to wait. A positive experience for another pedestrian may be to wait behind the barrier because this reduces anxiety about whether or not it is safe to cross. For a train driver, a positive subject experience is likely related to their level of anxiety about whether a pedestrian might step out in front of the train as it is approaching. Further, for the infrastructure domain the descriptions of the values are more formal as this reflects formal organisational reporting that is undertaken to determine whether the infrastructure is performing its functions to an acceptable level.

At the purpose-related functions level it is again emphasised that the infrastructure maintains separation between pedestrians and the train, as well as, alternatively maintaining traffic flow across the RLX. Interestingly, the functions within the pedestrian and train domains are similar. For example, both engage in control of locomotion with pedestrians having control of speed and direction, and trains only being controlled in relation to speed. Both work domains require hazard detection. An unexpected finding in the pedestrian domain was the function of 'assistance provision'. This was found to be quite unique to the pedestrian context, with people outside of their vehicles there is considerable opportunity for direct verbal and non-verbal communication and for assistance or helping behaviours to occur. Data that informed this inclusion in the AH included the verbal protocols from one participant who stopped at the mid-enclosure of the RLX and engaged in a discussion with another pedestrian, giving them route guidance. Another participant described during the critical decision method interview that she had considered overtaking another pedestrian while traversing the RLX as the other pedestrian, who was elderly, was walking relatively slowly. The participant chose to remain behind the other pedestrian and when asked whether her actions may have changed had the warnings activated while she was traversing, she responded 'if she was still there I would help her'. Furthermore, a number of eyewitness reports referenced in the reports of the Coroners Court of Victoria included content about the witness and other bystanders, upon realising that a collision was likely, taking action in an attempt to assist (such as calling out to another person or running towards the RLX to render assistance).

Turning attention now to the lower levels of Figure 3, the object-related processes and physical objects, it can be seen that the physical objects are shared between domains but the affordances they provide differ depending upon the domain. For example, rail tracks enable locomotion for trains and provide path guidance for them, but for pedestrians they inhibit / obstruct the path of pedestrians in areas adjacent to the RLX footpath. Further, the rail tracks enable the electrical process of train detection which is based on through track circuit activation.

Also many of the infrastructure / physical environment objects have affordances for pedestrians. In particular, many objects are linked to inhibit / obstruct path. There are varying ways in which this is achieved which is not necessarily indicated by the means-ends links in Figure 3. For example, the nature of a gate or barrier as a constraint is very different from signage, although both are intended to have the same effect. In other words, it should be kept in mind that all means-ends links are not equal in terms of the effectiveness in providing the affordance / constraint.

Finally, it is important to note the inclusion of road users within the work domain analysis. Rather than intending to create an actor-dependent representation, this inclusion acknowledges that other users can constrain behaviour through blocking the path ahead, through providing path guidance (based on observations that pedestrians often followed another walking in front), or through obstructing the visibility of other objects such as the train, or warning signs. Other road users may also warn of the need to stop, by stopping themselves and thus drawing attention to the requirement to stop.

The work domain analysis has provided a representation of the functional structure of the RLX domain, with a focus on pedestrian safety. The remainder of the analysis was focussed on the pedestrian domain of the multiple domain representation in Figure 3, taking account of the physical objects from the infrastructure / train domains that are used by pedestrians.

4.2 Control task analysis

Contextual activity template

The control task analysis phase of CWA considers the activities that must occur in the work domain for the system to achieve its purpose/s (Vicente, 1999). To analyse the activity in the pedestrian domain firstly, a contextual activity template (Naikar, Moylan, & Pearce, 2006) was created (see extract in Figure 4). As suggested by Naikar and colleagues (2006), functions are represented in each row in the contextual activity template, and different situations are represented in the columns. The situations were identified through considering the geographical position of pedestrians when approaching, traversing and exiting the RLX as well as the possible status of the RLX warning devices (e.g. bells not activated, gates and booms closing, gates and booms closed, etc.). The figure shows the situations relevant to the pedestrian's positions when they are in line with the fencing that funnels pedestrians towards the RLX and when they are in line with the holding line (a line that delineates the point of safety behind which a pedestrian is expected to wait if a train is approaching).

The contextual activity template matrix identifies the situations in which it is possible for functions to be performed (indicated by the dashed boxes) and those in which the function is typically performed (indicated by circles and whiskers). In total, 45 situations were identified for the four functions to be performed in – seven geographical areas (on approach, at fencing, at holding line, on tracks, at mid-enclosure, at final enclosure, post-RLX, in refuge area) and five states of the warning systems (bells not activated, bells activated, gates / booms closing, gates / booms closed, gates booms opening).

It can be seen in Figure 4 that the ability for some functions to be performed does not change based on the situation. For example, assistance might be provided at any situation, and this is not typically done during any particular situation. Potentially, this function becomes more important when warnings are activated and gates are closing or closed, as these represent high risk times for a collision if a pedestrian is on the tracks and in need of assistance. Similarly, monitoring for, and detecting hazards does not differ substantially across different situations. This is typically done across all situations, even when a pedestrian might be stopped at a closed gate. For example, pedestrians observed during data collection activities would often watch trains as they passed while waiting at the gate.

The functions that do change across situations are speed control and direction control. The contextual activity template suggests that these functions typically occur in most situations, except where gate activity means that they are likely to have had to stop. Speed control cannot occur when the pedestrian is at the holding line and the booms or gates are opening because there is some time delay between the gates beginning to open and pedestrians being able to move forward and through them. Further, road rules state that a pedestrian must not cross RLXs where a gate, boom or barrier at the crossing is opening or closing. However, directional control is still possible at this point and indeed pedestrians may turn as they prepare to begin to walk through the opening being created as the gates move.

Speed control is particularly interesting in the situation of the bells having activated. A pedestrian may have approached the RLX with little thought about the RLX, , reach the holding line and suddenly, on the onset of the bells, be required to make an important decision about whether they will traverse the RLX or wait. While the road rules prohibit crossing when the bells are activated (where the user is not already on the RLX) interestingly, with a pedestrian at this point in the flow of movement, it may be unintuitive to stop. Further, pedestrians may not be aware of the content of the road rules. Indeed, observations suggested that a number of users, on hearing the bells, instead began to rush across the RLX. Potentially the stress associated with the sudden onset of the bells activates the physiological fight or flight response with a natural response being to rush or run across. Potentially a more gradual transition from safe state (no warnings) to unsafe state could improve this response.

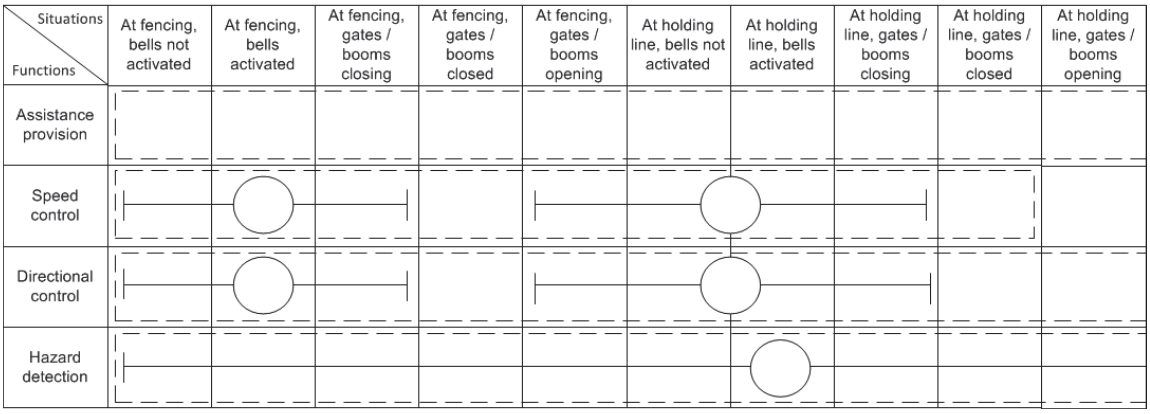

Figure 4. Extract of contextual activity template showing functions typically performed and those possible to perform when the user is approaching the RLX and is positioned in line with the fencing or the holding line, and the warnings are at various states.

Decision ladders

Decision ladders were developed to identify the constraints on decision making for key control tasks. Decision ladders outline the information processing activities (represented by boxes) and resultant knowledge states (represented by circles) that, if followed from the bottom left to the bottom right of the ladder, represent the process of novice decision making (Vicente, 1999). As expertise develops, shortcuts can occur which means that actors progress through the decision ladder without going through each information processing activity and experiencing every knowledge state. The shortcuts can be in the form of leaps or shunts. Shunts occur where an information processing activity is connected to a state of knowledge (box to circle) and leaps connect two states of knowledge (circle to circle). An example of a leap would be an alert being directly associated with knowledge of the system state. It is not possible to link information processing activities directly to one another as this omits the resultant knowledge state.

The format of the decision ladders follows the guidance provided by Elix and Naikar (2008) and Jenkins and colleagues (2010). It is intended to be a template showing the possible knowledge states based on the data collected within the studies undertaken. A template decision ladder enables leaps and shunts to be mapped on to the template to illustrate instances of rule-based and skill-based behaviour.

An example decision ladder is presented in Figure 5. The decision ladder is associated with the speed control function, for the context of an RLX with automatic gates where gates do not operate independently (i.e. all gates at the RLX operate in synchrony). The decision ladders contrast the decision making of pedestrians in three of the CAT situations: when at the fencing, bells not activated (indicated by the letter A); at the fencing, bells activated (indicated by the letter B); and at the fencing, gates closing (indicated by the letter C).

In Figure 5, the differences across the situations (indicated by the letters A to C) are shown for the left-hand side of the decision ladder only as there was no difference in options that users could select in relation to speed control – only speed up, maintain current speed or slow down / stop. Nor were there differences in the action execution relating to these options across the three situations.

In terms of what alerts pedestrians to the need to make a decision about their speed, the key differences relates to the different stages of the warnings being activated. The leap shown in Figure 5 (shortcut A) linking the ‘alert’ knowledge state and the ‘execution’ knowledge state represents a scenario where the bells activate and the pedestrian immediately comes to a stop. This is the intended effect of the bells and road rules which require that pedestrians do not enter an RLX when the bells are activated. However, as noted previously, given that pedestrians are already in motion, and have reached the fencing area, the actual skill-based behaviour observed was that on the onset of the bells pedestrians increased their speed to reach the other side of the RLX prior to the train arriving.

In relation to gathering information and cues from the environment, there was some information that was the same across situations, such as whether or not a train was identified. This was included even for situations when the bells are not activated, as the lack of a warning may not necessarily mean that no train is approaching and our data showed that many pedestrians checked for trains even when the warnings were not activated. A train could be approaching in the distance (and not yet have activated the warnings) or there could be a fault in the warning equipment. Where the user tries to look for the train but there is not sufficient sighting distance (due to a platform or curve in the field of field from their location) they may select to slow down or stop to enable them the opportunity for a longer look up and down the tracks. Interestingly, while users slowing down and checking for trains was a relatively typical behaviour identified during data collection, the engineered system and road rules are more focused on users detecting and complying with warnings.

An interesting insight from the decision ladder analysis is that much of the information about the train is not made available to pedestrians in any formal way. For example, information about the length of time the warnings have been active for, the presence of another train, the distance or time to arrival of the train at the RLX, and the type of train is not currently available to pedestrians.

In relation to knowledge of the system state, in this domain this includes consideration of the objective state of the RLX (i.e. is a train approaching, are the warnings working) as well as the relationship between the system and the capabilities of the pedestrian or the impacts on the pedestrian's intentions (i.e. is there time to get through the gate before it closes). This relates back to the affordances of the work domain (i.e. the means-ends relationships between physical objects and object-related processes). While the work domain is actor-independent and affordances are stable properties of objects, affordances are somewhat actor-dependent because what an object affords in a dynamic interaction with an actor depends on the actor's capabilities such as their height or strength (Gibson, 1979). In relation to RLXs, the edge of the closing gate affords locomotion / the opportunity to enter the RLX until it reaches a point where the gap is too small for the user to fit through. Further, the speed capability of the user will affect whether they are afforded the opportunity to enter the RLX, depending on the distance the user is from the gate when it begins to close. The shortcut connecting 'system state' and 'execution' in Figure 5 (shortcut B) is intended to illustrate a situation where a user realises the system state – that there is time for them to get through the gate before it closes – and executes the action of increasing their speed to enter the RLX.

For the three different situations the system states are different as the urgency of decision making increases across them. At the fencing / enclosure the user is very close to the tracks. When the bells are not activated (situation A) the user may search for information about whether or not trains are approaching and whether or not the warnings may begin to activate in the near future. They generally (except for rare cases of the warnings failing) have time to continue to gather information and monitor the environment. However, when the gates are closing (situation C), users have to gather information quickly so as not to lose the opportunity to make the decision. Further, given this decision making is dynamic, users are likely to have previously been alerted to the need to make a decision by RLX warnings such as the bells while they were on approach to the RLX. Therefore, they would have begun to gather information to assist in their understanding of the system state.

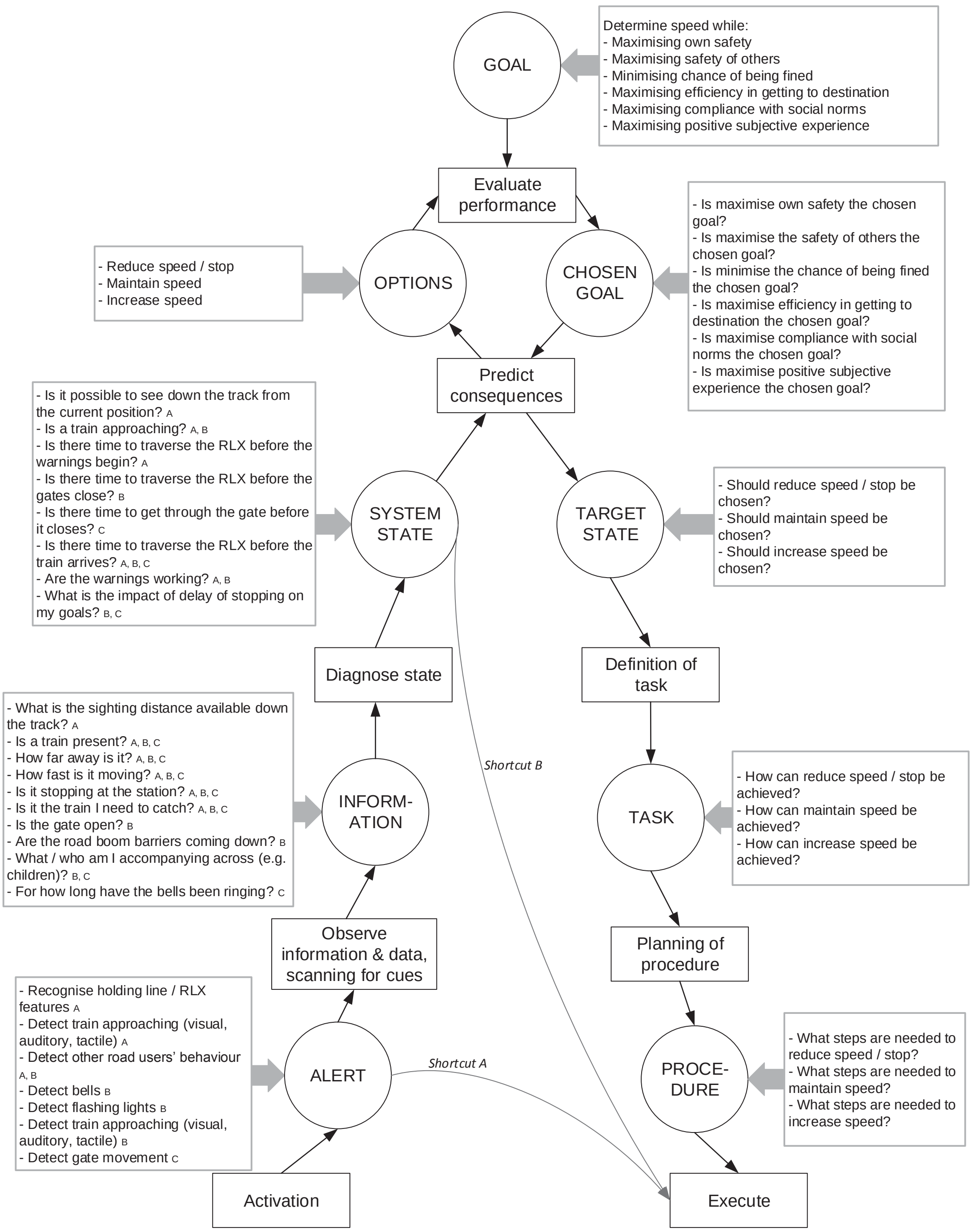

Figure 5. Decision ladder outlining the constraints on decision making for pedestrians controlling their speed in the following situations: A. At fencing, bells not activated; B. At fencing, bells activated; C. At fencing, gates closing.

4.3 Strategies analysis

In the strategies analysis phase of CWA, all of the possible strategies for achieving the control tasks are identified. For this analysis, the strategies analysis diagram and flowchart (Cornelissen, Salmon, Jenkins, & Lenné, 2013) was used to extract all possible strategies from the work domain analysis. These tools are used to exhaustively describe all of the activities that the system permits in its current configuration.

To develop the strategies analysis diagram a set of verbs were identified to apply to the physical objects in the work domain analysis. Further, a set of criteria or contextual factors that influence the selection of a particular strategies were identified. For example, a particular strategy may only be valid under some circumstances or may be preferred under certain circumstances but not in others. The verbs and criteria identified were added to the work domain analysis to create the strategies analysis diagram.

Subsequent to the development of the diagram, strategies analysis flowcharts (Cornelissen, Salmon, McClure, & Stanton, 2013) were derived from the diagram, for each target state and for each task documented in the speed control decision ladder. This enabled the flowcharts to reflect both the selection between options, as well as the actions involved in task execution. The flow charts were based on the key situations identified from the contextual activity template. These key situations included when the pedestrian was on approach to the RLX, and was prompted to make a decision by the activation of various warning devices. An extract from the flowchart developed for the 'tasks' in Figure 5 'How can reduce speed / stop be achieved?' and 'How can increase speed be achieved?' in situation B (at fencing when bells activated) is provided in Figure 6. Therefore, these strategies are relevant once the decision to reduce speed / stop or to increase speed has been made.

The flowcharts describe all the actions (verbs) that can be undertaken with each physical object, relevant to the affordances they provide. They also identify the situations (criteria) when this strategy is more likely to be chosen by a pedestrian and the values and priority measures (which reflect the goals in the decision ladder), which would influence the selection of the strategy. Finally, the flowchart notes which other functions are related to this strategy to acknowledge that behaviour cannot generally be categorised into one function but these functions occur in parallel in a constant and iterative flow. For example, reading across the top line of Figure 5 a pedestrian might 'stop' (verb) at the 'painted holding line' (physical object) which provides a 'safety boundary' (object-related process) when the line is 'present' (as these are not present at all RLXs) and 'visible' (the line may be faded) and / or where no 'gate is provided' (criteria). This strategy would be more likely to occur when the relevant value or goal chosen is 'maximise own safety'. In contrast, where there task is to increase speed, the first strategy identified was to 'run' (verb) on the 'footpath' (physical object), which affords a 'surface for locomotion' (object-related process). This could be done when the follow criteria are satisfied: 'no train approaching', 'train is far away', the pedestrian is 'feeling reckless', the footpath is 'quiet / not congested', where the pedestrian 'intends to catch the train', or there is 'adverse weather.' This strategy would be more likely to be selected where the goal chosen is 'efficiency', 'positive subjective experience' or 'maximise compliance with social norms'.

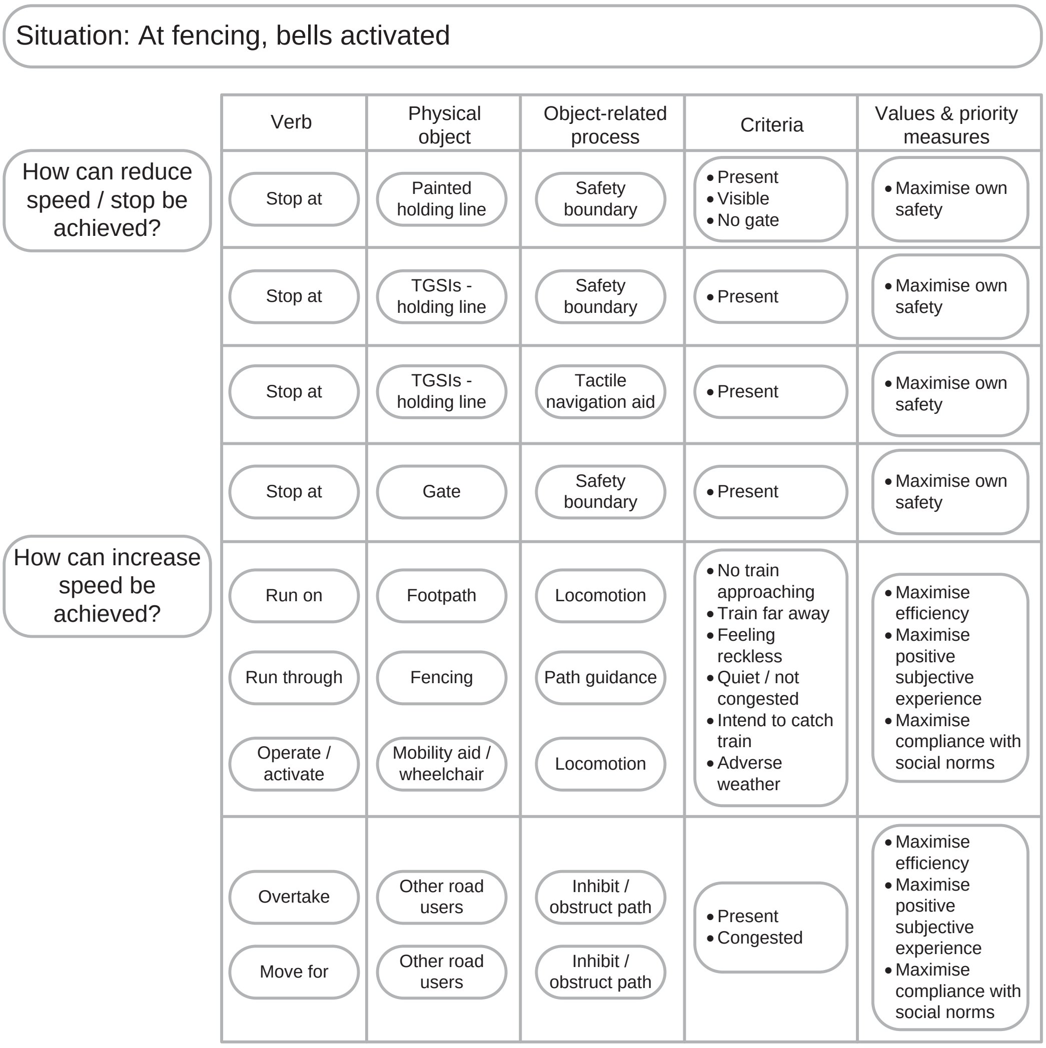

Figure 6. Extract of SAD flowchart for to tasks from the decision ladder analysis

Across all of the flowcharts speed control, the most common criteria that were found to influence strategy choice, apart from the presence of various physical objects were:

- Adverse weather (i.e. extreme heat, cold, wind, wet);
- Congestion at the RLX;
- Perceiving the situation as being safe or unsafe;

- Being in a hurry;
- Intending to catch the approaching train;
- Being unfamiliar with the RLX and / or the surrounding area;
- Using a wheelchair or mobility aid;
- Crossing with a bicycle, trolley, pram or push chair;
- Carrying heavy bags or luggage; and
- Accompanying small children or pets across the RLX.

This highlights the need to design for many types of contexts, especially for those that might lead to pedestrians choosing a strategy that is unsafe in the circumstances.

4.4 Social organisation and cooperation analysis

The fourth phase of CWA, social organisation and cooperation analysis (SOCA), uses the outputs from the previous phases of analysis and enables the analyst to allocate current or potential functions to the various human and non-human actors.

Table 4 uses the information from the decision ladder and indicates which actors (i.e. the warning system, pedestrian or train driver) currently provide alerts, which actors can know what information, and which actors can know or determine which system states. It demonstrates that there is information in the system that is held by some actors and not others. Key areas for improvement are highlighted in grey.

The first two issues highlighted in the table acknowledge that pedestrians are not aware of what train is approaching (i.e. 'is it the train I want to catch?') and what the train's intention is (i.e. 'is it stopping at the station'). Potentially, a display could be provided to pedestrians to provide them with information about the train service approaching the RLX and whether it is stopping at the station or running express.

The next highlighted row of the table relates to the system state 'is there time to traverse the RLX before the warnings begin?' (i.e. before the bells begin to ring). In this case, no actor currently holds this information. The warning system does not know that a train is approaching until it reaches the sensor that activates the automated warning system, and the warnings also have no information about pedestrians approach or their characteristics (i.e. how long it will take them to cross). Pedestrians do not receive prior warning of train approach, although they may see a train approaching in the distance (prior to the sensor point) and make some prediction for themselves about when the warnings will begin.

Finally, the automated warning system may not be ‘aware’ that it has failed if certain types of failure modes occur. For example, if the track circuit has been activated by something other than a train, such as through vandalism, the warning system will operate as if a train has been detected. Further, pedestrians would not be aware of the state of the automated system (i.e. failed or not), as the warning systems are designed to fail to a ‘safe mode’, which means that it will display the same warnings when in a failed state as when a train is approaching. If the warnings are not activated and a train is approaching (known as a ‘wrong side’ failure), the pedestrian would be unlikely to be aware of this until they are physically on the RLX where it is likely to be too late. The train driver may be aware of failure, but only if they check for the activation of the flashing lights, boom barriers and pedestrian gates on approach and notice failures in these warnings. Even then, due to the constraints of train braking, the train driver is unlikely to be able to take evasive action other than to sound the train whistle. Interestingly, there is nothing designed for the train driver to support them to identify RLX failures in advance.

Table 4.

SOCA for the decision ladder. The grey shading highlights key areas where improvements to the existing design could improve safety.

	Automated warning system	**Pedestrian**	**Train driver**
Alert – which actors do this?			
Recognise holding line / RLX features	-	X	-
Detect train approaching (visual, audible, tactile, electrical)	X	X	-
Detect other road users’ behaviour	-	X	X
Detect bells	X	X	-
Detect flashing lights	X	X	X
Detect gate movement	X	X	X
Information – which actors know this?			
What is the sighting distance available down the track?	-	X	-
Is a train present?	X	X	X
How far away is it?	-	X	X
How fast is it moving?	-	X	X
Is it stopping at the station?	X	-	X
Is it the train I need to catch?	-	-	-
Is the gate open?	X	X	X
Are the road boom barriers coming down?	X	X	X
What / who am I accompanying across (e.g. children)?	-	X	X
For how long have bells been ringing?	X	X	-
System state – which actors know or can determine this?			

Is it possible to see down the track from the current position?	-	X	-
Is a train approaching?	X	X	X
Is there time to traverse the RLX before the warnings begin?	-	-	-
Is there time to traverse the RLX before the gates close?	-	X	-
Is there time to get through the gate before it closes?	-	X	-
Is there time to traverse the RLX before the train arrives?	-	X	X
Are the warnings working?	-	-	X
What is the impact of delay of stopping on my goals?	-	X	-

4.5 Worker competencies analysis

The final phase of CWA is worker competencies analysis whereby consideration is given to the competencies (skill-, rule- or knowledge-based) that people carrying out tasks require. For this study, we used the information from the strategies analysis flowcharts to identify the competencies required. For example, for the first strategy shown in Figure 6, which is to stop at the painted holding line which provides a safety boundary, the following competencies were identified:

- Skill-based: Ability to stop; Ability to see the painted line & distinguish it from the background of the footpath.
- Rule-based: Relate to convention of road markings indicating stop – knowledge that a horizontal line across a path indicates stop.
- Knowledge-based: Understand that the line indicates a safe place / safety boundary which will not be reached by the train.

While there were a wide range of competencies identified in the worker competencies analysis, Table 5 provides a summary of the key skill-, rule- and knowledge-based behaviours identified which affect safety. In terms of skill-based competencies, these were associated with ability to perceive warnings and hazards and physical competencies associated with traversing the RLX either on foot or using a mobility device or wheelchair where required. For rule-based competencies, they related to using past experience to judge time of arrival of the train or to negotiate passing or overtaking other road users according to social norms (i.e. not passing too close, maintaining the Australian convention of overtaking on the right-hand side, etc.). In relation to knowledge-based behaviour, the competencies included knowledge that might be considered desirable. For example, that the emergency escape gate can be used to exit the track if the gates close in front of a traversing pedestrian. This reduces panic and uncertainty about appropriate behaviour. However, knowledge that these gates can also be used to gain access to the track when a train is approaching, could be considered undesirable as using the gates in this manner can lead to collisions.

Table 5.

Key competencies identified in the worker competencies analysis phase

Competency type	Key competencies
Skill-based competencies	- Ability to visually perceive the activation of warning devices - Ability to visually perceive / recognise train - Ability to hear bells - Ability to hear train whistle and judge distance away / direction - Ability to integrate visual and / or auditory information to judge train's speed and distance from crossing - Ability to maintain balance and momentum while traversing RLX - Ability to physically manipulate or steer mobility aid / wheelchair - Ability to physically manipulate or steer skateboard, scooter, rollerskates, etc. - Ability to perceive a hazard on the footpath (e.g. uneven footpath, stone, slippery surface, item dropped by another user) - Ability to perceive other road users and their behaviour - Ability to perceive and control behaviour of children, pets being accompanied over the RLX
Rule-based competencies	- Ability to judge or calculate time to arrival of train based on previous experience (i.e. once the train reaches a landmark it will arrive at the RLX within 5 seconds) - Ability to anticipate other road user behaviour based on experience / social norms - Ability to gauge appropriate timing to overtake other road user based on prior experience
Knowledge-based competencies	- Ability to judge or calculate time to arrival of train based on estimate of distance and knowledge of train speeds - Understand that refuge area is a safe place from the train - Understand that the emergency exit gate allows exit from the RLX - Understand that the emergency exit gate can be used to gain entry to the RLX - Understand that warnings are linked to train approach - Understand that the RLX fails to a safe mode (i.e. warnings activate but no train approaching) - Understand that the RLX could fail to an unsafe mode (i.e. warnings do not activate but a train is approaching)

Given the diverse backgrounds, attributes and experiences of pedestrians using RLXs (e.g. children, the elderly, people with disabilities, tourists, etc.) individual users will hold different competencies. Designing for all of these individual differences and varying situations is a difficult task and demonstrates the necessity of applying a systems-based approach to this domain so that the cognitive constraints of the wide range of users can be considered alongside the ecological constraints of the domain to identify mis-matches and issues that can lead to collisions. The risks to safety and potential design solutions will be discussed later in this paper. First, a conceptual model of pedestrian behaviour is proposed based on the findings of the five-phase CWA, and drawing particularly upon the strategies analysis phase.

5. A conceptual model of pedestrian behaviour at RLXs

Conducting the five phase analysis using CWA provides a significant amount of information and insight about RLXs and how they are experienced and used by pedestrians. From this analysis we have drawn together the key aspects to provide a conceptual model of pedestrian behaviour at RLXs based on Rasmussen's (1997) model of migration towards the boundary of acceptable performance (see Figure 7). Our model proposes slightly different boundaries to Rasmussen's to ensure fit with the context of pedestrian behaviour. Figure 7 includes the boundary of inefficiency (similar to the original 'boundary to economic failure'), boundary to unacceptable workload, boundary of compliance ('perceived boundary of acceptable performance' in the original model) and boundary of safety (titled 'boundary of functionally acceptable performance' in Rasmussen's original model. Figure 7 also includes an additional boundary which emerged from the data which emphasised the social pressures on behaviour at RLXs. This boundary was titled the boundary of socially unacceptable behaviour. Rasmussen's model shows that within these boundaries are the degrees of freedom for behaviour (at the centre of the diagram). The terms within the centre of Figure 7 are taken from the goals in the decision ladder (Figure 5) and the dotted lined boxes hold the strategies that are more likely to be selected for each goal chosen. The strategies are described quite specifically, relating to particular contexts or situations as relevant, as opposed to the more generic descriptions of strategies provided in the strategies analysis flowcharts. The arrows from each goal show which boundaries the associated behaviours indicate migration towards. For example, when the chosen goal is efficiency the associated behaviours can include running through the gate while it is opening or closing, lifting the boom barrier and overtaking other users. These behaviours can push the system towards the boundaries of compliance and safety, and beyond these to the point where an accident occurs.

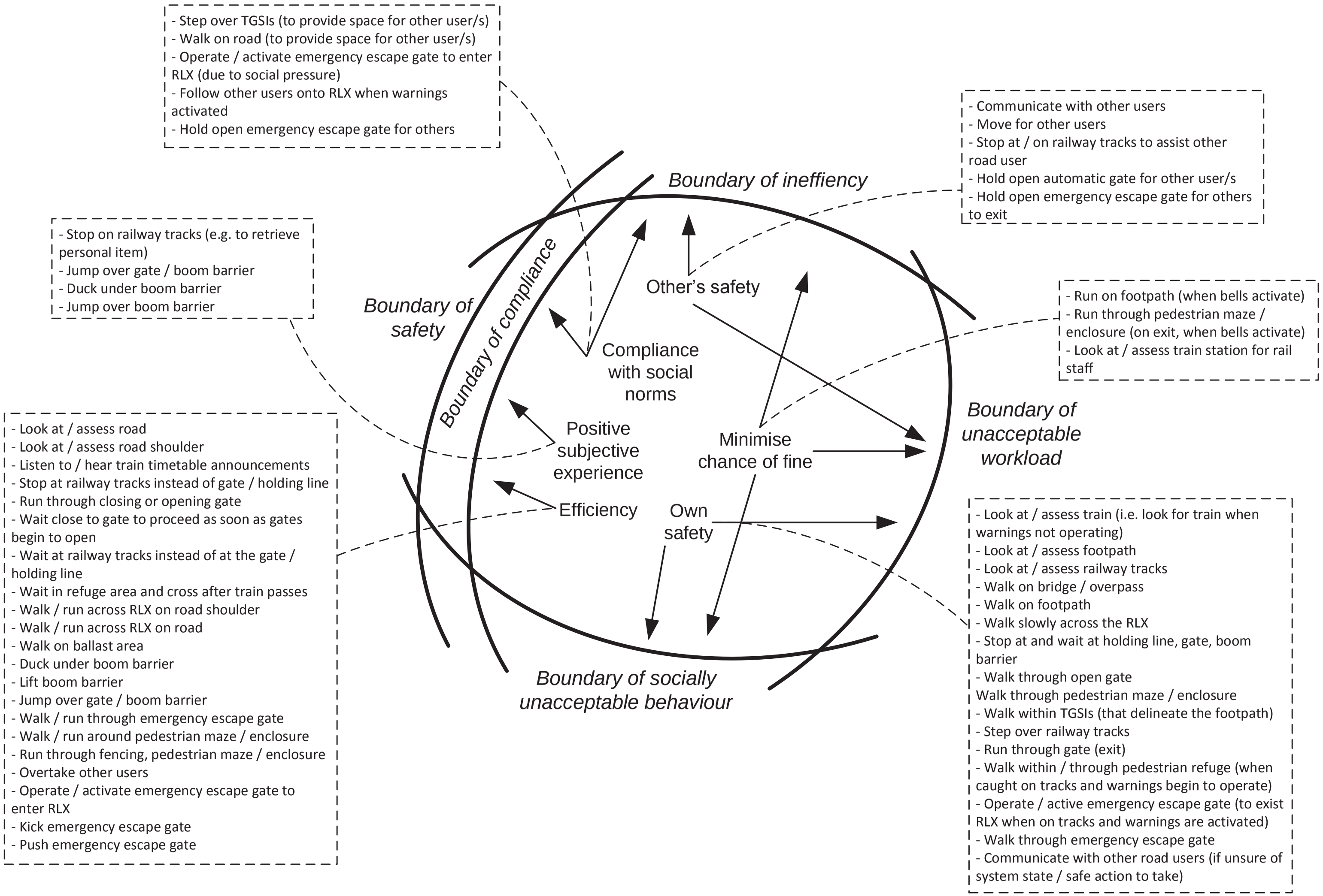

Figure 7. Conceptual model of pedestrian behaviour at RLXs

It should be noted that there are interactions and interrelations amongst the boundaries that may not be explicitly illustrated within Figure 7. For example, compliant strategies may indeed be most efficient, or most socially acceptable, depending on the circumstances. Further, what is considered socially unacceptable may be perceived very differently for pedestrians of different age groups and cultural backgrounds and may depend on whether there are bystanders present to observe the behaviour.

Regardless, the proposed conceptual model reinforces the importance of considering the differences in goals and how they influence behaviour. For example, focusing on compliance as a desirable goal may lead to users being concerned to avoid being fined (and checking whether staff are at the railway station who might fine them) rather than being concerned for their own safety and checking for warnings and trains. A key future research requirement is to collect data that would enable judgement on where pedestrians and different RLXS currently sit within the model and to what extent the different pressures influence behaviour.

6. Understanding risk through the CWA outputs

With the CWA outputs and conceptual model of pedestrian behaviour at RLXs it is possible to analyse the risks associated with pedestrian behaviour at RLXs and to recommend design improvement opportunities. The intention of the following section is to demonstrate how the findings of CWA can be used in a structured manner to inform the understanding of risks to safety, which is an important aspect of risk assessment process for managing risks in safety-critical industries. Risk assessment should involve the identification of all potential risks and therefore CWA's formative nature is very useful for this purpose. Firstly, the strategies identified in the conceptual model of pedestrian behaviour (Figure 7) that were associated with movements towards the boundary of compliance and safety were identified and classified into precursor behaviours (behaviours that can result in a risk event occurring). The risk event of collision with resulting fatal or serious injuries is also identified.

Table 6.

Key pedestrian strategies associated with the risk of being struck by a train

Key strategies	Summary risk precursors	Risk event & consequences
- Step over TGSIs (to provide space for other user/s) - Walk on road (to provide space for other user/s) - Walk on ballast area - Walk / run across RLX on road shoulder - Walk / run across RLX on road - Walk / run around pedestrian maze / enclosure	Pedestrian uses area other than designated pedestrian path and caught in unprotected area when train approaches	Pedestrian struck by train resulting in fatal or serious injuries
- Stop on railway tracks (e.g. to retrieve personal item)	Delayed crossing of RLX	Pedestrian struck by

- Overtake other users - Move for other users - Run through fencing, pedestrian maze / enclosure leading to trip, slip or fall - Run through closing or opening gate leading to trip, slip or fall - Walk slowly across the RLX	resulting on being on the tracks when the train enters the RLX	train resulting in fatal or serious injuries
- Operate / activate emergency escape gate to enter RLX - Follow other users onto RLX when warnings activated - Jump over gate / boom barrier - Duck under boom barrier - Jump over boom barrier - Listen to / hear train timetable announcements - Wait at railway tracks instead of at the gate / holding line - Wait in refuge area (on track side of gate) to cross after one train passes - Duck under boom barrier - Lift boom barrier - Jump over gate / boom barrier - Walk / run through emergency escape gate - Kick emergency escape gate - Push emergency escape gate	Enter crossing when train is close and on the tracks when the train enters the RLX	Pedestrian struck by train resulting in fatal or serious injuries

For each of the strategies identified in Table 6, it is possible to provide a deeper understanding of behaviour by reviewing the other phases of CWA. The analysis findings can also be used to identify design improvement opportunities that will reduce risk. This is an important part of the risk analysis process as it ensures that improvements are identified for further investigation.

Table 7 provides an example of how the outputs from the different phases of analysis can contribute to understanding pedestrian strategies that contribute to risk at RLXs. The example strategy used is walking on the road to traverse the RLX because the pedestrian footpath is congested with other users. This relates to the risk precursor (see Table 6) of a pedestrian using an area other than the designated pedestrian path and then being caught in an unprotected area when a train approaches. As it is possible for pedestrians to cross in using the road safely, even when trains are approaching, the table includes CWA findings associated both with the initial decision to use the road to traverse the RLX as well as how the design could be improved to mitigate the likelihood that the user is subsequently struck by a train. That is, to consider whether it is possible to support choice and variability in terms of paths selected but then provide additional information to assist pedestrians to safely cross using alternative paths. In addition to describing the findings from the five phases of analysis, the table also identifies related design improvement opportunities that were prompted by the findings.

Table 7.

Demonstration of how the findings from the CWA can be used to understand strategies and to develop ideas for design improvement opportunities.

Phase of analysis & output	**Relevant constraints & findings**	**Design improvement opportunities**
Strategy: Walk on road (to provide space for other user/s). *Risk precursor*: Pedestrian uses area other than designated pedestrian path and caught in unprotected area when train approaches.		
Work domain analysis (abstraction hierarchy)	- Other road users provide an obstacle and they inhibit / obstruct the path of pedestrians. Therefore large numbers of pedestrian can lead to a different path being selected.	- Ensure the design of pedestrian paths is appropriate for the numbers of pedestrians who will use it. It is of particular importance when the RLX is adjacent to a train station where morning and afternoon peak times will see large numbers of pedestrians accessing the platform via the RLX.
	- The road layout affords pedestrian locomotion.	- Change the surface of the road shoulder between the pedestrian footpath and road to inhibit or discourage locomotion (e.g. create a 'moat' or a sticky / muddy area which pedestrians would have difficulty crossing or would find it undesirable to traverse).
	- Fencing does not constrain access to the road (at the majority of RLXs).	- Install fencing to prevent pedestrians accessing the road to cross the RLX.
	- The road boom barriers do not constrain access onto the tracks (they extend only across half the roadway, to enable vehicles caught on the tracks to exit in an emergency).	- Provide full boom barriers across the roadway with curtains / solid barrier to prevent users ducking under.
Control task analysis (contextual activity template)	- The function of 'directional control' (i.e. selecting the path they will take through the RLX) can be performed by pedestrians in any situation.	- Constrain pedestrian flexibility by installing fencing to prevent pedestrians accessing the road to cross the RLX.
	- The directional control function may be performed when the RLX warnings are in any state, but for collision to occur it is likely that the warnings would be activated (i.e. bells activated, gates / booms closing, gates / booms closed) soon after a decision is made.	- Ensure that any fencing installed extends far enough along the approach footpath that the train would pass by the time a pedestrian had 'back tracked' to get around the fence and approached the RLX on the road.
Control task analysis (decision ladder)	- Pedestrians may take into account a range of considerations in deciding whether to change their path in response to others being on the RLX footpath. For example: What types of users are present on the RLX (e.g. cyclists, children, people with mobility impairments)? What is the intended path of users on the crossing? What is the likely consequence of continuing to approach on the footpath (e.g. have to stop and wait, have to stop on the tracks, collision or conflict with other road users etc.)?	- Consider implementing guidance to improve pedestrian flow to reduce congestion. For example, pavement markings depicting lanes and which direction of travel should use which lane. - An RLX supervisor (railway employee) could be engaged at peak times to control pedestrian traffic flow and monitor behaviour.

	- There are no formal rules to assist in determining 'right of way' on the pedestrian footpath.	
Strategies analysis (strategies analysis diagram & flowcharts)	The contextual factors (criteria) that would make the selection of this strategy as more likely include: - Crossing is congested - Cyclist present on the crossing (as this causes congestion) - In a hurry - Intend to catch the train - Adverse weather (i.e. extreme heat, cold, wind, wet) making waiting for others to clear the RLX undesirable - Road is quiet, not congested - Perceive as safe	- Ensure the design of pedestrian paths is appropriate for the numbers of pedestrians who will use it. - Encourage cyclists to utilise the road instead of the pedestrian footpath by installing a bike lane on the road. - Methods to improve pedestrian flow (e.g. footpath markings or a supervisor) could mean it is no quicker to use the road to cross when in a hurry or trying to catch a train. - Provide shelter at RLX waiting areas (near the gates) to make it more desirable to wait for the congestion to clear than to cross the RLX via the road. - Change perceptions of the road as being a safe or desirable place for pedestrians to cross the RLX by changing the surface between the pedestrian footpath and road to inhibit or discourage locomotion (e.g. create a 'moat' or muddy area which pedestrians would have difficulty crossing). - A pedestrian might not perceive this strategy to be safe if they are aware that the warnings will soon activate therefore information about train location and time to arrival at the RLX could discourage the adoption of this strategy.
	Once the user has selected the strategy to use the road, there are strategies that can mitigate the likelihood of being struck by a train. These include: - Listen to / hear warning bells - Check flashing lights, booms, pedestrian gates - Listen to / hear train approaching - Look at / assess train	- Provide duplicate visual warnings (e.g. to ensure they are salient to users not approaching via the footpath but also to be appropriate to alert pedestrians accessing the RLX via the road. For example, the flashing lights at RLXs are designed for approaching vehicle traffic and are not optimised for viewing by pedestrians who are situated past the initial flashing light assembly. - An RLX supervisor could alert the pedestrian to the train's approach and direct them to stop or to turn back, depending on their progress across the RLX.
SOCA (decision ladder)	- Pedestrians are not aware in advance of the warnings that a train will be approaching however this is known by the train driver / train.	- Provide information about train location and time to arrival at the RLX at the point where the pedestrian may make the decision to use the road (e.g. when on approach to the fencing / enclosure area, based on the contextual activity template).
Worker competencies analysis	- Ability to perceive other road users and their behaviour (SBB) - Ability to maintain balance and momentum while moving between the footpath and road and traversing the RLX on the road (SBB) - Ability to anticipate other road user behaviour based on experience / social norms (RBB)	- Methods to improve pedestrian flow (i.e. lane markings or a supervisor) would assist with these judgements. - Change the road should surface to inhibit or discourage locomotion.
	- Ability to visually perceive the activation of warning devices (SBB)	- Providing duplicate warnings would assist with visual perception of warning devices.

	- Ability to visually perceive / recognise train (SBB) - Ability to hear bells (SBB) - Ability to hear train whistle and judge distance away / direction (SBB) - Ability to integrate visual and / or auditory information to judge train's speed and distance from crossing (SBB) - Ability to judge or calculate time to arrival of train based on previous experience (i.e. once the train reaches a landmark it will arrive at the RLX within 5 seconds) (RBB) - Understand that warnings are linked to train approach (KBB)	- Provide a staged onset of warnings so that users can differentiate between a warning and an indication that the train is very close. - Provide information about train location and time to arrival. - An RLX supervisor could reinforce the warnings by alerting the pedestrian to the train's approach and direct them to stop or to turn back, depending on their progress across the RLX.

Table 7 demonstrates the large amount of information and insight offered by CWA. It shows how strategies are affected by work domain constraints, situational constraints, constraints on decision-making, contextual constraints and constraints relating to the skill-, rule- and knowledge-based competencies of RLX users. Some key aspects from the table include that the road affords pedestrians to walk on it, that other users represent an obstruction to locomotion (leading to pedestrians avoiding the designated path through the RLX) and that the perception of safety of the road environment can influence decision making. Further, it shows that once on the RLX, if the warnings activate, there are no physical barriers in place to protect pedestrians (i.e. there is no gate to block their path or any information to guide them to a safe place). Therefore, their ability to respond to visual and auditory warnings becomes important to ensure they negotiate the RLX safely.

Table 7 also describes design improvement opportunities relating to the findings from each phase of analysis for the walk on the road strategy. Some of the design improvements identified included interventions to better manage pedestrian traffic flow such as pavement markings to indicate lanes for direction of travel. These should be continuous from the train platform (where present) and adjacent footpaths to provide coherent wayfinding for pedestrians. Further a railway employee could be present at the RLX during peak times to supervise the RLX and provide guidance and assistance to users where necessary. It is intended that this role would have a customer service rather than enforcement focus. Another design solution identified was to change the road shoulder from an asphalted surface, which enables pedestrians to move from the footpath to the road, to a surface that would be difficult or undesirable for pedestrians to walk on. For example, this area could become a trench filled with water (like a moat separating the road and pedestrian footpath) or a muddy area that appears unappealing to traverse.

The proposed interventions could be evaluated for their potential effectiveness using the CWA outputs to understand how the RLX system would be changed by their implementation and the consequences of this. For example, an unintended consequence of implementing the moat idea might be that pedestrians continue to use this road shoulder area to access the road and could slip or fall leading to injuries. Consequently, there would need to be consideration of whether this idea could be implemented in a way that this would be minimised, or if the design intention could be provided through some other means. In addition to evaluation using the CWA outputs, other methods such as mock-ups, prototypes and simulation should be used to determine the effectiveness of the proposed interventions.

7. Conclusions

The aim of this paper was to apply the five phases of the CWA framework to RLXs with a focus on understanding the constraints imposed on pedestrian behaviour along with associated risks. Previous research has found that the application of all phases is beneficial for understanding complex sociotechnical systems (e.g. Jenkins, et al., 2008; McIlroy & Stanton, 2011). The analysis presented represents the first attempt at analysing pedestrian behaviour at RLXs with all five phases of CWA.

The CWA provided a comprehensive understanding of the possibilities for pedestrian behaviour in this context through identifying the constraints within which behaviour is possible. Coupled with naturalistic data sources including walk-throughs and covert observations, the CWA outputs enabled exploration of aspects of pedestrian behaviour often ignored in existing literature such as social interaction at the RLX (for example, a pedestrian may feel pressured to walk through the emergency escape gate to access the tracks because another pedestrian has held it open for them out of etiquette). Further, it enabled the identification of emergent functions within the RLX domain such as the ‘assistance provision’ function identified in the pedestrian domain of the AH. Such emergent features within the domain may not be captured if only building the outputs based on formal specifications of the system such as design documents and standards.

A contribution of the analysis is therefore an in-depth analysis of pedestrian behaviour at RLXs and the factors influencing it. It is concluded that decision making at RLXs is not straightforward as may first appear, and that there are many options, strategies, and influencing factors to be considered. It is questionable whether existing design processes cope with the complexity of the RLX system.

Based on a synthesis of the CWA outputs a model of pedestrian behaviour was proposed based on Rasmussen’s (1997) model of migration towards the boundaries of safe performance. The proposed model summarises the various pressures on the performance of the RLX system, capturing the inherent complexity associated with pedestrian behaviour and decision making in this context. It is proposed that the model could also be used in conjunction with the CWA outputs to display the situations in which certain goals are more likely to be chosen and the competencies associated with particular behaviours. There may also be individual differences in goal selection with some individuals more likely to select certain goals more consistently. However, rather than focusing on changing individual attitudes and beliefs the whole system design needs to be able to respond to these individual and situational differences to maintain safe performance. Potentially, the strategies identified in the model could be used as indicators for determining whether the RLX system, or an individual RLX, is moving close to a particular boundary. Coupled with a means of collecting real-time data about pedestrian behaviour at RLXs, based on the strategies, could provide a sophisticated means for identifying RLXs that are drifting towards the safety boundary and prioritising the implementation of interventions to avoid accidents.

The strategies were also used as a basis for identifying the risks associated with pedestrian behaviour at RLXs. Further, to demonstrate the value of the five phases of CWA to understand strategies, an in-depth review of one strategy associated with increased risk at the RLX 'walk on road (to avoid other users)' was undertaken. This led to the identification of recommendations for design improvements. The risk analysis assisted to demonstrate how CWA could be integrated with safety critical risk assessments. It is suggested that a similar process could be used to understand risk and to prompt the development of design improvement ideas in other domains.

In conclusion, CWA has proven to be highly useful in understanding pedestrian behaviour at RLXs and the associated risks and has enabled the identification of practical design recommendations to prevent future pedestrian deaths and injuries. It offers a comprehensive analysis of the system from multiple perspectives and the interrelations of those perspectives. Further applications of CWA in the RLX context both for pedestrians and users generally are urged, in particular across different countries and jurisdictions.

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9.2 Discussion

The aim of this chapter was to provide the results of a five phase CWA investigating pedestrian behaviour at RLXs. The CWA was informed by a range of data collection methods enabling the exploration of the domain in 'normal' circumstances (e.g. through covert observations, verbal protocols and critical decision method interview data) and in degraded or unsafe circumstances (e.g. through the review of incident data and coronial reports). This provided a comprehensive basis for identifying the constraints of the system and the associated degrees of freedom for behaviour, in the form of the various strategies that can be undertaken.

While the CWA resulted in a number of design solutions identified by the authors and provided in the paper submitted for publication, the analysis process also resulted in the generation of a number of design insights. A total of 78 insights were documented throughout the analysis process. A selection of the insights is shown in Table 9.1, using the format of the insights template from the CWA-DT. The insights include metaphors, leverage points, pain points, assumptions and design solutions. As described in the CWA-DT, the insights were not necessarily hard findings from the analysis but represented interesting, novel or inspiring aspects of the data that were drawn out either directly from collecting or preparing the raw data, or when using the data to develop the CWA outputs. For example, insight number 62 relates to the formal language used when referring to pedestrian crossing infrastructure. The insight related to a realisation that the same term 'enclosure' is used to describe the fencing area where pedestrians wait while the automatic gate is closed for the passing of the train as well as in general conversation to mean a place for the keeping of animals. This terminology may reflect an underlying assumption of the system that pedestrians should be controlled rather than given flexibility or choice, or being empowered to make their own decisions.

The raw forms of the insights in Table 9.1 have been maintained as much as possible to demonstrate the informal nature of the insight generation process. The insights template is intended to be a working document which informs the design planning stage in the CWA-DT process. Further, it should be noted that the insights sometimes referred to early iterations of the CWA analysis. This emphasises the benefits of the exploratory nature of the analysis and shows that early iterations may still provide insights for design, even though there might be little connection between an insight and the final version of the analysis outputs.

The insights contributed to the identification of the potential design recommendations presented earlier in this chapter. However, the key aim of documenting the insights was to use them in a design process driven by the CWA-DT. This will be further described in Chapter 10.

Table 9.1. Insights from the CWA of pedestrian behaviour at RLXs.

Insight no.	Description	Type of insight	How did it arise	How could it be incorporated in the design process
1	The road has lanes to separate opposing traffic – footpath does not. It is up to pedestrians (and cyclists) to determine how to pass on another. Generally the norm is to move to the left.	Metaphor	During VPA transcription where a pedestrian described moving around another pedestrian.	Investigate whether it would lower workload / make it easier if lanes were provided on the footpath over the crossing.
5	Participant waiting at road pedestrian lights said – ‘just waiting for the crossing to turn green’. What if the entire path lit up green when it was safe to cross? Using lights on / under a clear surface, or projections onto the asphalt.	Design solution	During VPA transcriptions.	Ask design participants how we can use the path to communicate to road users? Ask how we can make information about the boundary of safety more visible?
18	Pedestrians / people tend to follow one another.	Design solution / leverage point	During critical decision method interview transcription - participant mentioned just relying on person in front for information about when to cross. Also discussed learning about appropriate behaviour from observing what others are doing.	Ask the design participants - How could we leverage natural following behaviour of people? Possible design solution - What if there was a kind of ‘safety car’ at the crossing – a dummy pedestrian who blocks the gate and then crosses over when the gates open. They model safe behaviour and you just follow them. Could do this with cars as well.
38	People monitor their level of distraction / use of electronic devices, etc. With technology becoming more and more pervasive (the context for RLXs is shifting and RLX’s need to keep up) – is there a way to take advantage of the technological shift.	Leverage point	Reviewing critical decision method interview where pedestrian mentioned that she takes out her earphones at RLXs so she can hear a train if it is coming. Further, during observations, saw some circumstances where people put their phone away when crossing the RLX.	Ask the design participants - How can we use technology to help people use RLX’s safely?
62	The word ‘enclosure’ is something usually associated with animals. Suggests users need to be kept in, kept under control, and shouldn’t be allowed to roam free. Assumption that pedestrians are not capable to make own decisions.	Assumption	Developing WDA.	Incorporate in assumption crushing exercise.
68	Is there a way to encourage / reward social interaction that involves assisting other people	Leverage point	Early iteration of decision ladder – around function of ‘provide assistance to other road	Ask the design participants - How can we promote a culture of helping others at / around the RLX?

	using the RLX? Coronial reports included many examples of people who tried to help, as well as examples of witnesses who didn't help (for many varied reasons). Personal opinion is there is not a culture of helping associated with public transport. Could a better culture of assistance be created that spans the entire public transport system? Or general community engagement within a local area?		users'.	How can we empower and encourage people to help one another and overcome the bystander effect and diffusion of responsibility that may occur where there are more people present?
70	Pedestrians need to maintain separation between road users in all situations (i.e. when approaching the RLX, traversing the RLX and exiting). However, some stations can get very congested in the afternoon peaks when there are passengers disembarking trains at busy stations including two of the sites used for covert observation. Where it is very busy, pedestrians could find it difficult to exit the RLX and get caught on the tracks, or there may be too many pedestrians to fit in a refuge.	Pain point	CAT – version with detailed situations – analysing function 'maintain separation between road users'.	Ask design participants - What can be done to relieve congestion or manage pedestrian flow at RLXs near stations?
73	Pedestrians communicate with other road users but do not activate anything at the crossing. They are very passive. Perhaps if they at least had the ability to communicate their intention to cross to the 'system' they might feel a greater sense of agency.	Leverage point	Working on SAD diagram – linking 'communicate with' to physical objects.	Ask design participants – How can pedestrians be given more control or at least a greater sense of agency when using RLXs.
77	Pedestrians are more likely to check for trains and provide assistance when they perceive the situation as unsafe. If we want people to engage in cautious behaviours, we should make the crossing appear unsafe / dangerous. However, not necessarily threat of death because could create panic / anxiety or (according to terror management theory) can provoke risk taking behaviour if that is considered socially desirable in the peer group (e.g. teenagers).	Leverage point	Working on SAD diagram – linking 'check for trains' as decomposed function to 'perceive as unsafe' criterion.	Ask design participants - How can we make the crossing appear dangerous?

9.3 Conclusions

The CWA described in this chapter demonstrated the complexity of the RLX domain and the benefits of applying a formative, systems-based approach to understand the constraints and goals that influence pedestrian behaviour. It also resulted in the identification of a number of insights which were incorporated into the RLX design process described in the following chapter.

10 Evaluation of the CWA-DT

Read, G. J. M., Salmon, P. M., & Lenné, M. G. (Under review). Evaluating a design toolkit for Cognitive Work Analysis. *Ergonomics, submitted 24 June 2015*.

10.1 Introduction

Thus far, this thesis has described the development of the CWA-DT (Chapter 6), its proof of concept application to transport ticketing (Chapter 7) and associated refinements to improve its ability to support CWA-based design (Chapter 8). In this chapter, the CWA-DT is applied to the RLX domain and is formally evaluated based on this application.

As noted previously, when the case was made to apply a systems approach to RLXs (see Chapter 2), to take a genuine systems approach to design of RLXs all users of the RLX must be considered, rather than pedestrians in isolation. As such, this chapter describes a process that aimed to create RLX designs that would improve safety for all users. This was achieved through collaboration within a wider research program involving the use of CWA to investigate the RLX system at a higher level of granularity but considering all road users (e.g. drivers, cyclists, motorcyclists and pedestrians).

The aim of this chapter is to describe the application of the CWA-DT to improve safety at RLXs, and to evaluate the performance of the CWA-DT against the evaluation criteria proposed in Chapter 5.

Declaration for Thesis Chapter 10

Declaration by candidate

In the case of Chapter 10, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Primary author responsible for the design of the study. Facilitated the design workshops and expert panel workshop. Responsible for analysing and interpreting the results of the study and the initial drafting and subsequent editing of the paper.	85%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Paul M. Salmon	Contributed to the planning of the design workshops and provided critical review of draft versions of the paper.	n/a
Michael G. Lenné	Contributed to the planning of the design workshops and provided critical review of draft versions of the paper.	n/a

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work.

Candidate's Signature	[redacted]	**Date** 2 July 2015
Main Supervisor's Signature	[redacted]	**Date** 2 July 2015

When paradigms collide at the road-rail interface: Evaluation of a sociotechnical systems theory design toolkit for cognitive work analysis

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When paradigms collide at the road-rail interface: Evaluation of a sociotechnical systems theory design toolkit for cognitive work analysis

Abstract:

The Cognitive Work Analysis Design Toolkit (CWA-DT) is a recently developed approach that provides guidance and tools to assist in applying the outputs of CWA to design processes to incorporate the values and principles of sociotechnical systems theory. In this paper, the CWA-DT is evaluated based on an application to improve safety at rail level crossings. The evaluation considered the extent to which the CWA-DT met pre-defined methodological criteria and aligned with sociotechnical values and principles. Both process and outcome measures were taken based on the ratings of design participants and human factors experts. Overall, design participants were positive about the process and indicated that it met the methodological criteria and sociotechnical values. However, expert ratings suggested that the CWA-DT achieved only limited success in producing RLX designs that fully aligned with the sociotechnical approach. Discussion about the appropriateness of the sociotechnical approach in a public safety context is provided.

Keywords: Cognitive work analysis; Sociotechnical systems, Rail level crossings, Safety, Design

Practitioner summary:

Human factors and ergonomics practitioners need evidence of the effectiveness of methods. A design toolkit for cognitive work analysis, incorporating values and principles from sociotechnical systems theory, was applied to create innovative designs for rail level crossings. Evaluation results based on the application are provided and discussed.

1. Introduction

Human Factors and Ergonomics (HFE) needs systems-based methods to support the design of complex, safety-critical sociotechnical systems. The cognitive work analysis (CWA) framework has been proposed as a promising approach for supporting the design of such systems; however, CWA does not provide direct guidance for the design of sociotechnical systems. That is, there is no formal methodology or guidance for directly translating CWA outputs into design concepts. A number of authors have noted that the design aspects of CWA are not simple and without any guidance for a structured approach to design CWA practitioners are left to craft their own processes (Read, Salmon, & Lenné, 2015a).

The CWA framework is aligned with systems theory and aims to promote the design of systems that provide human decision makers with support for both routine behaviour as well as flexible, adaptive behaviour required to respond to external disturbances. The framework consists of five phases of analysis that begin by providing a holistic, actor- and event-independent description of the system via the work domain analysis phase, through consideration of the control tasks performed in the system, the strategies that can be used to perform tasks, the distribution of tasks between and amongst humans and technology, and the skill-, rule- and knowledge-based competencies required by actors to perform tasks (Vicente, 1999).

The framework is closely related to sociotechnical systems theory (Trist & Bamforth, 1951) which also has its roots in systems theory. The sociotechnical systems approach is a philosophy for designing work systems which also aims to promote adaptive capacity through the joint optimisation of human and technical aspects of the system (Walker, Stanton, Salmon, & Jenkins, 2008). It incorporates a set of humanist values which are applied to ensure that the introduction of technology in workplaces does not dominate working practices and that employees are provided with high quality working lives (Mumford, 2006). Through participatory design approaches, a sociotechnical systems approach to design is beneficial as it enables the application of worker knowledge in design, it ensures better acceptance of new designs as workers have a better understanding of the reasons for decisions and it respects the rights of workers to be involved in decisions that will affect their work or life (Gregory, 2003).

Both CWA and the sociotechnical systems approach were developed for industrial domains and have traditionally been applied in the context of work design within organisations. Organisations generally have a reasonable level of control over workers through processes such as selection, training, procedures and performance management and there is control over the equipment that workers use to ensure it is appropriate for the task and reliable. However, more recently the CWA and / or the sociotechnical approach are being applied to public domains such as the road transport system (e.g. Birrell, Young, Jenkins, & Stanton, 2012; Cornelissen, Salmon, McClure, & Stanton, 2013), online communities of practice (e.g. Euerby & Burns, 2012) and social networking (e.g. Whitworth & de Moor, 2009).

Interestingly, this transition from work systems to public systems appears to have occurred with little commentary or consideration about the appropriateness of such approaches in less controlled domains. Eason (2014) notes the ever-expanding use of the sociotechnical systems approach, and related approaches which adopt sociotechnical terminology, and he highlights the need to ensure that the theoretical foundations of the approach are retained in applications and extensions in new domains. It is therefore important to consider the theoretical underpinnings of the sociotechnical approach when it is applied in a new area, such as public safety.

To better support the use of CWA in design, and to incorporate the sociotechnical systems theory approach more explicitly, a design approach, called the Cognitive Work Analysis Design Toolkit (CWA-DT), has been developed (Read, Salmon, Lenné, & Jenkins, 2015b). Although the approach has been applied in initial studies, prior to the study reported in this paper it had yet to be tested formally. The aim of the current paper is to report the results of an evaluation of the CWA-DT, based on an application within the rail level crossing (RLX) domain. The paper also draws out interesting insights associated with the application of sociotechnical systems theory in a public safety context.

1.1 The CWA Design Toolkit

The CWA-DT was developed to provide HFE practitioners with guidance for moving from the analysis outputs created with CWA, to design concepts (Read, et al., 2015b). With CWA being underpinned by the sociotechnical systems approach, the CWA-DT aims to make the values and principles of this approach more explicit in the design process. A summary of the processes associated with the application of the CWA-DT and the content of the guidance is provided in Figure 1. As the CWA-DT is a toolkit, users are encouraged to use those aspects of the process, activities and tools that they consider would add value to their process. Tools within the CWA-DT, such as the Design Tool Selection Matrix, are intended to assist those decisions.

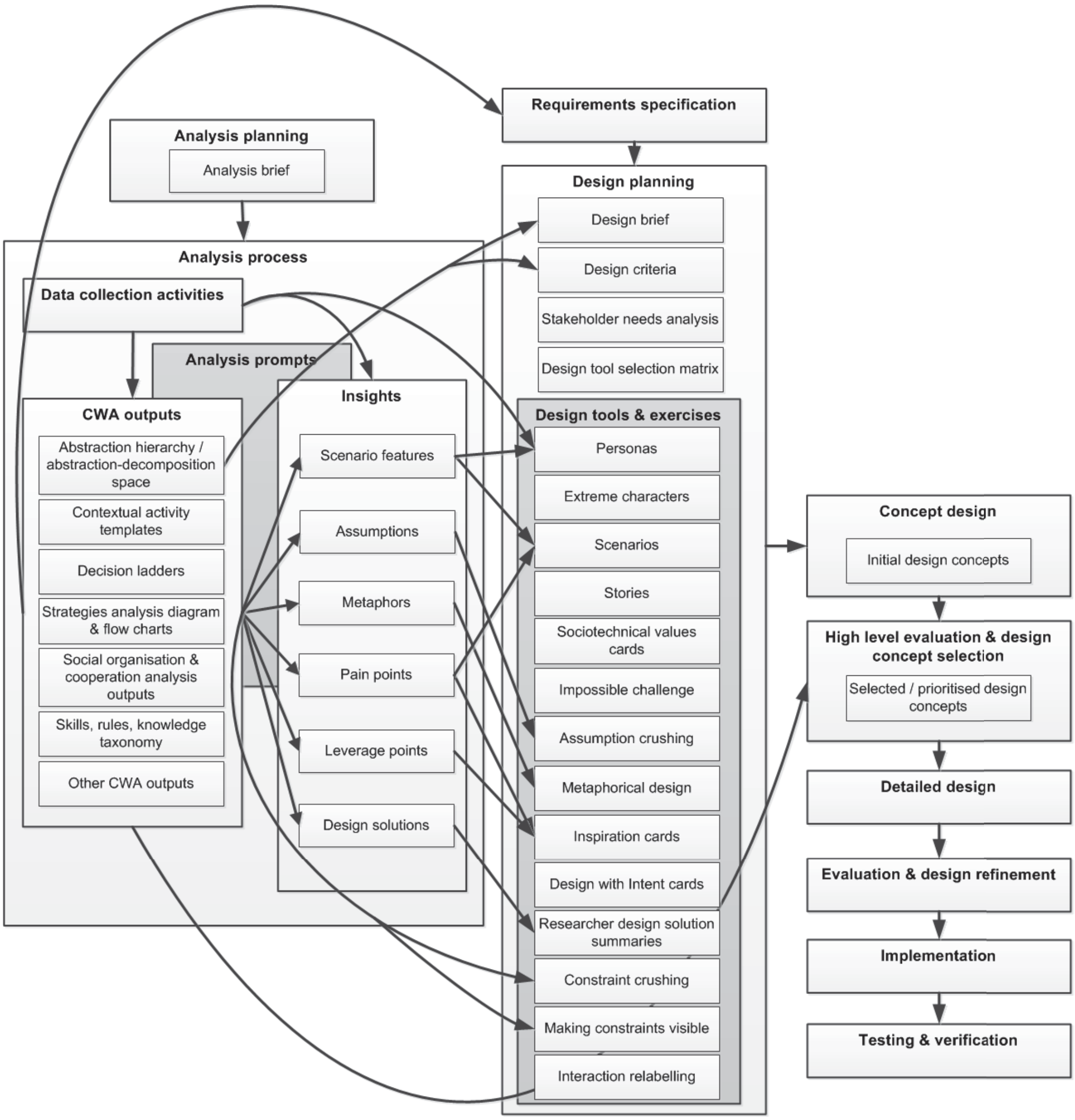

Figure 1. Overview of the CWA-DT generic process, activities and tools.

Evidence of the effectiveness and utility of HFE methods is needed to support researchers and practitioners in choosing those methods most appropriate for their need and most cost-effective in terms of time and resources (Stanton & Young, 1999). More recently, there have been calls for sociotechnical systems approaches to demonstrate their predictive validity in design (e.g. Carayon et al., 2015; Davis, Challenger, Jayewardene, & Clegg, 2014).

Prior to developing the CWA-DT, a range of criteria were identified for its evaluation (Read, Salmon, Lenné, & Stanton, 2015c). The criteria were of three types: HFE methodological criteria, sociotechnical values and sociotechnical principles. Each type of criteria is described in the following sections.

1.1.1 Methodological criteria

The methodological criteria stated for the CWA-DT were that the design process facilitates creativity and / or innovation, that it has structure and traceability between the analysis outputs and the artefacts of the design process, that it is holistic in that it supports the coordinated design of all system elements (e.g. interfaces, training, support materials, team structures, etc.), that it can integrate with existing systems engineering processes, that it provides a process that is efficient and / or cost effective, that it is valid (i.e. produces effective designs / designs sociotechnical systems with adaptive capacity) and finally, that it facilitates an iterative design process.

1.1.2 Sociotechnical values

The values of sociotechnical systems theory underpin the design process and should also be represented in the outcomes of the design process (i.e. in the designed sociotechnical system) (Cherns, 1987). The values include the notion of humans as assets (adaptable decision-makers as opposed to error-prone disturbances), technology being a tool to assist humans to meet their goals (rather than an end in its own right), the need to promote quality of life of the humans within a system (i.e. to undertake tasks that are challenging, to have choice and autonomy, to be given recognition, etc.), to respect individual differences in design (i.e. providing flexibility to meet different human needs and desires), and to demonstrate responsibility to all stakeholders (i.e. to consider and minimise physical, social, economic and environmental harms to any stakeholders stemming from design decisions).

1.1.3 Sociotechnical content principles

The content principles apply to the state of the designed sociotechnical system. Fourteen content principles were identified from the sociotechnical systems literature and these are described in our previous publication (Read, et al., 2015c). They include that the means for undertaking tasks are flexibly specified supporting performance variability and adaptability in the way tasks are performed over time (Cherns, 1976, 1987; Clegg, 2000), that problems are controlled at their source to reduce the length of feedback loops and promote learning (Cherns, 1976), and that those responsible for decisions should be provided with a sense of control over the situation (Clegg, 2000).

2. Evaluation framework

Two key research questions were identified as important for the evaluation of the CWA-DT. The first question was whether or not the CWA-DT can be considered a useful design approach and the second was whether sociotechnical systems theory is an appropriate and acceptable approach for designing for public safety (i.e. RLXs). A summary describing the relevant sub-questions, as well as the methods and standards for evaluation are displayed in Table 1. The evaluation incorporates both process measures and outcome measures.

Table 1. Research questions, measures and standards of success for the CWA-DT.

Sub-questions	Measure/s	Standard for success
Research question 1: Is the CWA-DT a useful design approach?		
1.1 Does the CWA-DT meet accepted HFE factors methodological criteria?	- Participant questionnaire (process measure)	- 75% agreement or strong agreement that the methodological criteria were met
1.2 Does the CWA-DT process align with sociotechnical systems values?	- Participant questionnaire (process measure)	- 75% agreement or strong agreement that the process aligned with the sociotechnical systems values
1.3 Does the CWA-DT create design concepts that align with sociotechnical systems values?	- Expert determination (outcome measure)	- 75% agreement or strong agreement that the designs meet the sociotechnical systems values - The design concepts are rated as more in line with sociotechnical systems values than existing RLX designs
1.4 Does the CWA-DT create design concepts that align with sociotechnical systems content principles?	- Expert determination (outcome measure)	- 75% agreement or strong agreement that the designs meet the sociotechnical systems content principles - The design concepts are rated as more in line with sociotechnical systems content principles than existing RLX designs
Research question 2: Is sociotechnical systems theory an appropriate and acceptable approach to designing for public safety?		
2.1 Do sociotechnical systems theory values and principles lead to more effective designs than traditional risk approaches in a public safety context?	- Participant concept prioritisation (outcome measure) - Expert concept prioritisation (STS concepts ranked higher than traditional) (outcome measure)	- Concepts ranked by experts as higher on sociotechnical systems criteria are prioritised more highly by participants - Concepts ranked by experts as higher on sociotechnical systems criteria are ranked as most effective in minimising collisions, injuries, near misses and risk
2.2 To what extent are sociotechnical systems theory values and principles accepted by stakeholders in a public safety context?	- Participant questionnaire	- 75% agree or strongly agree that the process would be useful for other safety-related design projects and that sociotechnical systems theory is an appropriate approach for RLX design

3. The RLX domain

Collisions at RLXs are a public safety concern in Australia and internationally. Between July 2002 and June 2012 there were 601 collisions between trains and road vehicles and 92 collisions between trains and pedestrians at RLXs (Australian Transport Safety Bureau, 2012). The annual cost of RLX incidents in Australia has been estimated at $116,279,817[1] (Tooth & Balmford, 2010).

In 2009, there were 2,817 public RLXs in Victoria (including pedestrian-only crossings) (Rail Industry Safety and Standards Board, 2009). The majority of RLXs in Victoria are located in rural environments, with approximately 350 crossings located in the Melbourne metropolitan area (Road Safety Committee, 2008). All crossings in the metropolitan area have what is known as 'active protection' (warnings to alert road users of train approach, such as flashing lights and boom barriers), while in rural environments there are RLXs with active protection as well as RLXs with 'passive protection' (static warning signs only). In 2008, 770 RLXs in Victoria were actively protected and the remainder had only passive protection (Road Safety Committee, 2008), although it should be noted that annual government upgrade programs are focussed on providing active protection at high risk RLX sites. This aligns with a safety management paradigm which adopts the hierarchy of control to manage safety risk. The hierarchy states that if a hazard cannot be eliminated (i.e. where the cost of separating road and rail via bridges or tunnels is prohibitive) or substituted for a less hazardous substance, engineering controls (i.e. boom barriers and gates) represent the next most effective control, followed by administrative controls (i.e. rules, enforcement activities, etc.). Risk assessment approaches have been criticised for their inability to address emergent risks and their focus on protecting individual workers or users from hazards (e.g. Carayon, et al., 2015).

This paper is concerned with one aspect of a wider research program that has taken a novel approach to understanding safety at RLXs through the application of CWA to understand the constraints and associated degrees of freedom for behaviour at RLXs and to create new design concepts. The findings of the CWA are published elsewhere (see Mulvihill, Salmon, Lenné, Beanland, & Stanton, 2014; Read, Salmon, Lenné, & Stanton, revision under review; Salmon, Lenné, Read, Walker, & Stanton, 2014; Salmon et al., in press) and will not be discussed directly in the present paper. Instead, this paper focuses on an evaluation of the CWA-DT which was used to guide the transition from the CWA findings to design concepts that aim to improve safety at RLXs.

The application of CWA assisted to clarify that the precursors to, and factors influencing RLX crashes in metropolitan and rural environments are different. For example, some of the key risk issues and insights identified during the application of CWA to RLXs for rural crossings included road users not being aware of an approaching RLX, not being aware of an approaching train and misjudging the speed or distance of a train. 'Pain points' identified by the analysts relating to these issues included

[1] In 2010 dollars, based on averages of 15 fatalities, 50 severe injuries and 50 minor injuries, at 65% urban and 35% non-urban locations.

rural RLXs being often located on high speed roads, no information about train approach being provided at passive RLXs and that there being nothing in the design to prevent users crossing in front of a train at passive RLXs.

The key risk issues identified for metropolitan RLXs included vehicle drivers queuing or short stacking on the RLX, road users not detecting a second or subsequent train and road users choosing to cross when warnings are activated / a train is approaching. Pain points relevant to these issues included visual clutter and distractions in the environment leading to users not realising a RLX is present, users not provided with information about second or subsequent trains approaching, and pedestrian users who intend to catch the approaching train being punished for compliance (i.e. for decision to stop and wait) and rewarded for non-compliance (by catching their train).

4. Method

4.1 RLX design process

4.1.1 Participants

Twenty participants (15 males, 5 females) participated in two design workshops (Workshop 1 and Workshop 2). Participants were invited as representatives of RLX stakeholder organisations (i.e. government departments, regulators, road authorities, road user peak bodies, transport investigators, etc.) or as interested persons with a professional interest in the research (i.e. HFE professionals, researchers, designers, etc.). Participants had a mean age of 45.7 years and Table 2 describes participants' self-reported areas of expertise. As there was some variation in numbers of participants across the workshop days, Table 2 shows the expertise represented in each workshop, as well as over both workshops. A total of eighteen participants attended Workshop 1 (however, four could attend one-day only), while 10 participants attended Workshop 2. Eight participants attended both workshops.

Table 2. Participant self-reported areas of expertise (note, the majority of participants indicated more than one area of expertise).

Area of expertise	Workshop 1	Workshop 2	Total
Technical knowledge about equipment / infrastructure from a railway perspective	8	7	10
Technical knowledge about equipment / infrastructure from a road perspective	4	2	5
Knowledge and skills in railway rules and operations	7	5	8
Knowledge and skills in road rules and operations	7	2	7
Knowledge about human behaviour / HFE considerations	9	7	11
Risk and / or safety management	11	5	11
Policy development / implementation	5	2	5
Other (industrial design, public education, safety investigation, general knowledge of road & rail systems)	4	2	4

The majority of participants in the workshops had extensive experience working in the road or rail safety fields. Participants' occupations and past experience were diverse and included working in operational railway roles (e.g. as signaller, driver), as safety investigators, rail signalling designers, road designers, safety managers and executives, and heads of HFE teams and research groups.

4.1.2 Materials & procedure

Overview of the application of the CWA-DT

The materials within the CWA-DT were used to plan the design process. The overall process that was adopted is illustrated in Figure 2. It shows that following the development of CWA outputs, and the documentation of associated insights, during the design planning stage a number of tools and activities were selected for use with the participants in Workshop 1. Workshop 1 was delivered over two days and involved participants engaging in activities to generate innovative design concepts and solutions for improving behaviour and safety at RLXs. By the conclusion of the workshop, participants had developed and prioritised design concepts. Following the generation of initial design concepts in Workshop 1, a high level evaluation process was undertaken and recommendations for design refinements were presented to the stakeholders in Workshop 2 to assist the design refinement process. The process undertaken has not yet extended to detailed design and considerable further work would be required prior to implementation of any of the design concepts or ideas. Consequently, these steps are shaded in Figure 2.

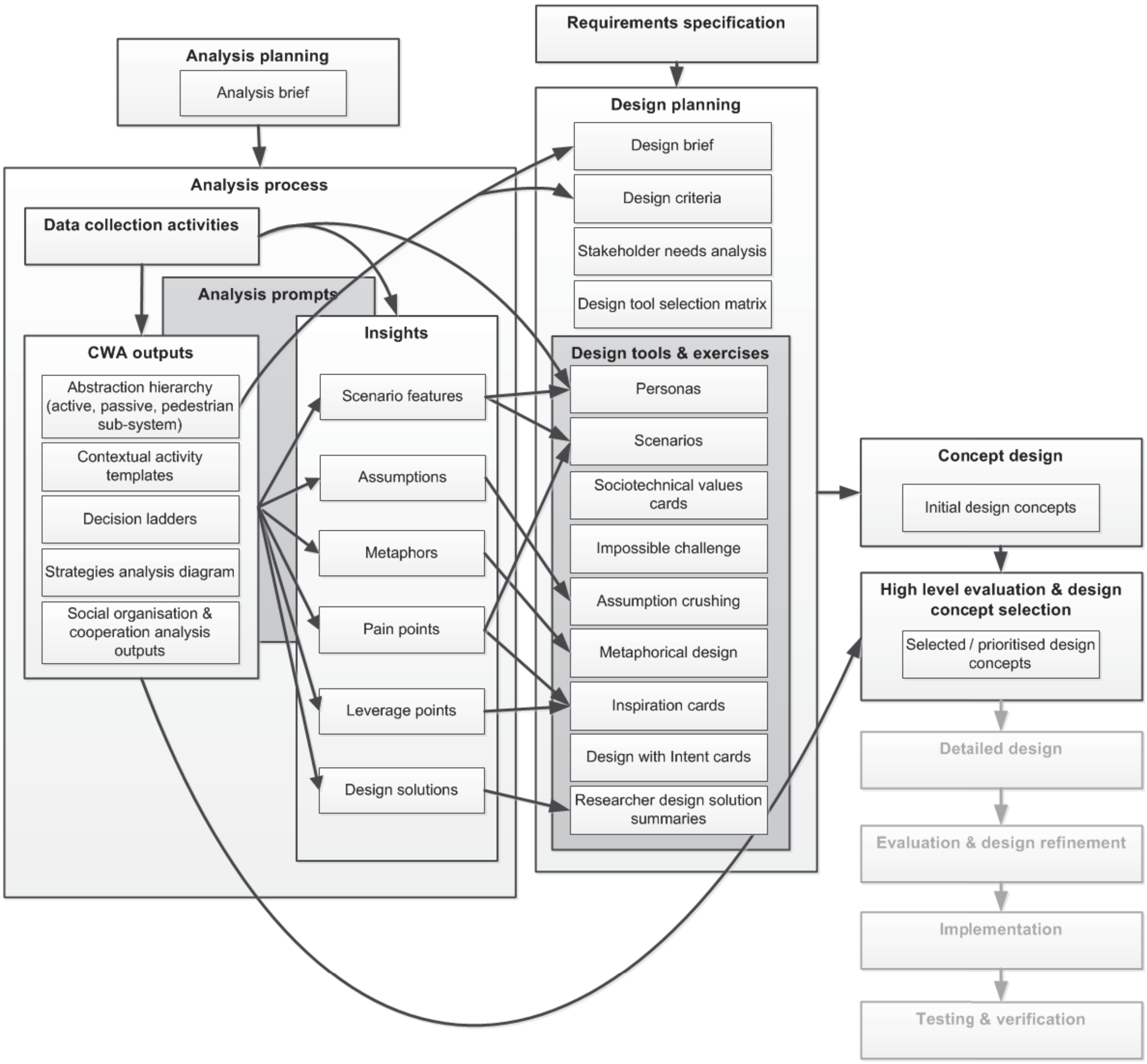

Figure 2. The CWA-DT as applied to RLX design.

The design planning stage was undertaken over two days. This involved the research team participating in a workshop, facilitated by the first author, to draw together the analyses and associated insights (documented during the analysis or via a ‘prompting’ process recommended by the CWA-DT) and then to define the scope, objectives and measures of success for the design process. This was documented in Design Brief and Design Criteria documents. Further, the Design Tool Selection Matrix was used to select the most appropriate tools and activities to be undertaken in the design workshops with stakeholders. The tools selected were: Assumption crushing, Inspiration cards, Personas, Scenarios, Metaphorical Design, The Impossible Challenge Exercise, and Sociotechnical Values Cards. These tools were considered useful for these workshops to assist stakeholders to think creatively and lateral thinking about a topic in which they have much existing knowledge and experience (achieved through assumption crushing, metaphors and the impossible challenge), to promote empathy with users (through personas) and to introduce sociotechnical systems thinking (through the sociotechnical values cards).

The Design Brief developed during the design planning stage outlined the aim of the design task as ‘to develop design concepts that will increase safety at Victorian public RLXs.’ The scope was constrained to improve the at-grade interface rather than the development of grade separation options (i.e. the construction of bridges or tunnels). Further, the focus was described as improving / shaping desired behaviour rather than improving technological reliability. Further, the design process was determined to be focussed on improving design for ‘well intentioned’ road users rather than to directly address intentional efforts to circumvent the system. Similarly, the designs developed were not intended to focus on reducing incidents involving intentional self-harm at RLXs; however, it was noted that it would be beneficial if design concepts introduced some positive indirect effects on such behaviour.

Workshop 1

The workshop was held in a conference venue configured to accommodate small and large group working. Following the gaining of informed consent, participants were provided with a detailed overview of the project and its aims. Members of the research team presented the key findings from the CWA analysis to provide participants with a general understanding of the analysis findings. Next, participants engaged in a range of activities described in Table 3.

The initial activities were introductory in nature and aimed to engage participants with the sociotechnical systems approach and values, and to promote lateral thinking. Following this was an idea generation phase which aimed to promote divergent and creative thinking about design possibilities for improving safety at RLXs. In the idea generation phase, participants were asked to consider particular types of RLX contexts and generate ideas for their design. The contexts were: a rural greenfield site, a metro greenfield site, an existing rural passive RLX site, an existing rural RLX site with flashing lights only, an existing metropolitan RLX site adjacent to a railway station and an existing metropolitan RLX site not adjacent to the station. Photographs showing an approach view of different types of existing RLXs were provided to remind participants of the contexts in which RLXs operate. These included photographs of a rural passive RLX, a rural RLX with flashing lights, a metropolitan RLX adjacent to a railway station and a metropolitan RLX not adjacent to a railway station.

Table 3. Description of activities undertaken by participants in Workshop 1.

Activity	Materials & procedure
Introductory activities	
General brainstorming	This warm-up activity provided an opportunity for participants to express ideas that they may have generated outside of the design process uninfluenced by the CWA findings or the sociotechnical systems theory philosophy. Participants were asked 'What are your ideas for improving RLX safety?' They were asked to brainstorm and record their ideas individually on note paper. They were then asked to share their ideas, one-by-one, adding any novel ideas they had generated. The ideas were recorded by the facilitator on butcher's paper.
Sociotechnical Values Cards	This activity provided participants with information about the sociotechnical system theory values which underlie the approach of the CWA-DT. To ensure participants understood and engaged with the values and philosophy, they were asked to discuss the values in small groups. To promote discussions around the values Sociotechnical values cards (Figure 3) were created with each having the title of a sociotechnical value and a picture to represent its meaning. For example, the card for 'Humans as assets' contained a picture of a ballerina to emphasise the point that humans have creative and artistic abilities that cannot be matched or replaced by technology. The sociotechnical values cards were randomly distributed amongst the small groups so that each group received two values on which to focus. The groups were asked to consider the following questions for their values and document their discussion on butchers paper: • What is your understanding of this value? • Do you believe it is important? • In what ways is the value supported at RLXs? • In what ways is the value not supported at RLXs? • How is this value relevant to today's workshop? Groups then shared key aspects of their discussion with the wider group.
User Profiles (personas)	Personas (described to participants as user profiles) were used to encourage the development of empathy for different RLX user types, to enable them to better consider their perspective and understand their motivations and challenges. The personas were based on generic characteristics of users at RLXs. They included a user name, occupation, road user type (pedestrian, cyclist, motorcyclist, car driver or heavy vehicle driver), main reason for travel, a short description of the person's travel patterns, personal preferences and motivations. The user profiles were intended to describe a concrete user, although were not intended to be overly stereotypical. The handout included a space for participants to draw a sketch of the user as well as questions for participants to answer. The questions were related to: the user's concerns when travelling generally, the user's concerns at RLXs, what the user thinks is good about RLXs and what challenges has the user faced at RLXs. Participants were provided with the user profiles handout and were asked to consider each written profile and provide answers to the questions, discussing this within their small group and reporting back to the larger group.
The Impossible Challenge Exercise	This exercise posed a problem for participants to solve that has such tight constraints (e.g. time, budget, resources) that it could not be solved through rational, linear thinking (Imber, 2009). The idea of introducing such an exercise forces the brain to begin to think laterally and acts as a 'warm up' activity to promote lateral thinking during the remainder of the session. In the session, participants were posed an impossible challenge unrelated to RLXs and asked to work in small groups to generate three solutions within five minutes.

Idea generation	
Scenarios	For each RLX context, participants were presented with a scenario or scenarios that highlighted relevant research findings relating to that context, including important features of the RLX functioning as well as pain points and scenario features identified within the analysis insights. Each scenario focussed on a particular user type and similarly to the user profiles, the scenarios described a fictional, but typical, concrete experience for each road user type. For example, for the context of metropolitan RLX adjacent to a railway station, the scenario involved a pedestrian running late for a train. The handout for the scenarios included spaces in the text for participants to complete. These prompted the participants to consider the emotions of the road user to further promote empathy and understanding. This is shown in an extract taken from the scenario involving Ken the heavy vehicle driver: "*As he is crossing he realises that he forgot to check the other track, being so focused on the train on his right. He looks to his left when he's on the crossing and it is clear. Once past the crossing he keeps an eye on the rear view mirror to watch the train cross. It comes earlier than he had anticipated, but not so early that he feels like he took any risk. He feels* ________." During the session, participants were introduced to the relevant RLX context and provided with the written scenario handout. Participants were asked to read the scenario and to fill in the blank spaces to describe the emotion that might be felt by the user in the scenario. Participants reported back on each scenario sharing the emotions they attributed to the user.
Assumption Crushing	For the greenfield RLX contexts, participants undertook an assumption crushing exercise (Imber, 2009). This involved presenting assumptions that the researchers identified while completing the CWA outputs (i.e. that decisions should be taken away from humans) and asking participants to develop alternative statements or assumptions and come up with design ideas based on those alternative assumptions. Participants were presented with assumptions and were asked to undertake the following activities within their small groups: • Discuss the extent to which you agree with the assumption. • Brainstorm alternative statements. • Choose an alternative statement and discuss how would you design a RLX that aligns with this assumption? • Document design ideas (using A5-sized coloured sheets of paper provided). Following this, participants shared aspects of their discussion with the wider group.
Metaphorical Design	For each of the greenfield RLX contexts, participants were asked to consider a metaphor (i.e. the concept of separation) and undertake the following within their small groups: • Brainstorm how separation is achieved in other areas / domains. • How could these other types of separation be used at rural RLXs? • Document design ideas (using A5-sized coloured sheets of paper provided). Following this, participants shared aspects of their discussion with the wider group.
Inspiration Cards	For each of the existing RLX contexts, participants were provided with a set of inspiration cards and were asked to use the cards to generate ideas for improving the existing RLX. The inspiration cards included: • Pain point cards – Selected pain point insights identified from the analysis were printed on palm sized, red card (Figure 3). • Leverage point cards – Selected leverage points identified from the analysis were printed on palm sized, pink card (Figure 3). • Cards from the Design with Intent toolkit (Lockton, Harrison, & Stanton, 2010) – Selected Design with Intent cards were used (Figure 3). These cards present design patterns drawn from one of eight lenses or perspectives including the architectural lens, ludic (playful) lens and cognitive lens. They provoke the consideration of opportunities or ideas from various disciplines to design to influence behaviour.

	Participants were given the flexibility to choose the way in which the cards were used and were asked to document any design ideas inspired by the cards on the A5-sized coloured sheets of paper provided in the session.
The RLX Impossible Challenge Exercise	In this exercise, each table of participants was allocated a different existing RLX context. They were provided with the following challenge: • The Queen is coming to visit Victoria next week and the premier has announced that she will open a new, world-leading RLX upgrade. You have a budget of $1,000. What will you do in one week to the existing crossing to make it world-leading? Participants were asked to generate and document their ideas to meet this challenge on the A5-sized sheets of coloured paper provided.
Concept design & selection	
Design Concept Definition	Following the idea generation activities, participants were asked to create more comprehensive design concepts. To assist this, the ideas documented throughout the workshop on the A5-sized coloured sheets of paper were displayed around the room (on tables and walls) along with ideas suggested by the researchers (i.e. design solution insights identified during the CWA) and ideas proposed in previous research. Participants were asked to work in small teams and to browse through the ideas available and use one or a combination of ideas as inspiration for creating a more holistic design concept. Participants were reminded of the requirements to design for all road users and to consider the sociotechnical systems theory approach and values. Once the teams had developed one or more design concepts, a representative from each presented each concept to the wider group. Participants used Design concept templates to document the design concepts which provided space to describe the concept in words and / or provide diagrams or sketches to describe the idea. The larger sheets (A3-sized) incorporated prompts to give the concept a name, to identify the context for the concept (metro, rural or both) to provide a drawing or sketch of the design, describe the expected benefits, identify which users the design would be effective for, and identify the sociotechnical values addressed. This was intended to ensure that participants were reminded of the need to consider all road users and the values.
Design Concept Prioritisation	Following the presentation of the concepts, participants were asked to discuss each of the design concepts developed and to prioritise them in relation to how effective they were likely to be in improving safety at RLXs. The process by which the participants were to conduct the prioritisation was left for them to determine and they chose to use a voting system whereby each participant could indicate their first, second and third preferences (using sticky notes that were placed on each concept indicating a vote of 1, 2 or 3). The outcome of the prioritisation process was a ranked order of 11 design concepts for RLXs.

At this point, participants were encouraged to adopt a road user by selecting and wearing a badge (badges were provided displaying symbols representing different road user types - drivers, cyclists, motorcyclists, heavy vehicle drivers and pedestrians). Participants were asked to represent this user group's perspective at their table for the following session. At various points in the workshop, participants were asked to change their badge and adopt a new perspective to increase the opportunity for them to share perspectives of different user types.

Following the idea generation phase were the concept design and selection activities which involved divergent thinking to combine and refine the design ideas to generate more holistic design concepts. These concepts were then prioritised by the design participants based on the extent to which they thought they would be effective in improving RLX safety.

At the conclusion of the workshop participants completed a demographic questionnaire and an evaluation questionnaire. The questions in the evaluation questionnaire intended to gain participant feedback on the relevant evaluation criteria on a rating scale from 'strongly disagree' to 'strongly agree' and also included open-ended questions to gather participants' views about the workshop and recommendations for improvements.

a. Sociotechnical values cards

b. Pain point cards

c. Leverage point cards

d. Design with Intent cards (Lockton, Harrison & Stanton, 2010)

Figure 3. Examples of the card-based materials used in Workshop 1.

Evaluation process

The time between workshops was used to conduct the high level evaluation of the initial design concepts. This involved the research team, in collaboration with participants who expressed their interest in being involved, conducted an evaluation of the more highly prioritised concepts against the work domain analysis models developed. Participants were involved in the work domain analysis evaluation of two of the concepts. The researchers completed the work domain analysis evaluations of the remaining concepts, as well as the evaluation using the sociotechnical systems content principles. Findings from a human error analysis using the Systematic Human Error Reduction and Predication Approach (SHERPA; Embrey, 1986) were also incorporated into the evaluation, as an additional method for understanding the impact of design changes on system safety.

Workshop 2

Workshop 2 was held approximately six months after Workshop 1, enabling the evaluation activities to occur in the interval.

Prior to the workshop, participants were provided with a written summary of the top five ranked design concepts from Workshop 1 and a summary of the overall evaluation findings (comparing each concept). The summary document included a comparison of each concept using the work domain analysis measures, findings from the SHERPA analysis and findings from the evaluation against the sociotechnical content principles. For each design concept the summary outlined the components incorporated, the key risks addressed, the potential negative effects, costs and suggestions for improvement identified during the evaluation process.

At the beginning of the workshop participants who did not attend Workshop 1 (n=2) provided informed consent and completed a demographic questionnaire. Participants were then presented with the findings from the evaluation of the top five prioritised concepts. They were given an opportunity to ask questions, and provide feedback and comments on the findings. A detailed overview of each prioritised concept was also provided to ensure participants had a shared understanding of each concept, mirroring the information provided in the written summary. Following this introduction, participants engaged in the activities described in Table 4. These activities included reviewing the suggested design improvements identified during the evaluation process, and conducting an evaluation and final ranking of concepts following the inclusion of the design improvements.

Table 4. Description of activities undertaken by participants in Workshop 2.

Activity	Materials & procedure
Design improvement review	Participants worked in small groups each facilitated by a member of the research team. A booklet of design suggestions for each concept was used to present each suggestion and record the consensus of the group (i.e. accept suggestion, reject suggestion) and the reasons for these decisions. Further refinements proposed by the groups were also recorded for inclusion in the refined concepts. Each group then presented the agreed refinements to the broader group for discussion.
Evaluation & ranking of concepts	Once the concepts were refined, a large, printed scoreboard of evaluation criteria was introduced to the participants. The scoreboard displayed the following evaluation criteria: • whether the design concept supported the values and priority measures from the work domain analysis (e.g. minimise collisions, maximise efficiency, minimise road rule violations), • whether it considered different road user types (e.g. drivers, cyclists, pedestrians), • whether it addressed or mitigated key risks associated with RLXs (e.g. road user not aware of an approaching train, road user queues or short stacks on the RLX), • the cost of the proposed designs (e.g. high, medium, low), and • the level of innovation in the design concept (a rating from 1 to 5, with 5 being the highest level of innovation). As a large group, participants discussed each of the criteria for each design concept and provided a consensus rating or ranking on each. At the conclusion of this process each participant was provided with three voting tokens which they used to vote for the design concepts they felt best met the criteria and would be best to go forward into further detailed design and testing processes. Voting was achieved by placing the tokens at the bottom of the scoreboard aligned with the chosen design concept.

At the conclusion of Workshop 2 participants completed a final evaluation questionnaire which requested feedback about the workshop, relevant to the criteria, on a rating scale from ‘strongly disagree’ to ‘strongly agree’. This questionnaire also included open-ended questions to gather participants’ views about the workshop and recommendations for improvements.

4.2 Expert panel

4.2.1 Participants

Three HFE experts were approached via the researcher team’s professional networks to participate. The panel consisted of three males with a mean age of 44 years, and mean experience in the field of HFE of 17 years. Two participants were employed in academic positions and the other in an industry role. All held PhD qualifications in the HFE field. Participants in the expert panel were asked to self-rate their level of expertise in topics and methods relevant to the research project. As can be seen in Table 5, all participants considered themselves expert HFE and road and rail safety, while there were some differences in other ratings. For example, while two participants considered themselves expert in the sociotechnical systems approach, one rated themselves a beginner. It should be noted that the panel was not intended to be representative of those working in the fields of CWA and sociotechnical systems but instead to bring together those with HFE expertise. Having diversity in HFE backgrounds was seen as a strength in ensuring balance in the discussion and assisted to ensure clarity around the measures applied by the panel (based on the sociotechnical systems principles and values), rather than relying on assumed prior knowledge.

Table 5. Participant self-ratings of expertise in areas relevant to the research.

Topic / method	Novice	Beginner	Competent	Proficient	Expert	*Total*
HFE (generally)	-	-	-	1	2	*3*
HFE and road transport	-	-	-	-	3	*3*
HFE and rail transport	-	-	-	-	3	*3*
Design generally	-	-	1	2	-	*3*
Participatory design approaches	-	-	1	2	-	*3*
Cognitive work analysis	-	1	-	-	2	*3*
The sociotechnical systems approach	-	1	-	-	2	*3*
Methodology evaluation	-	-	-	1	2	*3*

4.2.2 Materials

A demographic questionnaire was used to gather information about the expert panel participants and information about their areas of expertise. Further, a questionnaire with a rating scale was used which incorporated statements related to the sociotechnical content principles and values with options ranging from 'strongly disagree' to 'strongly agree'.

Definitions of each sociotechnical systems theory content principle were provided to participants as were 'indicators' to assist them in determining whether or not the principle was met within each of the RLX designs they were presented for assessment.

Participants in the expert panel were shown photographs of a prototypical Victorian metropolitan and rural RLX. They were also presented with the three most highly prioritised design concepts developed during the stakeholder workshops. These new concepts were presented both via written descriptions and via low fidelity visual mock-ups with photographs of new components added to each photograph of the existing RLX environments (either metropolitan or rural as relevant). Descriptions of the three concepts are provided in Table 6.

Table 6. Description of RLXs rated in the expert panel session.

Design	Description / key features
Existing active RLX in metropolitan environment (Main Road, St Albans – adjacent to St Albans railway station)	- Half (two-quadrant) boom barriers - Flashing lights and bells - Yellow box markings - Automatic pedestrian gates - Fencing, road markings / stop line - Passive signage at the RLX - Train horn - Associated road rules
Existing passive RLX in rural environment (Schumakers Lane, Maiden Gully)	- Give way sign - Passive signage at the RLX - Road markings - Advanced passive warning signage - Rumble strips on approach - Associated road rules
Design concept 1 – metropolitan environment	As for existing metropolitan RLX, with the addition of: - Traffic lights at the RLX with automatic enforcement using number plate recognition – revenue collected via fines would be used for RLX upgrades - Traffic light sequence would be coordinated with upstream and downstream lights - Addition of a 'skirt' on the boom gate – which could be used to display safety messages and / or advertising (when the boom barriers are down only) - In-road lights at the painted stop line that would activate with the flashing lights, bells, boom gates - Staggered platforms (one on each side of the roadway, rather than directly across from one another). This would enable the train to stop at the platform after traversing the RLX, meaning that the RLX warnings would not need to be activated while passengers are boarding and alighting enabling road users to continue to use the RLX. Further, the train would be moving at a relatively slow speed through the RLX (if stopping at the station) - Advanced stop line allowing cyclists to wait at the head of the traffic queue - Shelter at the pedestrian waiting areas – with some incorporating a ticket machine and / or community hub display that can be used to access community information and news - Cafes near the RLX with electronic displays that provide train information and information about the RLX (recent near misses, performance, etc.) to encourage conversations about the RLX - Default closed pedestrian gate - Pedestrian gate unlocks between trains - RLX supervisor – at certain high risk times of day, e.g. peak hours - All-cross mode – with formalised pedestrian paths enabling diagonal crossing - Signage instructing vehicles to 'keep tracks clear' and 'clear tracks' when cars are detected queued on the far side of the RLX - An emergency lane available for vehicles to use if stuck queued on the RLX, with active bollards blocking its use when the RLX warnings are not activated - 'No standing / parking' sides on the far side of the RLX to avoid congestion on the road and related queuing - An awareness campaign asking drivers to 'break the chain' and avoid queuing on the RLX - Vehicle-to-vehicle collision avoidance on road vehicles to avoid crashes occurring on or near the RLX
Design concept 2 – metropolitan environment	As for existing metropolitan RLX, with the addition of: - Vehicle-to-infrastructure technology to enable trains to communicate with infrastructure, and that infrastructure to communicate with road users - In-vehicle warnings of approaching trains - Warnings of approaching trains provided to smartphones - Dynamic displays for pedestrians near the pedestrian gates providing train information and other information such as news and weather

	- In-vehicle warnings of vehicles queued ahead - In-vehicle instruction if detected stopped on the RLX – 'move off RLX or exit vehicle' - In-vehicle route advice to avoid the RLX when it is congested - Coordination of RLX warnings with traffic lights to obtain smooth traffic flow - Automatic train protection system used on-board the train to enable trains to be stopped at a platform prior to the RLX without RLX warnings activating - Automatic train protection system would also provide a constant 25 second warning time of train approach - For heavy vehicles with automatic braking, prediction of collision between train and vehicle would result in braking applied - If heavy vehicle detected stopped on the RLX, train braking would be applied to avoid collision - Automated collection and analysis of speed, incident and near miss data
Design concept 3 – rural environment	As for existing rural RLX, with the addition of: - Trains and road vehicles communicate with cloud software - giving speed and location information - The software calculates a target speed for each road vehicle to maintain to avoid stopping at the RLX, based on an estimate of when the train would traverse the RLX – provides this to road users via an in-vehicle display - If the GPS fails, the interface would provide a warning of a RLX ahead and alert the road user if they have adopted an unsafe speed profile - In-vehicle device would re-route to avoid RLXs or to encourage road users to use RLXs with active protection - On the interface, each RLX is given a unique 'look and feel' based on its risk level - If collision predicted, automatic braking would be applied on road vehicles - Regular forums between local road users (particularly heavy vehicle drivers) and train users would be held - Road users and train drivers would be educated about the device and how it operates - Automated collection of incident and near miss data - To encourage up-take, heavy vehicle companies adopted the in-vehicle device would receive monthly reports identifying cost and efficiency savings and would be provided with a subsidy / discount on insurance - Aggregate data would be provided to heavy vehicle drivers with the aim of promoting positive social norms. For example, demonstrating that the majority of drivers meet the target speed and thus avoided having to stop for a train

3.2.3 Procedure

Prior to the half day workshop participants were provided with written information about the three design concepts and the definitions of the sociotechnical systems values and principles that would be used to evaluate them.

During the session, after gaining the informed consent of each participant, participants were provided with information describing the background to the research project and an explanation of each of the sociotechnical systems theory values and content principles.

Following this, participants were provided with the visual mock-ups of the RLX concepts and following each, were asked to discuss and record an agreed rating for each evaluation criteria on the questionnaire. During the discussions, the researcher leading the session clarified questions about the design concepts and about the sociotechnical values and principles, but did not offer an opinion on the ratings. The discussions were audio recorded. The ratings were predominantly a comparative process, with the existing metropolitan and rural designs considered as a baseline. This provided some standardisation to the ratings which could potentially have been quite difficult to conduct otherwise. Participants considered the effects of the design on all road users (e.g. motorists, pedestrians, cyclists, heavy vehicle drivers) as well as the train driver and any other rail users of the RLX. In some cases, the participants suggested that the ratings would be different for different user groups (e.g. agree for pedestrians but disagree for motorists). In such cases, they provided an average or compromise rating (e.g. neutral).

4. Results

The results of the evaluation measures are structured to align with the evaluation framework presented in Table 1.

4.1 Is the CWA-DT a useful design approach?

4.1.1 Does the CWA-DT meet accepted HFE methodological criteria?

Participant ratings

The ratings provided by participants at the conclusion of Workshop 1 and Workshop 2 in relation to their level of agreement with the positive statements regarding each of the methodological criteria of interest is provided in the top section of Figure 4. The raw data, including the relevant statements to which participants responded is provided in Appendix A. Figure 4 shows that all but one statement in this group (statement 14) reached the criterion of more than 75% of participants agreeing or strongly agreeing that the methodological criteria were met. Statement 14 was worded as ‘The process was more efficient than my usual process or other processes I have participated in’. This data was gathered at the conclusion of Workshop 1 which ran over two days, and may reflect the fact that many current design processes are conducted by experts working alone, rather than involving group processes that generally move somewhat slower.

When looking at all statements together, for each of the methodological criteria in Figure 4, it is clear that each criterion as whole met the 75% standard for success. Criteria that received particularly strong support included that the process was structured and that it could be integrated into current design processes (e.g. engineering design processes). Areas for improvement included the efficiency criterion, as well as holism and creativity. However, overall the results suggest that participants agreed that the process met the methodological criteria.

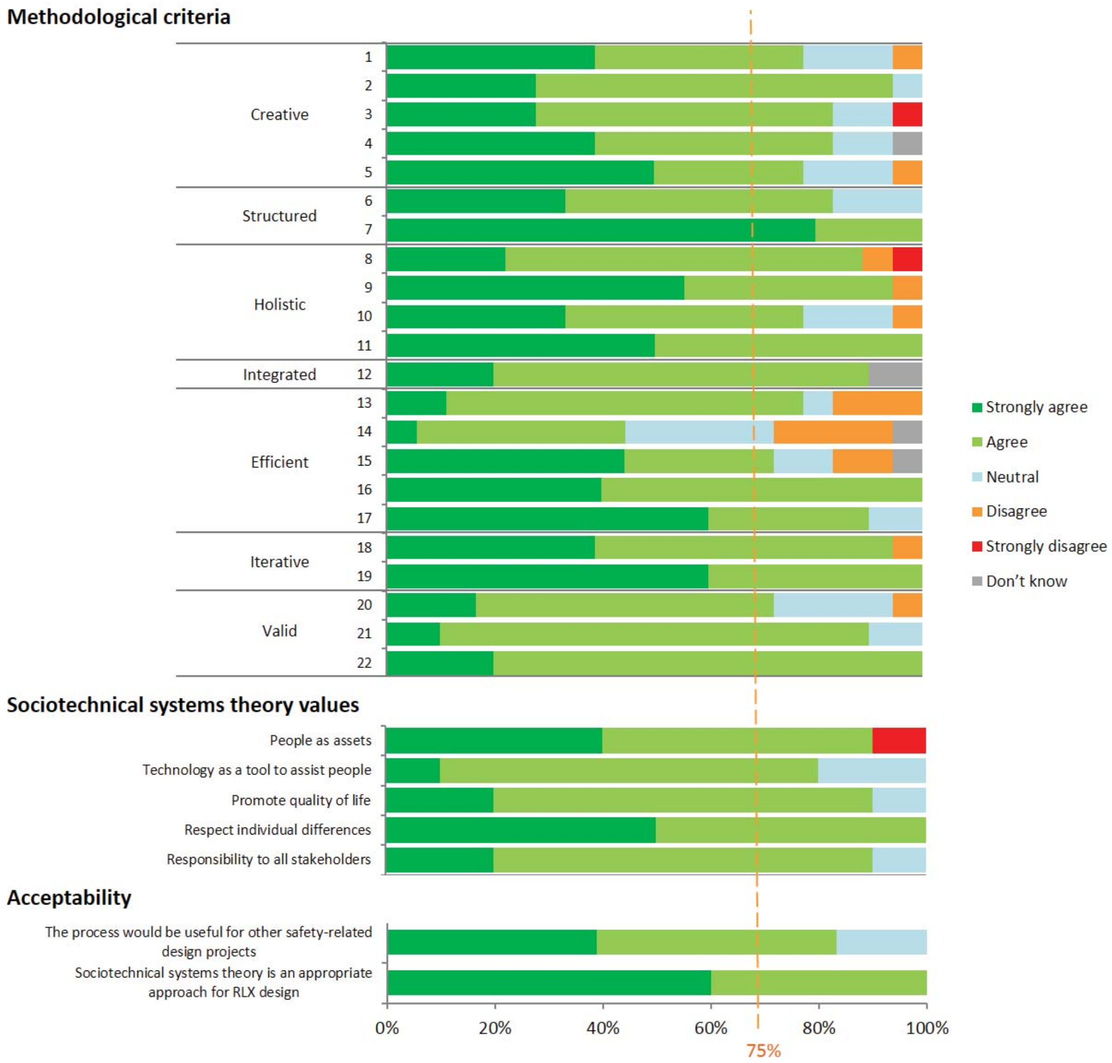

Figure 4. Summary of responses to participant questionnaires relating to the methodological criteria, the alignment of the design process with the sociotechnical systems values and stakeholder acceptability of the sociotechnical systems approach.

4.1.2 Does the CWA-DT process align with sociotechnical values?

The questionnaires completed by participants at the conclusion of Workshop 2 included questions asking participants to think about the entire design process and to rate the extent to which they felt the sociotechnical values were incorporated within the design process in which they participated. The results of this section of the questionnaire are presented in the middle section of Figure 4 (with raw data provided in Appendix B). It can be seen from the figure that the 75% standard of agreement from the ten participants was exceeded. In fact, excepting one strongly disagree rating, participants were generally very positive in stating that they felt the design process they participated in was in line with the values of sociotechnical systems theory.

4.1.3 Does the CWA-DT create design concepts that align with sociotechnical values?

Expert panel participant ratings of the outcomes of the RLX design process (the three prioritised design concepts) against the sociotechnical values is presented at the top of Figure 5. The ratings suggest that designs associated with a rural context are more aligned to sociotechnical values than those in a metropolitan environment. The discussions occurring within the panel session indicated that this is because in the rural environment there is higher latitude for road user and pedestrian decision making and flexibility due to the lack of technology such as barriers and gates. When comparing the existing RLX environments to the new designs, there appears to be little improvement in relation to meeting the values. Concept 1 was rated as promoting quality of life more than the existing situation due primarily to the better provision of amenities and promotion of social engagement of pedestrians (e.g. through the provision of shelter, community hub facilities, cafes, etc.). However, Concept 2 was rated as less aligned to the value of humans as assets than the existing design. This was due to the design being seen as more restrictive and authoritative (with stronger barriers, camera enforcement, etc.).

	STS Criteria	Existing metro	Concept 1	Concept 2	Existing rural RLX	Concept 3
Sociotechnical values	The design concept aligns with the view of humans as assets	Disagree	Neutral	Strongly disagree	Strongly agree	Agree
	The design concept aligns with the view of technology being a tool to assist humans	Agree	Neutral	Neutral	Agree	Agree
	The design concept would promote quality of life for rail level crossing users	Neutral	Agree	Neutral	Agree	Neutral
	The design concept respects individual differences	Disagree	Disagree	Disagree	Agree	Neutral
	The design concept upholds responsibility to all stakeholders	Strongly disagree	Strongly disagree	Neutral	Disagree	Disagree
Sociotechnical content principles	Within the design concept, tasks are allocated appropriately between and amongst humans and technology	Agree	Agree	Agree	Disagree	Disagree
	Within the design concept, useful, meaningful and whole tasks are designed	Disagree	Disagree	Agree	Strongly agree	Disagree
	Within the design concept, boundary locations are appropriate	Strongly disagree	Disagree	Disagree	Disagree	Neutral
	Within the design concept, boundaries are managed	Disagree	Agree	Agree	Agree	Disagree
	Within the design concept, problems are controlled at their source	Agree	Agree	Strongly agree	Agree	Agree
	The design concept incorporates the needs of the business, users and managers	Agree	Neutral	Agree	Disagree	Agree
	The design incorporates intimate units and environments	Strongly disagree	Neutral	Strongly disagree	Agree	Agree
	The design is appropriate to the particular context	Agree	Agree	Agree	Agree	Strongly agree
	Within the design concept, adaptability is achieved through multifunctionalism	Strongly disagree	Neutral	Strongly disagree	Agree	Agree
	Within the design concept, system elements are congruent	Strongly disagree	Strongly disagree	Strongly disagree	Disagree	Strongly disagree
	Within the design concept, the means for undertaking tasks are flexibly specified	Strongly disagree	Strongly disagree	Neutral	Strongly agree	Strongly agree
	Within the design concept, authority and responsibility are allocated appropriately	Neutral	Strongly disagree	Disagree	Agree	Neutral
	Within the design concept, adaptability is achieved through flexible structures and mechanisms	Disagree	Strongly disagree	Agree	Agree	Agree
	Within the design concept, information is provided where action is needed	Neutral	Agree	Agree	Disagree	Agree
Average rating	Average rating of agreement with sociotechnical values and principles (each rating converted to numerical value, i.e. strongly disagree = 1, strongly agree = 5)	1.65	1.85	2.15	2.4	2.35
Overall effective-ness	Overall, how effective is / would the design be in minimising collisions, injuries, trauma, near misses and risk to safety?	8	7	9	2	6

Figure 5. Expert panel ratings of RLX designs against sociotechnical systems theory values and content principles, and ratings of overall effectiveness.

4.1.4 Does the CWA-DT create design concepts that align with sociotechnical content principles?

Expert panel participant ratings against the content principles are also provided in Figure 5. It can be seen that within the metropolitan design concepts the ratings indicated that the current and new designs were not consistent with the principles of congruence, appropriateness of boundary locations. Low ratings were also provided for intimacy and flexible specification. However, while there was little improvement overall when comparing the new designs to the existing, there was some improvement in the boundary locations set and the provision of information where action is needed. The better provision of information was associated with additional displays and warnings either infrastructure-based or in-vehicle. This was a strong feature of all new designs and reflects the recommendations for improvements in RLX safety generally documented in the literature and government reports.

4.2 Is sociotechnical systems theory an appropriate and acceptable approach to designing for public safety?

4.2.1 Do sociotechnical systems theory values and principles lead to more effective designs than traditional risk approaches in a public safety context?

To answer this question, we considered whether those concepts rated by experts as higher on the sociotechnical criteria were prioritised more highly by workshop participants (i.e. seen by them as more likely to improve safety). There was little difference between the top three concepts in the participant voting at the end of Workshop 2. The concepts received the following votes: Concept 2 (7 votes), Concept 1 (6 votes), Concept 3 (6 votes). According to the expert ranking, Concept 2 was most aligned with the sociotechnical values and principles, followed by Concept 3 and then Concept 1. So there is some agreement that Concept 2 was considered to have the most potential to be effective by the workshop participants and considered to be most aligned to the sociotechnical philosophy by the expert panel.

The second consideration was whether the concepts ranked by the experts as higher on the sociotechnical systems theory criteria were also considered by them to be most effective in minimising collisions, injuries, near misses and risks. As can be seen in Figure 5, there is some discrepancy in these findings, both for the existing and new RLX designs. For example, the existing metropolitan design concept and Concept 1 fell, on average, in the disagree rating for alignment with the sociotechnical approach, however, they were rated an 8 and 7 out of 10 for effectiveness in minimising collisions, risk, etc. Further, the existing rural design was considered to have very low effectiveness in minimising collisions, risk, etc., yet this design was given the highest average rating in relation to the sociotechnical criteria (albeit still a neutral average). These results raise questions about the relationship between the sociotechnical approach and designing to minimise accidents in a public safety context, as opposed to improving performance and safety in industrial contexts.

4.2.2 To what extent are sociotechnical systems theory values and principles accepted by stakeholders in a public safety context?

Participant ratings

While there were mixed results from the expert panel regarding the relationship between the sociotechnical approach to RLX design and safety effectiveness, the feedback from workshop participants was that the approach was useful and appropriate for this context and for other safety-related projects. These results are shown at the bottom section of Figure 4 and the raw data is provided in Appendix C.

5. Discussion

The aim of the research presented was to evaluate the CWA-DT, a new approach developed to support the use of CWA outputs in design. The findings are discussed below in relation to three key lines of inquiry: whether the CWA-DT a useful design approach; whether sociotechnical systems theory is an appropriate and acceptable approach to designing for public safety; and what improvements are required to improve the CWA-DT. The results relating to the first two areas of inquiry are summarised in Table 7.

Table 7. Summary of results obtained in relation to the research questions.

	Met	Somewhat met	Not met
Research question 1: Is the CWA-DT a useful design approach?			
1.1 Does the CWA-DT meet accepted HFE methodological criteria?	X		
1.2 Does the CWA-DT process align with sociotechnical values?	X		
1.3 Does the CWA-DT create design concepts that align with sociotechnical systems values?		X	
1.4 Does the CWA-DT create design concepts that align with sociotechnical systems content principles?		X	
Research question 2: Is sociotechnical systems theory an appropriate and acceptable approach to designing for public safety?			
2.1 Do sociotechnical systems theory values and principles lead to more effective designs than traditional risk approaches in a public safety context?			X
2.2 To what extent are sociotechnical systems theory values and principles accepted by stakeholders in a public safety context?	X		

5.1 Is the CWA-DT a useful design approach?

In answering the question of usefulness of the CWA-DT, the results showed that the toolkit was generally successful in meeting the methodological criteria.

Firstly, the workshop participants rated the process as meeting the methodological criteria that it was designed to achieve (i.e. that the CWA-DT promotes creativity, provides an efficient process, provides a valid process, etc.). Secondly, participants reported that the sociotechnical values were met in the process. That is, they felt that they were treated as assets, that technology was only used in the design process where it met their needs, etc. Finally, HFE experts rated whether the outcomes of the design process aligned with the sociotechnical systems theory values and content principles. The results gained from this assessment were less clear. It appears that while participants were positive about their experience of the workshops, the outcomes of the workshops were designs that did not fully align with the sociotechnical systems philosophy.

Based on these results, it could be concluded that the design process was not effective in changing the underlying mindsets of the design participants with the outcomes not representing revolutionary change in RLX design. For example, all designs retained the key features of the existing design that road users are warned to the presence of trains and are required to give way to the train.

There are a number of explanations for this result. Firstly, the sociotechnical systems approach represents a very different paradigm to the safety and risk management approach which is currently applied in public safety contexts including RLXs. Whether a new paradigm that inherently conflicts with the existing design philosophy can be introduced and effectively adopted by participants over three days of workshops is questionable. It is reasonable that changes of this nature would need to occur over a much longer period of time. The use of the CWA-DT in this context could instead be viewed as the beginning of an ongoing process to introduce the sociotechnical systems approach and integrate it into RLX design and evaluation processes. The workshops provided a means to initiate conversations about sociotechnical systems theory and systems thinking amongst a diverse group of RLX stakeholders (i.e. rail engineers, road policy officers, HFE researchers and consultants, safety executives, etc.). This in itself has potential positive effects on how the participants might approach RLX safety issues in their future work and has also potentially increased or strengthened professional networks across the various stakeholder groups.

A second explanation for the finding that the design concepts did not fully align with sociotechnical systems values and principles relates to the scope of the design process. Participants were asked to consider road user behaviour and how it can be influenced by the design to improve safety. This scope may have reinforced the existing system design rather than encouraging the kinds of revolutionary changes that would engender concepts that fully align with sociotechnical systems values and principles. It should be acknowledged however that there were some aspects of the design clearly inspired by the sociotechnical approach. For example, Concept 1 included cafes situated near the RLX incorporating displays of train information and information about the RLX (near misses, etc.). This was included in the design to encourage conversations about the RLX and to promote an intimate environment which engages pedestrians with the RLX. The concept also included an RLX supervisor with appropriate training and authority to intervene to avoid collisions. For example, the supervisor might be able to assist where a road user is unable to clear the RLX (such as a vehicle queued on the RLX, a pedestrian who has tripped and fallen, etc.). This inclusion within the design increases the adaptive capacity of the RLX by enabling more flexible response to unanticipated and emergency scenarios.

A further explanation for design concepts being assessed as not fully meeting the sociotechnical systems criteria relates to the methodology used for the expert panel review. The expert panel participants were asked to provide ratings taking into account a wide range of information about each concept which may have represented a difficult task. It is possible that the tangible components within the design concepts (i.e. gates, warnings, road design) took precedence over the more abstract components as their impacts on behaviour and system functioning in the short term are more direct. For example, the potentially distant and subtle safety improvements that could flow from the automatic collection and analysis of data about road user behaviour (to enable better monitoring of risk across RLXs), forums between road users and train drivers (to promote a better understanding and empathy for one another's experiences) and the provision of aggregate data about the behaviour of peers at the RLX (promote positive social norms) are difficult to quantify. On the other hand, the safety effectiveness of a concrete engineering intervention such as a gate or barrier is more obvious. Therefore, ratings may have been more easily based on a consideration of the technical aspects, rather than taking into account both the technical and the social aspects of the designs.

A useful avenue for further research would be further application and refinement of the criteria and indicators developed, as well as refinement of the process for evaluating the extent to which designs meet the sociotechnical design values and principles to more holistically consider the design. Such a methodological extension to sociotechnical systems theory would be beneficial to meet the needs of the HFE discipline as it strives to incorporate sociotechnical systems thinking into system design and evaluation (Carayon, et al., 2015) and to focus on predicting the effects of design designs in complex systems (Davis, et al., 2014).

5.2 Is sociotechnical systems theory an appropriate and acceptable approach to designing for public safety?

The finding that the design concepts did not fully align with the sociotechnical systems theory approach relates to the wider question of whether this approach is indeed appropriate for this context. In relation to this, it was interesting to find that the expert ratings of concepts against the sociotechnical systems criteria and safety effectiveness ratings did not correlate. Two of the three new design concepts were considered better than the existing in minimising collisions, injuries, near misses and risk, even though they were found to not fully align with the sociotechnical systems approach. This may explain why the participants, although stating that the toolkit provided a good process for RLX design and could be useful for future safety projects, appeared to take some selected concepts from the sociotechnical systems approach and incorporate these into concepts that were not radically different from the existing RLX designs.

Potentially the choice of system boundary for the design exercise was influential in the way in which the sociotechnical systems principles were applied. In this design application, the focus was on designing the RLX. It would be interesting to use CWA and the sociotechnical systems approach to instead design the *process* for RLX design. Related to this, Meadows (1999) argued that the most effective leverage point in a system is the ability to transcend paradigms. That is, to not remain attached to one paradigm or another but to be flexible and adapt to the needs of the problem at hand. Therefore, perhaps in some systems, or aspects of a system, the existing safety management approach will provide the best results while the sociotechnical systems approach will be best for other areas. For example, it may be that the safety management approach is best for controlling behaviour at the physical RLX sites because there are vulnerable road users that need protecting (i.e. pedestrians, who may be children or may have cognitive or physical impairments or drivers who may be distracted in cluttered urban environments). However, the sociotechnical systems approach could be applied to wider transport system (encompassing RLXs as well as other components of the road and rail networks) meaning that adaptive capacity is within the wider system, rather than just at the physical RLX location. Potentially, the sociotechnical systems approach could be used to design the technical and social aspects of a dynamic transport monitoring system that intervenes when issues or variances are detected, rather than an RLX environment per se.

5.3 How can the CWA-DT be improved?

The findings of this evaluation have implication for the CWA-DT and suggest the need for improvements to the toolkit generally and for its application to public safety problems. One improvement to the CWA-DT could be an explanation of the potential barriers associated with changing paradigms, and recommendations about the use of processes as an on-going engagement with the system participants, rather than a single, isolated design task. The toolkit could also provide guidance as to the appropriateness of different paradigms for different system types, based on recommendations in the literature. Obviously, what will be effective will not be known in advance, or the design process would not be needed. Consequently, some bravery is required to make radical or revolutionary changes to a system, especially in safety-critical areas. Snowden and Boone (2007) propose the use of safe-to-fail experiments which can be used to gather effectiveness of interventions prior to implementation. Hettinger and colleagues (2015) propose simulation and computer-based modelling techniques such as agent-based modelling and systems dynamics as methods for exploring the impact of novel and radical ideas in safety-critical domains, assuming the project resources enable this. More traditional testing methodologies such as desktop evaluations (similar to the expert review conducted in this study) and the use of mock-ups or prototypes may also provide insights into the effectiveness and potential unintended consequences of design decisions.

Additionally, the CWA-DT could provide tools with more structured, explicit use of the sociotechnical principles within a design process. For example, with an initial idea, participants could be asked 'now think about the boundaries that are created within this idea, are they appropriate? What would happen if you moved them?'

6. Conclusion

The evaluation of the CWA-DT, based on an application to the design of RLXs, found that it met relevant process measures (e.g. methodological criteria and alignment of the process with sociotechnical values). However, expert ratings showed that the outcomes of the design process were not fully aligned with sociotechnical values and principles, although there were some improvements on the existing designs. Thus, the CWA-DT was not effective in producing designs that are fully consistent with sociotechnical systems theory, rather it appeared to have provided a means for sociotechnical thinking to be incorporated within the existing safety management paradigm. Questions remain about the appropriateness of the sociotechnical approach in this public safety context and further testing and evaluation of the design concepts may provide further insight into this matter. Further exploration of sociotechnical systems design in public safety should also consider the system boundary and whether adaptive capacity is indeed better sought at a higher hierarchical system level.

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Appendix A: Participant responses to questionnaires relating to the seven methodological criteria

Methodological criteria	Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know
Creative	1. The workshop activities facilitated me to generate a large number of ideas (Workshop 1)	38.9% (N=7)	38.9% (N=7)	16.7% (N=3)	5.6% (N=1)	-	-
	2. The workshop activities facilitated me to generate a variety of different kinds of ideas (Workshop 1)	27.8% (N=5)	66.7% (N=12)	5.6% (N=1)	-	-	-
	3. The workshop activities facilitated me to generate novel ideas (Workshop 1)	27.8% (N=5)	55.6% (N=10)	11.1% (N=2)	-	5.6% (N=1)	-
	4. The workshop activities made me think about the design problem in a different way (Workshop 1)	38.9% (N=7)	44.4 (N=8)	11.1% (N=2)	-	-	5.6% (N=1)
	5. I felt creative when participating in the workshop (Workshop 1)	50% (N=9)	27.8% (N=5)	16.7% (N=3)	5.6% (N=1)	-	-
Structured	6. The workshop activities were structured (Workshop 1)	33.3% (N=6)	50% (N=9)	16.7% (N=3)	-	-	-
	7. The workshop activities were structured (Workshop 2)	80% (N=8)	20% (N=2)	-	-	-	-
Holistic	8. The workshop activities facilitated me to think about all users of rail level crossings when developing design ideas (Workshop 1)	22.2% (N=4)	66.7% (N=12)	-	5.6% (N=1)	5.6% (N=1)	-
	9. The workshop activities facilitated me to consider different aspects of rail level crossings (Workshop 1)	55.5% (N=10)	38.9% (N=7)	-	5.6% (N=1)	-	-
	10. The workshop activities led to me to generate design ideas that covered different aspects of rail level crossings (Workshop 1)	33.3% (N=6)	44.4% (N=8)	16.7% (N=3)	5.6% (N=1)	-	-
	11. The workshop activities ensured that the design concepts considered impacts on different aspects of rail level crossings (Workshop 2)	50% (N=5)	50% (N=5)	-	-	-	-
Integrated	12. This design approach could integrate with existing rail level crossing design processes (Overall)	20% (N=2)	70% (N=7)	-	-	-	10% (N=1)
Efficient	13. The workshop activities were efficient (Workshop 1)	11.1% (N=2)	66.7% (N=12)	5.6% (N=1)	16.7% (N=3)	-	-
	14. The process was more efficient than my usual process or other processes I have participated in (Workshop 1)	5.6% (N=1)	38.9% (N=7)	27.8% (N=5)	22.2% (N=4)	-	5.6% (N=1)
	15. The outcomes of the workshop were worth the time invested in my participation (Workshop 1)	44.4% (N=8)	27.8% (N=5)	11.1% (N=2)	11.1% (N=2)	-	5.6% (N=1)
	16. The workshop activities were efficient (Workshop 2)	40% (N=4)	60% (N=6)	-	-	-	-
	17. The outcomes of the workshop were worth the time invested in my participation (Workshop 2)	60% (N=6)	30% (N=3)	10% (N=1)	-	-	-

Iterative	18. The workshop activities facilitated me to revisit my own and others' ideas to build upon and / or refine them (Workshop 1)	38.9% (N=7)	55.6% (N=10)	-	5.6% (N=1)	-	-
	19. The workshop activities facilitated me to revisit my own and others' ideas to build upon and / or refine them (Workshop 2)	60% (N=6)	40% (N=4)	-	-	-	-
Valid	20. The workshop activities facilitated me to generate good quality ideas (Workshop 1)	16.7% (N=3)	55.6% (N=10)	22.2% (N=4)	5.6% (N=1)	-	-
	The design approach produced effective designs to improve human behaviour at rail level crossings (Overall)	10% (N=1)	80% (N=1)	10% (N=1)	-	-	-
	The design approach provides answers to relevant design problems (Overall)	20% (N=2)	80% (N=8)	-	-	-	-

Appendix B: Participant ratings of the extent to which the design process aligned with the five values espoused by sociotechnical systems theory

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know
During the workshops, participants were treated as assets	40% (N=4)	50% (N=5)	-	-	10% (N=1)	-
During the workshops, technology was treated as a tool to assist participants	10% (N=1)	70% (N=7)	20% (N=2)	-	-	-
The workshops promoted quality of participants' lives	20% (N=2)	70% (N=7)	10% (N=1)	-	-	-
During the workshops, the individual differences of participants were respected	50% (N=5)	50% (N=5)	-	-	-	-
The workshops promoted consideration of responsibilities to all stakeholders of the design process	20% (N=2)	70% (N=7)	10% (N=1)	-	-	-

Appendix C: Participant ratings of statements relating to stakeholder acceptability of sociotechnical systems theory

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know
The process would be useful for other safety-related design projects (Workshop 1)	38.9% (N=7)	44.4% (N=8)	16.7% (N=3)	-	-	-
Sociotechnical systems theory is an appropriate approach for rail level crossing design (Overall)	60% (N=6)	40% (N=4)	-	-	-	-

10.2 Discussion

In this chapter, the process undertaken to use the CWA-DT to design novel RLXs has been described, as have the outcomes of this process. Further, the paper submitted for publication has described the formal evaluation of both the CWA-DT process and its outcomes in the RLX context. The methodological, practical and theoretical implications of this work are discussed further here.

10.2.1 Implications for the CWA-DT

This section will describe some additional detailed evaluation results gained from participants and discuss their implications for the CWA-DT. It will also describe the methodological improvements made to the CWA-DT in response to the overall evaluation results.

As with the application to transport ticketing (described in Chapter 7), participants in the design workshops provided positive feedback about their experience of the process with all but one measure meeting the 75% agreement criterion. Particularly positive were the ratings that the CWA-DT would be useful to apply to other safety-related projects (80% agreed or strongly agreed) and that sociotechnical systems theory is an appropriate approach for RLX design (100% agreed or strongly agreed). Participants were asked within the evaluation questionnaire to describe the best part of the workshop and opportunities for improvement. A selection of the responses is provided in Table 10.1.

Table 10.1. Design participant responses regarding their experience of the CWA-DT.

Best thing about the workshop	**How the workshop could be improved**
Workshop 1	
- *"Challenging past / current practices, engaging across various stakeholders and experts."* - *"It was well structured and relevant. The workshop had a good representation of stakeholders."* - *"Having people from a range of backgrounds to ensure different design perspectives could be captured rather than e.g. just behavioural scientists or engineers. The novel process - it's worth trying something different even if it proves to be no better than individuals working in isolation."* - *"Well structured & facilitated, good tools & prompts, especially 'Design with Intent' cards & assumption crushing"* - *"The approach allowed the debunking of bounded paradigms, facilitating some out of the square thinking."* - *"Free ranging enquiry, out of the box thinking & ideas."*	- *"We covered a lot of different elements. There were times when team members were not able to easily communicate or resolve the communication of their ideas to the group. Perhaps more time - however appreciating the limited time available - it appears that a lot of information was still produced for consideration."* - *"Run over three days for about 5 hours."* - *"Would have liked more sharing of the research findings - too much on theory. More opportunity to look at real world sites would have been better."* - *"Ensure smaller groups (3-4) in workshop discussions, Encourage workshop participants to be open and good listeners, as well as good contributors"* - *"Cards can get lost a bit, perhaps have a pin board per table (large one) that we can pin them on."*
Workshop 2	
- *"Open discussion, all views considered & valued"*	- *"Consideration of cost-effectiveness to enable informed*

- *"Looking at effective solutions and provide alternative solutions"* - *"A framework that promoted innovation and team work"* - *"Facilitated very well, Great method"* - *"The creative approach was refreshing"* - *"Lateral thinking, approaching problems from very different angles - creative thinking"* - *"Design was fun in group setting"*	*discussion with the budget holders and support business cases / investment proposals."* - *"A planned process of workshops so they are spread out over time so that we can optimise the people who can attend."* - *"Pre-qualification of participants - ability to work in teams, relevant knowledge, diversity of skills"*

The responses from participants were generally very positive, especially regarding the idea generation activities. This type of workshop would have been unfamiliar for many participants and it was encouraging to observe that they embraced the approach and engaged with it almost immediately. Further, the feedback suggests that participants appreciated the opportunity to work with other experts and stakeholders and to gain the perspectives of others. It is expected that the connections made within the workshop might themselves represent a benefit to the RLX domain with potential opportunities for collaboration between participants on future projects and issues.

Workshop timing and duration

Similarly to that found with the transport ticketing application, the improvements suggested by participants were predominantly associated with the logistics of the workshop, rather than the CWA-DT process itself. Duration and scheduling of the workshops was raised, with at least one participant noting the time constraints and another suggesting that the workshops be shorter and run over consecutive days. It is generally difficult to meet the needs of a diverse range of participants who may have different preferences that would suit their availability.

The time constraints of three days in total created some challenges in designing the workshops. In determining the way in which the workshops would be scheduled and run, an optimum process had to be traded-off against the need to provide scheduling that would be suitable given the practical constraints of the participating organisations and individuals. Optimally, a much longer time commitment would have been achieved, such as two full weeks or one day per week for three months. Unfortunately, the project did not have this level of buy-in across the diverse stakeholder groups and so practically, it was considered important to provide an opportunity for as many interested stakeholder representatives to be involved as possible. Consequently, a two-day workshop followed up by single day was seen as a reasonable time commitment, considering that the vast majority of design participants held diverse roles with safety issues at RLXs representing one small part of a much wider safety or operational responsibility. Potentially, if the CWA-DT was applied within a single organisation, leadership support for the project could be gained to ensure that design participants are provided with the time needed for full involvement in the various aspects (including analysis, design and evaluation).

Further information about the research findings

Another area where at least one participant suggested an improvement was that the findings of the CWA were not provided in sufficient detail. While an overview of the findings was presented at the beginning of the first workshop, it was intentionally given as a high level summary. This was done to avoid alienating the design participants at the outset through the use of technical CWA language and presenting detailed outputs which can be difficult to follow on initial introduction. Instead, the CWA findings were introduced to the design participants throughout the activities, based on the insights identified during the analysis process. Participants may not have been aware of the link between the design activities and the CWA and thus felt that they were not receiving the full benefit of the research findings. Potentially, a better explanation could be provided to participants at the beginning of the workshop.

Alternatively, participants who have not been involved in the analysis process could be introduced to the CWA outputs in the workshops. Sanderson (2003b) notes that, at the time of publishing, CWA was being practiced by a small but growing number of cognitive engineers. While this group of users has grown over time, concerns remain that the complexity of the framework and its underpinning theory make it difficult to access.

In a recent study by Hassal and Sanderson (2014), decision ladders were presented to industry stakeholders who were asked to use them as part of a process to identify safety risks. The researchers reported that most participants found the decision ladder challenging to interpret although those who had received prior training made such comments less often than those who had not. This suggests that with appropriate familiarisation and support, CWA outputs could be used in workshops with users and stakeholders. Therefore, to provide design teams with the option for incorporating the CWA outputs directly (rather than relying on insights from the analysis), the 'Constraint crushing' tool was developed for the CWA-DT (see page 136 of the Appendix). This design activity involves taking key outputs such as the WDA and assisting the design participants to identify the key constraints. Following this, participants are asked to consider each constraint and to discuss the effects of removing the constraint, strengthening the constraint, or making the constraint visible to users and to document design ideas arising from these discussions. This tool provides an opportunity for design teams who wish to use the CWA outputs in the sessions to do so. It might be selected where it is felt appropriate given the backgrounds of those participating and where sufficient time is available to introduce the outputs and explain how they are used.

Better integration of the sociotechnical systems theory principles and values

As noted previously in this chapter, the HFE expert panel found that the RLX design outcomes did not fully align with the sociotechnical systems theory values and principles. Instead, it would appear that the design participants integrated ideas from the sociotechnical systems theory approach into the safety and risk management paradigm within which they undertake their day-to-day work. Potentially, a longer duration for the workshops could have provided additional opportunities to explore the sociotechnical values and principles and better integrate these into the designs.

Another potential reason for the outcomes of the process failing to fully incorporate the sociotechnical principles and values was the way in which the instructions for creating the design concepts were communicated. During the idea generation phase of Workshop 1, participants were encouraged to undertake divergent thinking, to crush the assumptions that underlie the business-as-usual approach to RLX design, to empathise with the experiences of different users at RLXs and explore new metaphors for thinking about RLX design. Then, once many ideas were generated, participants were advised that they have been allocated the task by their manager to create design concepts for a new world-leading RLX upgrade that would be implemented in two years' time. This instruction may have unintentionally placed them into the mindset of their normal role with all the usual constraints of cost, time, public acceptance, political pressures, requirements for changes to engineering standards, etc. This may have led design participants be more conservative when drawing together ideas for design concepts. Further, up until the point of creating full design concepts, the participants may not have been provided with sufficient opportunity to engage in substantial debate about these practical constraints. The need to draw out political debate is an important sociotechnical principle. While it was expected that the discussions about the sociotechnical values and the assumption crushing exercise would provide ample opportunities to debate issues and perspectives of different stakeholders, upon reflection, an additional tool could have addressed this principle more directly. Consequently, a tool called 'Stimulate debate' was added to the CWA-DT (see page 127 of the Appendix) to ensure that political issues and constraints on the design process are discussed and resolved by participants early in the process and thus do not sub-consciously restrict innovative design thinking at the latter stages.

The discussions at the HFE expert panel made it clear that the task of applying the values and principles to whole design concepts was challenging due to the difficulties envisioning the functioning of a complex sociotechnical system encompassing multiple components. Occasionally, one aspect of a design would be considered to balance out another on some value or principle. For example, in rating Concept 1 against the principle 'the design incorporates intimate units and environments', it was thought that this was met for pedestrians (due to inclusion of cafes and other social aspects) but not for other road users, leading to an overall rating of neutral. Interestingly, if the values and principles were used as a checklist by the design participants themselves, there would be an opportunity to further refine the concepts to improve their match with the criteria. Therefore, a tool was developed for the CWA-DT, called 'Refining design concepts through sociotechnical systems theory principles' (see page 145 of the Appendix) which uses a template prompting design participants to consider whether the sociotechnical systems theory content principles are incorporated into design concepts and enabling them to make refinements to improve the designs. This tool could also be used earlier in the design process, to review and evaluate design ideas as they are generated. For example, with an initial design idea, participants could be asked 'now think about the boundaries that are created within this idea, are they appropriate? What would happen if you moved them?'

A final change made to the CWA-DT to improve the likelihood of the sociotechnical systems theory approach being more fully integrated into final design concepts was made to the guidance provided to toolkit users. Further guidance was included regarding the need to be explicit that sociotechnical systems theory is a new paradigm and may require participants to engage in thinking that is different, and perhaps contrary to standard processes applied in their domain. Further, design teams are encouraged to engage with participants over time in an on-going manner using mediums such as webpages, email communication and presentations so that the new approach is introduced over time rather than at the time of a design workshop (see Section 1 'Participation and Engagement' of the Appendix).

Final version of the CWA-DT

The final version of the CWA-DT, incorporating improvements from this latest application, is provided in the Appendix, with a summary of the process shown in Figure 10.1. The changes include the addition of the 'Constraint crushing' and 'Stimulate debate' tools both within the idea generation phase of concept design, as well as the 'Refining design concepts through sociotechnical systems theory principles' tool for design concept definition.

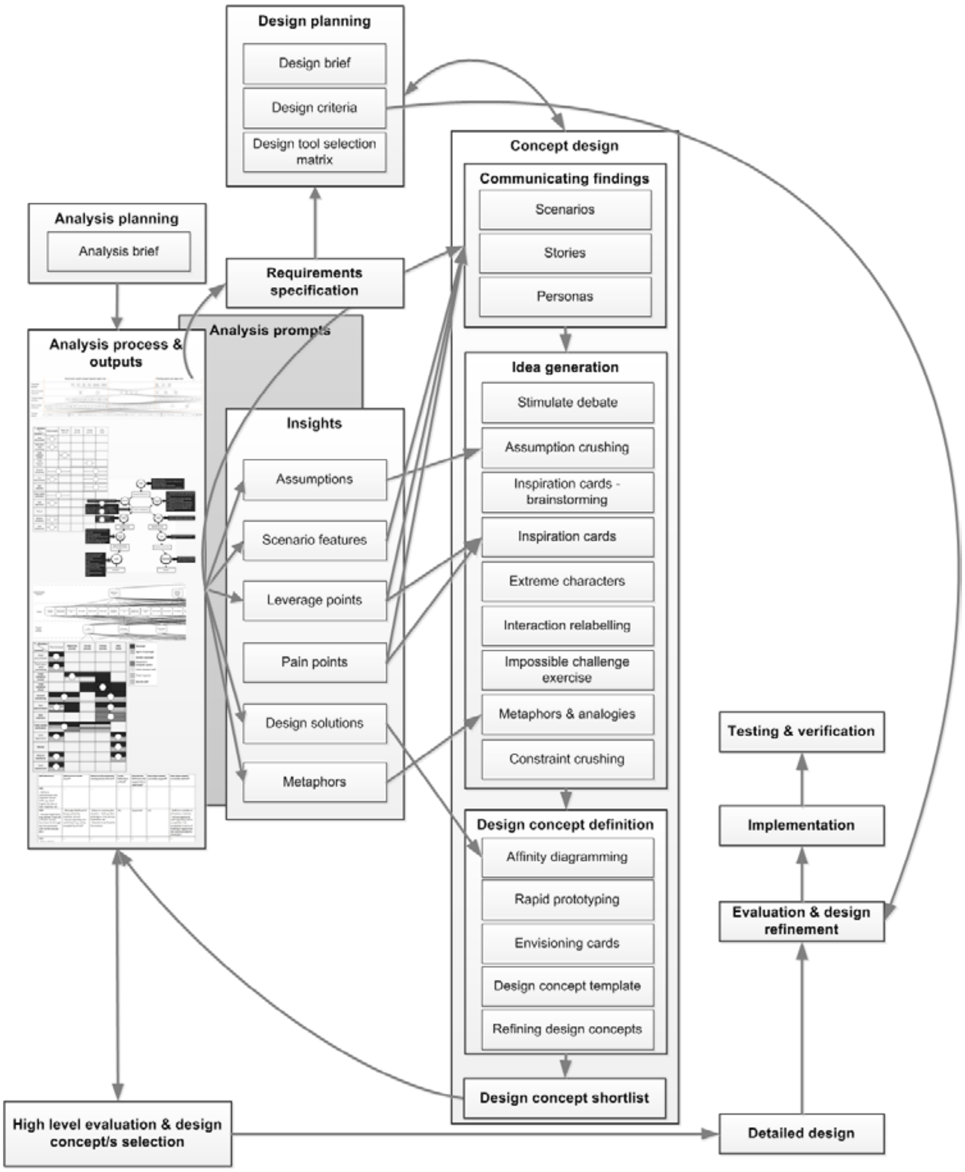

Figure 10.1. Final version of the CWA-DT.

10.2.2 Implications for RLX design

This work represents a first endeavour at using the sociotechnical approach to design RLXs and it resulted in the creation of three shortlisted design concepts as well as two additional concepts (that were ranked lower in the shortlisting process). These concepts incorporate novel components and aspects that would not be gained through a traditional design process using a safety management approach. For example, the inclusion of cafes near the RLX with electronic displays that provide train information and information about the RLX (recent near misses, performance, etc.) to encourage conversations about the RLX would be very unlikely to be suggested as a risk control because it does not have a direct, causal link to an identified risk. It could not even be categorised within the hierarchy of control (i.e. it is not an engineering intervention, procedure or training package). Yet, the benefits of establishing stronger community relationships near the RLX and drawing people's attention to the existence of the RLX could have important benefits that emerge over time. Such ideas also have benefits for the local community and local economy that demonstrate the broader influence that can be gained from applying systems thinking.

For illustrative purposes, an image taken from a 3-dimensional computer mock-up of Design Concept 1 is shown in Figure 10.2. A number of design features are incorporated in this concept, however focussing on those aspects relating to pedestrians, it encompasses:

- A cafe: To encourage conversations about the RLX (shown at the top right-hand corner of the RLX).
- RLX supervisors: Monitoring pedestrians who are crossing the road.
- Pedestrian lights: Providing an indication to pedestrians regarding whether the automatic gate is locked or unlocked.
- Pedestrian shelters: Provided at each waiting area containing blue ticketing machines and community information displays.

Figure 10.2. Mock-up of Design Concept 1. © Centre for Human Factors and Sociotechnical Systems. Reprinted with permission.

These attributes as well as additional specific design recommendations for pedestrians arising from this work will be provided in Chapter 11 and will not be repeated here. However, the overwhelming acceptance of the sociotechnical systems theory approach and the novel ideas generated by participants during the design workshops indicate that there is appetite for this form of thinking within the domain and that the design concepts created have a chance of being implemented, following more detailed design and additional evaluation and testing processes. Even if the designs are not implemented in the real world, the transformative process of participating in the workshops may have altered participants' mindsets and thinking about RLX design generally which has a chance of permeating current practice and future work in this area.

10.2.3 Implications for sociotechnical systems theory

Interestingly, although the three RLX design concepts did not fully align with the sociotechnical systems theory approach, two of the three designs were rated by the HFE experts as representing an improvement on the existing system design in terms of effectiveness. This may suggest that designs not aligned with sociotechnical systems theory can be effective in improving public safety at RLXs. The extent to which sociotechnical systems theory-based designs are appropriate for RLXs or for public safety applications more generally remains somewhat unknown as the process did not create designs that were fully aligned with the approach.

Therefore, the validity of the sociotechnical systems theory approach to design in public safety contexts remains an important research question for future consideration. The sociotechnical systems theory approach had its origins in efforts to improve employee well-being and efficiency within organisations and not necessarily to improve safety in domains such as RLXs. Design in public safety domains must encompass the needs of many diverse individual including vulnerable users such as children, the elderly and people with cognitive and physical disabilities. Further, these systems do not have the types of barriers to entry that organisations use to control work system functioning. For example, there is no selection process, no formalised training, few rules and few disciplinary processes. It could be considered at the extreme end of the continuum between closed and open systems however, instead of embracing open systems principles, RLX designers have attempted to impose rational, closed system philosophies that assume simple cause and effect relationships. This approach is also promoted within the legal system that looks for causes and applies punitive measures to those considered at fault.

Further research to address the question of the validity of the sociotechnical systems theory approach could involve working with stakeholders to create a concept that is optimally aligned to the sociotechnical values and principles and test the effectiveness of this versus a design based on the safety management approach. Determining appropriate methods for evaluating the effectiveness of the designs from a sociotechnical systems theory perspective is a challenge (Hettinger, Kirlik, Goh & Buckle, 2015) and care would need to be taken to ensure that standard safety management thinking does not drive the evaluation. The approach taken within the HFE expert panel could provide one method for this, enhanced with methods suggested by Hettinger and colleagues (2015) such as simulation and computer-based modelling.

10.3 Conclusion

This chapter presented the first full application of the CWA-DT which was undertaken within the RLX domain. The evaluation of the process by design participants was highly positive and ideas for improvement provided by participants, as well as other opportunities for improvement identified were incorporated into the final version of CWA-DT. Finally, the evaluation process raised interesting questions about the validity of the sociotechnical systems theory approach within safety-critical domains.

The following chapter will draw out specific design recommendations for improving pedestrian safety at RLXs, which is the particular focus of this thesis.

11 Recommendations for improving pedestrian safety at RLXs

11.1 Introduction

The preceding chapters have provided design recommendations arising from the CWA of pedestrian behaviour at RLXs (Chapter 9) as well as from the application of the CWA-DT to identify new design concepts that intend to provide a safer RLX environment for all road users (Chapter 10).

The aim of this chapter is draw out the recommendations, specific to pedestrian behaviour and safety, that flow from the research described in those previous chapters. The intention of this is to clarify the practical contribution of this thesis in relation to improving pedestrian safety. The work described in Chapter 10 related to all road users and the focus was on the evaluation of the toolkit, rather than the in-depth discussion of design recommendations. Further, as the design concepts generated using the CWA-DT were rated as not aligning with sociotechnical systems theory, the recommendations presented in this chapter were selected from those design concepts more closely aligned with the sociotechnical philosophy as this is the theoretical underpinning for this thesis. However, the recommendations have also endeavoured to take into account the need to provide a protective environment for certain classes of vulnerable pedestrians.

In total, the recommendations encompass design ideas generated as part of the CWA application, by the design participants during the workshops, and inspired by discussions with participants and research colleagues throughout the course of the research. The recommendations have been refined based on the findings of the high level desktop evaluation of the design concepts produced in the workshops. Further testing and evaluation of the recommendations to determine their effectiveness is, however, outside of the scope of this thesis.

Further, while during the design process it was worthwhile to consider blue sky designs appropriate for greenfield sites where the designer has few constraints other than the topography of the location, in Victoria government policy is that no new RLXs are to be introduced (Victorian Rail Industry Operators Group, 2011). Therefore, the design recommendations presented in this chapter focus on re-design opportunities that could be implemented at existing RLXs. This ensures that they are relevant to improving safety in practice.

11.2 RLX design requirements

A large number of design requirements were generated directly from the CWA analyses as well as from insights generated through the process of data collection and analysis. Table 11.1 outlines the key design requirements identified throughout the analysis process that are relevant to pedestrian safety. The table notes the analysis phase or activity that prompted the requirement and also the relevant principles from sociotechnical systems theory. The following section of this chapter will provide potential design solutions to address these requirements.

Table 11.1. Key design requirements for pedestrians at RLXs.

	Requirement	Generated from	Relevant STS content principle/s
1	Provide access across the railway line	Functional purpose (WDA)	- Design incorporates the needs of the business, users and managers
2	Protect road users	Functional purpose (WDA)	- Design incorporates the needs of the business, users and managers
3	Support pedestrians to reach their destination	Functional purpose (WDA)	- Design incorporates the needs of the business, users and managers
4	Support trains to reach their destination	Functional purpose (WDA)	- Design incorporates the needs of the business, users and managers
5	Support pedestrians to make appropriate speed control decisions	Purpose-related function (WDA)	- Information is provided where action is needed - Means for undertaking tasks are flexibly specified
6	Support pedestrians to make appropriate directional control decisions	Purpose-related function (WDA)	- Information is provided where action is needed - Means for undertaking tasks are flexibly specified
7	Support pedestrians to identify and respond to hazards in the RLX environment	Purpose-related function (WDA)	- Information is provided where action is needed - Adaptability is achieved through multifunctionalism - Authority and responsibility are allocated appropriately
8	Support pedestrians to provide assistance to others	Purpose-related function (WDA)	- Intimate units and environments are designed - Adaptability is achieved through multifunctionalism - Authority and responsibility are allocated appropriately
9	Maintain road / rail / pedestrian traffic flow	Purpose-related function (WDA)	- Boundaries are managed - Design incorporates the needs of the business, users and managers - Adaptability is achieved through flexible structures and mechanisms
10	Change reward structures so that pedestrians who stop and	Insight from application of organisational metaphor	- System elements are congruent

	wait for trains are rewarded while those who engage in undesirable behaviour are not rewarded	prompts	
11	Design to support choice between desirable strategies for crossing the RLX but to constrain undesirable strategies	Strategies analysis flowchart and risk analysis	- Means for undertaking tasks are flexibly specified - Design incorporates the needs of the business, users and managers
12	Create a stronger human connection between pedestrians, and between pedestrians and rail staff (including train drivers)	Insight from analysis of transcripts of verbal protocols during walk-through study – participants tended to refer to car drivers when interacting with cars but no reference to train driver, only the train itself	- Intimate units and environments are designed
13	Provide pedestrians with control or a sense of control over the situation	Strategies analysis – insights from observation of pedestrians pushing the gate while its opening and that pedestrians do not have many actions on objects in the WDA	- Useful, meaningful and whole tasks are designed
14	Increase the priority of pedestrian traffic at / near the RLX	Insight from verbal protocols during walk-through study – pedestrians were regularly stopping to give way to other road users and the train	- Design incorporates the needs of the business, users and managers - Value – responsibility to all stakeholders. Encouraging walking via improving pedestrian priority is better for environmental sustainability and population health
15	Ensure the RLX design is suitable for existing and forecasted pedestrian flow, especially where adjacent to stations during peak times or near schools, sports grounds, etc.	Contextual activity template – insight that pedestrians must maintain separation from other road users and that in observations some RLXs were very congested at peak times	- Design is appropriate to the particular context - System elements are congruent
16	Separate pedestrians and cyclists	Strategies analysis diagram / flowchart and observations of cyclists using the pedestrian footpath at the RLX	- Boundary locations are appropriate - System elements are congruent
17	Provide information about expected delay and impact on goals	Decision ladder	- Design is appropriate to the particular context - Useful, meaningful and whole tasks are designed

11.3 RLX design recommendations

A number of design recommendations have been identified to address the design requirements described in Table 11.1. A matrix is shown in Table 11.2 which provides a summary of how the design recommendations address the requirements. Each RLX design recommendation is then described in detail in the following sections.

Table 11.2. Matrix of design recommendations and design requirements.

	1. Diagonal paths across the RLX	2. Aesthetically pleasing and integrated	3. Cafes and meeting areas near the RLX	4. Default closed gates	5. Gates unlock between trains	6. Multiple access points to board/disembark	7. Shelter and amenity at waiting areas	8. Supervisor at the RLX	9. Train information at the RLX	10. Natural barriers and hazards
1. Provide access across railway line	✓	✓			✓					
2. Protect road users				✓		✓		✓		
3. Support pedestrians to reach their destination	✓				✓	✓		✓	✓	
4. Support trains to reach their destination				✓		✓		✓		
5. Support pedestrians to make speed control decisions							✓	✓	✓	✓
6. Support pedestrians to make directional control decisions						✓		✓		✓
7. Support pedestrians to identify and respond to hazards			✓	✓				✓	✓	✓
8. Support pedestrians to provide assistance to others										
9. Maintain road / rail / pedestrian traffic flow					✓			✓		
10. Change reward structures						✓	✓	✓		
11. Support desirable and constrain undesirable strategies	✓			✓	✓	✓		✓		
12. Create a stronger human connection		✓	✓				✓	✓		
13. Provide pedestrians with control or a sense of control				✓	✓					
14. Increase priority of pedestrian traffic	✓				✓					
15. Suitability for existing and forecasted pedestrian flow								✓		
16. Separate pedestrians and cyclists				✓						
17. Provide information about expected delay and impact on goals									✓	

Recommendation 1 – Provide diagonal paths across the RLX

In the existing design, pedestrians are provided formal paths across the RLX that guide them directly across from one side to the other of the railway line to the other. At a small number of

RLXs, traffic lights are provided adjacent to the RLX with a pedestrian path that enables pedestrians to also cross the road adjacent to the RLX. Thus, pedestrians are given a square around which they are given permission to traverse. At locations where traffic lights are not provided, a number of pedestrians were observed (during the covert observations, Chapter 9) to cross the road near the RLX, potentially because cars slow at these points to avoid traversing the uneven railway tracks at high speed. Pedestrians were also observed crossing diagonally across the RLX using the roadway, meaning that they disregarded the formal pedestrian path completely and thus were not separated from cars when traversing the railway tracks. Pedestrians taking such informal paths sometimes appeared to be more concerned about checking for cars than checking for trains.

This recommendation incorporates providing formal diagonal paths across the RLX for pedestrians to use, as well as the existing paths across the railway and across the road. Through formalising a strategy that was unanticipated by the original designers but has emerged due to factors such as the location of train platforms and car parking areas, situations of confusion involving pedestrians caught in the roadway when a train approaches could be minimised. This is a location specific recommendation, only implemented where there are local features drawing pedestrians to wish to cross diagonally. It would require the addition of traffic lights, where these are not already provided, and would entail the implementation of specific traffic light phases which are for pedestrians only (i.e. trains are not approaching and road vehicles are facing a red traffic light).

Although the existing system is founded on the rule that road users must give way to trains as the road is a ‘right of way’ over railway property, such ideas may be outdated especially with the large number of train services now being delivered and more planned in the future, and with the push for more sustainable transport modes. The pedestrian-only phase would enable the RLX to give priority to pedestrians (and potentially cyclists) and thus give priority to those modes of transport that are most active (with a positive impact on population health) and most sustainable (requiring no power and producing no emissions).

The paths would need to be carefully designed to avoid the safety issues associated with wheels (e.g. of prams or wheelchairs) as small wheels can become trapped in the gap between the rails and asphalt more easily when the path is on an angle other than 90 degrees (which would be the case on a diagonal path; Victorian Rail Industry Operators Group, 2006).

This recommendation would address the following design requirements:

- Provide access across the railway line
- Support pedestrians to reach their destination
- Design to support choice between desirable strategies for crossing the RLX but to constrain undesirable strategies
- Increase the priority of pedestrian traffic at / near the RLX

Recommendation 2 – Make the RLX aesthetically pleasing and integrate it with the local environment

Current RLX design is based on engineering standards such as Australian Standard 1742, Part 7 (Standards Australia, 2007) and VRIOG Standard 003.2 – 2006 (Victorian Rail Industry Operators Group, 2006). These standards communicate the minimal design requirements to provide protection to users. Standards are consensus documents and the content is likely to be influenced by considerations such as cost and ease of maintenance. These considerations are important and should not be disregarded. However, the outcome of the application of the standards is an environment that is often aesthetically stark, exposed and potentially uninviting. A participant in the walk-through study described how she felt when using one of the pedestrian RLX footpaths in the study that crossed over three tracks, saying '*… there doesn't seem to be as many barriers and its… and the train tracks feel quite open and you're more exposed to things*.' RLX design that takes account of the user experience could be more visually and aesthetically attractive, without detracting from communicating that the tracks are a dangerous area and that care needs to be taken.

It is suggested that the RLX should be viewed as a pathway or link that connects each side of the community. The look and feel of the pathway would be determined at each particular location, based on the features of the local community. For example, a community with many older, heritage buildings nearby might choose to have gates that look similar to the original white picketed gates used at RLXs, while an area known for its modern art galleries might have fences and gates with abstract shapes and styles, designed by local artists. Linking the RLX to the community not only creates a point of interest making the RLX more likely to be a topic for conversation, but also creates a sense of community ownership and responsibility for the RLX.

This recommendation would address the following design requirements:

- Provide access across the railway line

- Create a stronger human connection between pedestrians, and between pedestrians and rail staff (including train drivers)

Recommendation 3 – Provide cafes and meeting areas near the RLX

It is recommended that the establishment of local businesses is encouraged, such as cafes near the RLX which have some association with the RLX. For example, at a cafe, digital displays could be provided for patrons to obtain train information and also information about the RLX, facts about its use (such as number of trains, pedestrians and road vehicles that traverse it each day), profiles of the train drivers that come through the RLX, safety trends and issues associated with the RLX, recent incidents and near misses, how it compares to other RLXs in Melbourne based on safety data, etc. Artwork inspired by the history of the railway in that location could be hung on the walls. The key purpose of the cafe would be the provision of a place where conversations about the RLX can occur. This would engage users to think about the RLX and take responsibility for it as belonging to the community. It could also be used for public meetings relating to RLX design / re-design.

This recommendation would address the following design requirements:

- Create a stronger human connection between pedestrians, and between pedestrians and rail staff (including train drivers)
- Support pedestrians to identify and respond to hazards in the RLX environment

Recommendation 4 – Default closed gates

It is recommended that the use of pedestrian gates at the RLX is maintained with fencing along the road footpath on approach to direct road users to the formal RLX path. The gates would be closed by default to reinforce to the pedestrian that they are approaching a dangerous area and that it is railway property rather than simply part of the public footpath. However, this should not be implemented in a threatening or unwelcoming manner. Pedestrians would be able to push the gate open when it is unlocked (when the technical system indicates that no train is approaching). People who are unable to push the gate open due to mobility impairment or where they are pushing a pram or trolley would be able to press a button and have the gate open automatically.

Lights on or above the gate lock would display green when gate is unlocked and no train is approaching and would show red when they are locked because of an approaching train. When the gate is locked, pedestrians would be encouraged to push the button (similar to when waiting at road traffic lights) to let the technical system know that pedestrians are waiting. The effect of pushing the button would be that the gates would unlock between approaching trains if sufficient time is available and once train/s have passed would unlock more quickly than other gates. The effect of this is that pedestrians would see that their gate has opened more quickly and be able to attribute this to their action of pressing the button. This would provide a sense of agency and control over the situation, rather than pedestrians remaining passive when waiting at RLXs.

The gates being closed by default would also provide a deterrent for cyclists wanting to ride through the pedestrian infrastructure rather than dismounting (as required by the road rules). Acknowledging that cyclists may take this action because they perceive the road to be unfriendly for them, it is also recommended that with this intervention a separated cycle path be provided along the roadway.

While the use of gates as barriers in this way may not be seen as in accordance with the sociotechnical values, it represents a design trade-off between supporting pedestrians to make their own decisions and protecting vulnerable users given the tight coupling and error intolerance of the system once the train is close to the RLX.

This recommendation would address the following design requirements:

- Protect road users
- Support trains to reach their destination
- Support pedestrians to identify and respond to hazards
- Design to support choice between desirable strategies for crossing the RLX but to constrain undesirable strategies
- Provide pedestrians with control or a sense of control over the situation
- Separate pedestrians and cyclists

Recommendation 5 - Gates unlock in-between trains

Historically, when there was a gatekeeper whose job it was to operate the road gates and pedestrian gates, they would open the pedestrian gates in-between trains (Warwick, 2009). This would be done because pedestrians can take-off more quickly than vehicles and clear the crossing as a group as they need not move in a queue. It is suggested in this recommendation, however, that there be some human oversight of this such as by supervisors at the RLX or by CCTV monitoring so that it would not occur where there are large numbers of pedestrians waiting, such as groups of schoolchildren or pedestrians with mobility impairments, who would require a longer time to traverse the RLX.

The light on the gate could begin to flash red when the gates unlock in between trains to inform users that they can cross if they choose to but that they must decide whether this is safe. Preferably, users would be given an indication of the time they have available to complete the crossing, thus giving them access to the system state (i.e. that a train is arriving in X seconds). This might appeal to those who would be considered 'high risk' users or sensation seekers who might feel satisfied that they have taken a risk that others would not. Other pedestrians who are not comfortable to take risks, could remain stopped and feel their needs were satisfied as the gate remains closed with an overall recommendation not to cross.

This recommendation would address the following design requirements:

- Provide access across the railway line
- Support pedestrians to reach their destination
- Maintain road / rail / pedestrian traffic flow
- Design to promote choice between desirable strategies for crossing the RLX but to constrain undesirable strategies
- Provide pedestrians with control or a sense of control over the situation
- Increase priority of pedestrian traffic

Recommendation 6 – Multiple access points to board / disembark a train

Given that the need to get across the RLX to catch an approaching train is a strong motivator of pedestrian behaviour, exploring ways to provide pedestrians with access to the train without needing to cross the track on which the train is approaching could be very beneficial. For example, where the RLX has a centre platform configuration, a smaller platform could be placed at the outside of the tracks with the train driver able to operate the front door of the first carriage to let passengers on the train. This could occur where the pedestrian was unable to reach the centre platform as the gates were closing or closed for the approaching train.

Further, where possible, RLXs one platform on each side of the set of tracks could have independently operating gates and small centre platforms where the train driver can operate the leading or trailing carriage door (depending on the direction of travel) to allow passengers to access the train from the centre. Such configurations would mean that unless another train is approaching on an adjacent track (meaning that the gates will be closed), at most RLXs pedestrians would have considerably increased access to trains and it would avoid behaviour associated with rushing across at the last moment to catch a train.

Computer-based modelling could be used to further explore this idea, for example using agent-based models. Further, potential risks such as confusion about access points and potential congestion on the smaller platforms would need to be considered and resolved.

This recommendation would address the following design requirements:

- Protect road users
- Support pedestrians to reach their destination
- Support trains to reach their destination
- Support pedestrians to make appropriate directional control decisions
- Change reward structures so that pedestrians who stop and wait for trains are rewarded while those who engage in undesirable behaviour are not rewarded
- Design to promote choice between desirable strategies for crossing the RLX but to constrain undesirable strategies

Recommendation 7 – Provide shelter and amenity at waiting areas

Pedestrians will still be required to stop and wait for trains on occasion, particularly if train services continue to grow as projected (Public Transport Victoria, 2012). Providing shelter for pedestrians waiting at the gates would protect them from rain, hail, extreme sun and wind and will avoid situations where pedestrians cross to get to shelter provided at the train station. While the provision of amenities such as seats, ticketing machines, community noticeboards / digital displays, wifi, music, etc. will not necessarily encourage all users to stop (particularly where they are motivated to get across quickly such as to catch a train), it could engender a level of respect between the owners / operators of the system and its users. If users believe that train companies and the government are concerned with their comfort and their safety then they may be less likely to intentionally break the rules as a way to undermine the RLX owner / operator. Such design changes could demonstrate that the system owner shares the goals of pedestrians that they want pedestrians to catch their train, to cross safely and in comfort and overall to have a positive experience at the RLX and on public transport more generally.

This recommendation would address the following design requirements:

- Support pedestrians to make appropriate speed control decisions

- Change reward structures so that pedestrians who stop and wait for trains are rewarded while those who engage in undesirable behaviour are not rewarded
- Create a stronger human connection between pedestrians and railway employees, particularly train drivers

Recommendation 8 – Provide a supervisor or supervisors at the RLX

The re-introduction of railway staff at RLXs could greatly increase the requisite variety (Ashby, 1956) within the system. Currently, the technical functions of the RLX are fully automated based on quite unsophisticated rules (involving train detection and timing of various warnings and barriers). There are no humans monitoring this technical system thus it cannot be sensitive to changes in conditions either in the immediate situation (i.e. a pedestrian has tripped and fallen on the RLX) or in the long-term (i.e. train patronage at a particular train station has risen due to a new housing estate being built meaning the pedestrian path is congested in peak times). While some train stations have customer service staff on-site, they do not have a formal role in supervising the RLX. Further, although protective services officers are present at Melbourne train stations to supervisor passenger behaviour between 6pm and the last train of the night, they do not appear to have any responsibilities for supervising the RLX and are more concerned with deterring anti-social and violent criminal behaviour (Chief Commissioner, 2012).

A supervisor would introduce the capacity to intervene to mitigate a potentially dangerous or emergency situation at the RLX. For example, a number of years ago a task force was set up in Victoria to deal with the problem of the wheels of wheelchairs becoming stuck in the gap between the rail and the asphalt of the footpath at RLXs. This task force was set up following the deaths of three RLX users whose wheelchairs had become stuck in the tracks and were not able to move off the tracks before the train arrived at the RLX (Victorian Department of Infrastructure, 2002). Potentially, a supervisor could have intervened and assisted to recover from such a situation. A supervisor could physically assist a person to move the wheelchair, they could be provided with an emergency button that would automatically put the rail signals back to stop or be provided with some other means to alert approaching train drivers of the emergency situation ahead.

Providing one to two trained staff members to supervise the RLX from a customer service perspective (rather than an enforcement perspective) could have additional benefits such as assistance for passengers who are not regular train users. RLX supervisors could provide rewards for desired behaviour, they could provide guidance to users who may be confused about the crossing configuration or who may be walking outside of the formal footpath area. They could also direct pedestrian traffic in the case of congestion on the crossing or even direct car drivers who have become queued on the RLX. It is important that the supervisors would take a customer service, rather than enforcement, perspective given the focus of sociotechnical systems theory on quality of life as well as findings from organisational psychology that employees are more likely to comply with requests where supervisors demonstrate consideration for the needs of workers and treat them with care and respect (e.g. Cialdini & Goldstein, 2004).

This intervention could be location and time specific based on risk (e.g. implemented at busy crossings during peak times) to reduce costs. However, it should also be noted that this initiative would create local jobs for communities which has a positive economic benefit. Consideration would need to be given to ensuring there is sufficient variety in the work of the RLX supervisor to maintain their engagement and the quality of their working life during shifts. This could potentially be achieved through task rotation such as alternating RLX supervision with other customer service tasks or changing locations regularly to maintain novelty and interest.

This recommendation would address the following design requirements:

- Protect road users
- Support pedestrians to reach their destination
- Support trains to reach their destination
- Support pedestrians to make appropriate speed control decisions
- Support pedestrians to make appropriate directional control decisions
- Support pedestrians to identify and respond to hazards in the RLX environment
- Maintain road / rail / pedestrian traffic flow
- Change reward structures
- Design to support choice between desirable strategies for crossing the RLX but to constrain undesirable strategies
- Create a stronger human connection between pedestrians and railway employees, particularly train drivers
- Ensure the RLX design is suitable for existing and forecasted pedestrian flow, especially where adjacent to stations during peak times or near schools, sports grounds, etc.

Recommendation 9 – Provide train information at the RLX

Currently, the RLX provides warnings where a train is approaching but it does not provide any information about the number of trains approaching or the attributes of the approaching train (i.e. is it stopping at the station? Is it running express?). Deaths have occurred due to pedestrians assuming that following the passing of the first train, the threat is over and the warnings are continuing to operate either due to an extended safety margin or because of some fault with the warnings. By providing information about approaching trains where pedestrians are waiting at the RLX, such incidents could be avoided.

It is recommended that the information would be provided through the implementation of dynamic visual displays visible at pedestrian waiting areas. The displays could also be used by approaching pedestrians to inform them of the platform their train will arrive on. Further, when the gates are locked, information could be provided about expected wait time to give pedestrians knowledge about how long they are likely to be waiting so that they can engage in other tasks (e.g. use personal electronic devices or engage with the displays provided at the RLX).

This recommendation would address the following design requirements:

- Support pedestrians to reach their destination
- Support pedestrians to make appropriate speed control decisions
- Support pedestrians to identify and respond to hazards in the RLX environment

Recommendation 10 - Use natural barriers and hazards rather than abstract warnings

Warnings are ubiquitous in modern society. Traffic lights provide warnings, mobile phones provide an alert when the battery is running low and alarms are ever present in control rooms, medical settings, cockpits, etc. Auditory warnings are often used because they do not require focussed or selective attention – instead they are obligatory (Watson & Sanderson, 2007). Further, the colour red has an implicit meaning of warning or danger (Pravossoudovitch, Cury, Young & Elliot, 2014), and may potentially be an innate signal of danger.

Rasmussen (1983) discusses three types of information from the environment – signals, signs, and symbols. Signals are processed in a skill-based manner – they are sensory data, processed as continuous variables. In contrast, signs activate rule-based behaviour by indicating a particular state of the system or feature of the environment. Further, symbols are processed using knowledge-based processing. It could be suggested that the RLX bells are intended to be processed in a rule-based manner, for pedestrians to hear them and apply the rule to stop. However, the bells may instead be interpreted as a symbol (an abstract construct). So, through experience and convention pedestrians come to understand that the bells mean a train is approaching, but as they can also be interpreted to mean that a train is approaching in 25 seconds, or that the RLX warnings have failed. Consequently, their activation may simply lead to a search for further information to understand the true state of the system and to make a decision based on this understanding and the user's personal goals.

Instead of the use of symbolic warnings and alarms which are discrete (either on or off), continuous variables regarding the state of the system could be provided to pedestrians. Further, these could be linked to the actual hazard, increasing their ability to be processed as signals.

It is therefore recommended that the abstract warnings such as the flashing lights, bells, signage, etc. would be removed. Instead, warnings should be provided that relate directly to train approach. For example, as a train approaches, the sound it produces (both from its movement on the rails and the whistle) could be amplified by a certain factor and played through a speaker at the RLX. Further, cameras could be used to display the actual train as it approaches as part of dynamic displays at the RLX (with the image of the train beginning as a small image in the distance and become larger and larger on approach). Further, amplified vibration could begin lightly on the ground near the RLX when the train is far away and get stronger as the train gets closer. This would more closely link warnings with the actual danger in the environment and could lead to better understanding and decision making.

An additional natural barrier that could be applied would be to remove the asphalt that provides a link between the pedestrian footpath and the road surface, also known as no man's land. Instead of a flat surface, this could be left as ballast (the crushed stone used as the railway track bed). This would provide a natural hazard deterring pedestrians from leaving the footpath and walking on the no man's land area or on the road as the ballast is difficult to walk on and slows locomotion. This would reinforce the limits of the safe areas for pedestrians.

This recommendation would address the following design requirements:

- Support pedestrians to make appropriate speed control decisions
- Support pedestrians to make appropriate directional control decisions
- Support pedestrians to identify and respond to hazards in the RLX environment

11.4 Future directions for RLX design

The design recommendations provided above could be implemented given existing technology. However, there are potential design solutions that can be considered from a longer-term point of view. For example, with emerging technologies potentially trains could be designed to have more sensitive braking systems, to reduce the tight coupling and enable the train driver to recover from emergency situations. Further, technologies such as obstacle detection could provide a benefit if it can be designed in a way that avoids an unacceptable number of false alarms.

A promising line of inquiry in technology development would be the implementation of a field of safe travel (Gibson & Crooks, 1938) display for pedestrians at RLXs. This would provide pedestrians with a continuous and dynamic representation of the safe area around them and would incorporate the required braking distance of the approaching train – showing this constraint in the environment. Potentially this could be achieved by projecting a light onto the road surface or by integration with personal electronic devices or forms of wearable technology. A personal field of safe travel would be most beneficial as the technology could be pre-programmed with the competencies of the pedestrian and thus include their individual constraints within the integrated field of safe travel display.

11.5 RLX design process recommendations

The focus of this thesis has predominantly been the development of recommendations for changes to the content of the RLX system and how it should function. However, an important consideration is the processes and mechanisms that are used to make RLX design decisions and to undertake monitoring, evaluation and ongoing re-design work over the longer term. During the conduct of the research described in this thesis, recommendations concerning the process by which RLXs are managed have arisen and these are documented in the following sections.

11.5.1 The current RLX design process

The current process for designing RLXs is based around the application of engineering standards and a requirement for consistency across RLXs in Victoria and across Australia. The standards are developed by Victorian organisations (e.g. the Victorian Rail Industry Operators Group) and National organisations (e.g. Standards Australia) and involve the bringing together of committees for particular topics with expert and public consultation processes on draft versions prior to acceptance. The formality of these processes means that they tend to extend over long timeframes and require compromise and trade-offs to gain approval. This makes it very difficult for standards, and therefore RLX design, to be adapted to local contexts and to be responsive to changing conditions.

Additionally, while it is understood that research findings and international good practice are considered in standard development, no research could be found that has demonstrated the effectiveness of RLX design, as set out in the standard, from a HFE perspective. Potentially, a process more aligned to the sociotechnical philosophy could provide substantial benefit. Such process recommendations are made in the following section.

11.5.2 Design process recommendations

Based on the sociotechnical systems theory process principles, recommendations can be made to improve the process of RLX design. The process may not necessarily be focussed on pedestrians solely and it is expected that it would need to take account of all road users. However, as pedestrians are a vulnerable group, there should be specific consideration of their needs throughout the process.

Table 11.3 Recommendations for RLX design processes based on sociotechnical systems theory principles.

Process principle	Recommendation/s
Adoption of agreed values and purposes	- Development of a clear, agreed vision for RLX design for pedestrians documented in a strategy endorsed by all stakeholders including user representatives. - The strategy should be developed via a process of engagement with all relevant stakeholders including users and user representatives.
Provision of resources and support	- The strategy should include commitment to dedicated, on-going funding for RLX design and monitoring as well as re-design processes. - Funding to resource dedicated positions within key stakeholder organisations to enable the functions of design, monitoring and re-design to occur (including funding for SMEs such as HFE professionals, designers, etc.). - The funding commitment would need to be long-term meaning that it must be supported by all political parties. To enable this, RLX safety should be advocated not as a political issue but as a moral issue. - Funding should be linked to appropriate performance measures (such as the amount and quality of user engagement). Users and stakeholders could be involved in evaluating the program on an annual basis.
Adoption of appropriate design process	- Development of a documented process appropriate for RLX design which incorporates the sociotechnical values and content principles. - Consideration would need to be given to whether the current process of the development and application of industry standards is achieving desired outcomes or if another process is necessary (i.e. site specific design based on guidelines and local user and SME input). - The CWA-DT would be an appropriate approach to adopt for RLX design generally.
Design and planning for the transition period	- Guidelines for managing transition periods should be provided identifying potential risks and ensuring processes consider the transition appropriately.
Documentation of how design choices constrain	- A database could be implemented to record design designs over time for individual RLXs and also for RLXs state-wide. This could show how decisions made at individual

subsequent choices	RLXs affect the network and would provide a resource for learning about successes in other communities.
User participation	- Local community engagement in RLX design, operation and re-design would be beneficial. This could be facilitated through the establishment of reference groups involving local users, businesses, police, railway station staff, RLX maintainers, train drivers, etc. - Reference groups could act as a citizen's jury where users and local stakeholders have decision making power regarding how funding is used, with support from experts, employed by government to advise on RLXs across the state, who would provide advice on engineering, HFE, design, urban planning, etc. The reference group should be assisted by a professional facilitator to ensure process runs appropriately.
Constraints are questioned	- The strategy developed for RLX management should provide a commitment to innovation which means that current constraints on RLX design are questioned. - Use of the CWA-DT would assist to ensure that constraints are questioned.
Representation of interconnectedness of system elements	- The AH, and outputs from the latter phases of CWA, developed for RLXs, could be used over time to understand system functioning and to evaluate potential design changes to understand effects on other aspects of the system (as recommended by the CWA-DT).
Joint design of social and technical elements	- The CWA-DT could be used to promote joint design of the social and technical elements.
Multidisciplinary participation and learning	- Teams responsible for upgrades, monitoring and re-design should represent multiple disciplines and have diverse training and experience including HFE, engineering, urban planning, sociology, stakeholder relations, etc.
Political debate	- Performance indicators for success of the design process should include amount of debate or opportunities for debate provided to users, stakeholders, experts, etc.
Design driven by good solutions – not fashion	- The adoption of the CWA-DT would promote this principle. - The participation of users and a broad range of stakeholders is likely to avoid the situation of technological solutions being promoted at the cost of social aspects of RLX functioning.
Iteration and planning for ongoing evaluation and re-design	- Real time monitoring systems should be implemented that are able to identify emergence and undesirable variability / behaviour enabling action to be taken quickly to intervene and re-design. - Such systems could be based on the strategies identified from the CWA that move the system towards the safety boundary (i.e. using the model of pedestrian behaviour developed in Chapter 9).

11.6 Discussion

This chapter has recommended design changes to improve pedestrian safety at RLXs. These changes relate to both the physical design of the system (following sociotechnical content principles) and the on-going process for RLX design, monitoring and re-design (following the sociotechnical process principles). Some recommendations would be relatively simple and inexpensive to implement (e.g. encouraging cafes to be established near RLXs) however some represent a radical change to the status quo (such as a citizen's jury to make decisions about RLX design) and would therefore require further research and evaluation before being formally adopted.

An important constraint for government in addressing public safety issues is cost. Government resources are limited and funding must be distributed across many areas including health, education, welfare, defence, infrastructure, etc. In order to be successful, these design recommendations need to be shown to be effective in improving safety, as well as demonstrating a cost-benefit from their implementation.

Taking account of this, the types of interventions proposed are not necessarily more costly than the current situation. The design process specifically focused on low-cost ideas where possible and there are many opportunities for sharing costs or cost-recovery. For example, the implementation of shelters at pedestrian waiting areas (Recommendation 7) could incorporate advertising to reduce costs. Further, accidents at RLXs are expensive with the annual cost of RLX incidents in Australia estimated at $116,279,817 (Tooth & Balmford, 2010). Therefore, even if only few accidents are prevented, there can be large savings to the economy.

Importantly, in arguing for a paradigm shift from safety management to sociotechnical systems theory, the cost-effectiveness notion needs to be questioned. Cost-effectiveness is a rational, management perspective, while it is possible to instead take a moral perspective to the problem of road crashes. For example, the vision zero approach adopted in Sweden (e.g. Belin, Tillgren & Vedung, 2011), commits to the goal of no fatalities or serious injuries on the road. This vision provides a model for overcoming the constraint of costs and considers all the ways in which safety can be improved.

11.7 Conclusion

This chapter has described recommendations for the improving the design of RLXs to increase pedestrian safety and to improve the on-going process of RLX management. These recommendations are based predominantly on the design concepts generated by RLX stakeholders using the activities described in the CWA-DT. Other recommendations have been inspired by insights from the CWA that were not included in the scope of the design workshops with stakeholders (due to time constraints). The recommendations represent a paradigm shift in thinking about RLX design and have the potential to make vital improvements in this area of longstanding safety concern.

12 Discussion and conclusions

12.1 Addressing the aims and research questions

12.1.1 Research aims

The overall aim of the research described in this thesis was to develop and evaluate a CWA-based approach for the design of complex sociotechnical systems to address the enduring difficulties in using CWA for system design. The approach developed, the CWA-DT, was also applied to provide recommendations to improve the design of RLXs to support pedestrian safety.

The CWA-DT was developed to assist HFE professions in their efforts to negotiate the gap between CWA analysis and design (established in Chapters 3 and 4). Its development (described in Chapter 5) drew upon the CWA and design literature, a survey of CWA practitioners (described in Chapter 4) and a structured process of identifying requirements for a CWA-based design approach that aligns with sociotechnical systems theory (described in Chapter 5). Version 1 of the CWA-DT was applied in the ticketing system domain and was evaluated successfully, with minor improvements made to the toolkit (described in Chapters 7 and 8). The more exhaustive application to improve safety at RLXs was well received by design participants but did not fully achieve the successful integration of sociotechnical values and philosophies in the design concepts created. The design concepts were, however, judged to be reasonably effective in minimising collisions, fatalities and injuries (see Chapter 10). Finally, recommendations for improving RLX design for pedestrian safety were identified, based on the previous research activities (Chapter 11).

Given the paucity of studies exploring pedestrian safety from a HFE perspective and particularly the lack of systems-based methods applied to this problem domain (as verified in the literature review in Chapter 2), the secondary aim of the research was to investigate pedestrian behaviour at RLXs using CWA. An exhaustive understanding of pedestrian behaviour at RLXs was achieved via a five phase CWA of pedestrian behaviour at RLXs (described in Chapter 9). The CWA led to the generation of a number of design insights that were used as part of the CWA-DT application to RLXs and also informed the more specific pedestrian design recommendations (provided in Chapter 11). The findings and recommendations made in this thesis thus address a gap in the literature on safety in this domain and can be used to contribute to RLX design practice.

12.1.2 Research questions

The research has addressed the six research questions posed at the outset of this thesis. A summary of how each research question has been addressed is provided below.

1. *What methodological adaptations or extensions can be made to CWA in order to support translation of analysis outputs into system design solutions?*

This research question was addressed through the findings from the review of the CWA literature, the survey of CWA users and the development of the AH incorporating CWA outputs and the values and principles of sociotechnical systems theory values and principles. The findings from these activities converged to an understanding that a toolkit, rather than a structured methodology, was required. Furthermore, the key notion of insights representing a bridge between the CWA outputs and participatory design activities emerged from these research activities (see Chapter 6).

2. *What are the desirable methodological attributes for a design approach to be used to support CWA-based design?*

In relation to desirable methodological attributes for a design approach to be used in conjunction with CWA, 13 attributes were initially identified from the HFE literature and these were prioritised based on the rankings provided by respondents to the CWA practitioner survey (Chapter 5). The seven prioritised methodological criteria were: creativity, efficiency, holism, integration, iteration, structure and validity.

Interestingly, while validity was considered an important attribute, commonly applied criteria in HFE such as reliability were ranked relatively low. This can be explained by the nature of design methods which should not be measured against the same criteria as analytical or evaluative methods. Similarly, it would not be appropriate for analytical methods to be measured against design-relevant attributes such as creativity. Potentially, the criteria developed in this thesis could be used in future research to evaluate other HFE design methods.

3. *Can the design approach developed be shown to be useful?*

To determine the utility of the CWA-DT, evaluation criteria were derived from the AH that explored design incorporating both CWA and the values and principles of sociotechnical systems theory design (described in Chapter 5). The evaluation criteria included: that the process meets the prioritised methodological criteria, that the process aligns with the sociotechnical systems values, and that the outcome aligns with the sociotechnical systems values and content principles.

Initially, the performance of the CWA-DT was assessed in relation to the proof of concept study focussing on transport ticketing system design (Chapter 7). In that application, the results of participant ratings against the methodological criteria were generally positive. Further, analyst reflections suggested that the process aligned with the sociotechnical systems values and produced designs that aligned with the sociotechnical systems theory content principles. In that application it was concluded that overall, the CWA-DT performed successfully.

The comprehensive application and evaluation of the CWA-DT was undertaken to create design concepts to improve safety at RLXs (see Chapter 10). This evaluation also drew upon participant ratings of the process against the methodological criteria. Similarly to the experience with the ticketing system design application, participants rated the process highly, providing positive ratings to each of the methodological criteria and also indicating that the sociotechnical values were evident in their experience of the workshop process. In contrast, however, the ratings of HFE experts suggested that the concepts did not fully align with the sociotechnical values and content principles.

While the CWA-DT did not meet all of the evaluation criteria established for its success, it can still be considered a useful design approach. It was well-received by those who participated in workshop sessions and it facilitated the creation of novel design concepts of which, in the RLX context, two of three shortlisted were rated by HFE experts to be more effective than existing designs. Further, the sessions held in the RLX domain had potential positive benefits amongst the stakeholder group that may be unable to measure in the short-term, but could represent longer-term benefits for the RLX system. These benefits include the stakeholders gaining familiarisation with systems thinking and systems-based methods for design and evaluation, questioning the existing assumptions of the system, expanding their field of design possibilities for RLXs, gaining understanding of each other's roles and gaining empathy for different road users. This experience has the potential to affect how RLX stakeholders understand the safety problem at RLXs and has provided a solid first step in broadening the conversations and ways of thinking about RLXs to enable future innovations to occur.

Future applications of the CWA-DT will provide further evidence regarding its utility as well as further opportunities to refine the toolkit. In terms of measuring the reliability and validity of the process, it will be important to establish that the toolkit reliably produces valid results over time.

4. What are the constraints and goals that influence pedestrian behaviour at RLXs?

The application of CWA to understand the constraints shaping pedestrian behaviour at RLXs, described in Chapter 9, represented the first application of CWA to this problem domain. The CWA demonstrated the flexibility in options for pedestrian behaviour in the RLX context and the influence of both engineered constraints (such as gates, barriers, etc.) and intentional constraints (such as social norms, road rules, motivations for crossing, etc.). A key finding was the need to design for the competencies of a wide range of users (e.g. elderly users, children, people with cognitive and mobility impairments, etc.). This represents a challenge for the application of the sociotechnical systems theory approach which generally promotes wider decision latitude and autonomy of users.

The CWA also identified the goals that influence pedestrian behaviour at RLXs. These were: maximising one's own safety, maximising the safety of others, minimising the chance of being fined, maximising efficiency in getting to one's destination, maximising compliance with social norms and maximising positive subjective experience. These goals influence selection between behavioural strategies and these aspects of the CWA were used to develop a model of pedestrian behaviour based on Rasmussen's (1997b) model of migration towards the boundaries of safe performance. This model could potentially be used as a basis for data collection and monitoring of RLX system performance over time.

5. Can effective designs be produced from the design approach developed to improve safety at RLXs?

The effectiveness of the designs produced by the application of the CWA-DT was assessed by the expert ratings of the three design concepts (see Chapter 10). The HFE expert panel found that two of the three design concepts developed represented an improvement on existing RLX designs in terms of how effective the design would be in minimising collisions, injuries, trauma, near misses and overall risk to safety. In particular, the proposed design for the rural context achieved a considerably higher rating (6/10) than the existing design (2/10). Therefore, based on the opinion of HFE experts, it can be concluded the CWA-DT produced effective designs to improve safety at RLXs. This finding does, however, require validation through future research testing user behaviour and system functioning in response to the proposed designs.

6. *Is the sociotechnical systems theory approach to design appropriate for public safety contexts?*

There is little research explicitly exploring the effectiveness of designs aligning with the sociotechnical systems theory approach in public safety contexts (i.e. in non-industrial or workplace settings). Two measures were used to explore the appropriateness of the approach in this thesis (see Chapter 10). The first measure involved gaining participants' views about the design approach and the extent to which they believed it was appropriate and the second was the expert panel ratings of the effectiveness of the designs produced.

The participants in the RLX design process indicated that the sociotechnical systems theory approach is acceptable in public safety domains. Strong agreement was given to statements regarding whether the design process would be useful for other safety-related design projects and whether the approach was appropriate for RLX design. However, while the HFE expert panel found the outcomes of the design process to be overall more likely to minimise safety risk at RLXs, they found that the designs did not fully align with the sociotechnical values and principles. This would suggest that the stakeholders did not fully embrace sociotechnical systems theory when creating the proposed designs. This could be explained by the dominance of the safety / risk management paradigm in which stakeholders' usual work is conducted. This existing paradigm underpins legal requirements around safety and is seen as vital for the protection of vulnerable users who, unlike workers in an industrial context, cannot be selected or trained. It is unknown to what extent the sociotechnical systems theory approach, which promotes autonomy and user decision making, will be acceptable to the public and how the legal system will regard the approach in the case of a collision or incident.

In conclusion, while the sociotechnical systems theory approach achieved face validity with RLX stakeholders, as the outcomes of the design process were not fully aligned with its values and principles it is not possible to provide conclusive findings about the effectiveness of designs aligned with this approach in this domain. Furthermore, questions of public acceptability and the response of the legal system require exploration. Consequently, further research is required to provide further insight into validity of the sociotechnical systems theory approach for public safety contexts.

It should be noted that there are a number of examples in the literature of CWA-based designs (using approaches other than the CWA-DT) that are not aligned with the values and principles of sociotechnical systems theory. For example, in an application of CWA to investigate scheduling tasks in manufacturing, there was discussion about improvements to be made to improve performance but no mention of aspects relating to the sociotechnical values such as meaningfulness of tasks, flexibility of design to cater for different preferences of operators, etc. (Higgins, 1998). Therefore, although the RLX designs created did not fully encompass the sociotechnical systems theory values and principles, they may reflect this approach more than they otherwise would have using other CWA-based design approaches.

12.2 Implications for RLX research and practice

12.2.1 Understanding RLXs from a systems perspective

The application of CWA confirmed the complexity of the RLX system and reinforced the appropriateness of systems-based methods and approaches to its evaluation and design. This confirmation was obtained through the results of the CWA application to pedestrian behaviour (Chapter 9). The findings of the CWA demonstrated evidence of the key systems principles of emergence, individual and system performance variability, dynamicism and organisation into hierarchical structures.

Emergence

The WDA showed emergent features including the function of 'provide assistance'. Further, the SAD flowchart also identified emergent behaviours such as running through fencing or bypassing the formal pedestrian infrastructure and crossing the RLX via the road. It can therefore be seen that the RLX system does not necessarily operate in the way that its designers intended. Instead, the components within the system interact in both predictable and unpredictable ways leading to emergence that might be desirable (e.g. pedestrians assisting one another to cross) or undesirable (e.g. pedestrians using the road to cross the RLX and being in an unprotected place when warnings begin to activate). Such emergent phenomena are important for designers to consider.

Individual and system performance variability

Similarly to emergence, this research has demonstrated the variability of pedestrian performance at RLXs. For example, pedestrians have many options when selecting a route across the RLX. They may choose to take the formal footpath directly across the RLX, or to begin on the formal path and then deviate onto the road and across diagonally, or bypass the formal footpath altogether and cross using the roadway. Further, the circumstances under which pedestrians chose different strategies were identified. These included adverse weather, congestion at the RLX, perceiving the situation as being safe or unsafe, being in a hurry and intending to catch the approaching train. The SAD flowcharts enabled the categorisation of strategies that would be more likely given these circumstances as well as the strategies that would be more likely depending on the user goal/s (e.g. to maintain their own safety, the safety of others, efficiency, compliance, etc.).

This analysis was a key input in the development of a model of pedestrian behaviour based on Rasmussen's model of migration towards the boundaries of safe performance which aims to assist in the understanding of performance variability associated with pedestrian use of RLXs. Further, this work has provided further support for the utility of the SAD methodology developed by Cornelissen and colleagues (2013) and it is hoped that it can be used to assist RLX designers to better consider the range of pedestrian behaviour that is possible given the current constraints of the RLX system.

Dynamism

While the technology installed at RLXs has experienced small, evolutionary change over the years, the conditions under which RLXs operate have shifted. For example, trains are generally more frequent, they are quieter and faster and they traverse urban areas which have seen high population growth meaning increased numbers of RLX users with resultant congestion. Further, there are concerns regarding the proliferation of personal electronic devices potentially leading to increased user distraction. Issues regarding congestion and interaction with other road users were identified in the CWA. For example, during the covert observations it became clear that the flow of pedestrians was not easily predicted leading to some pedestrians being trapped near the tracks on one side of the RLX while many others flowed through in the opposite direction. The congestion effect can make decisions about the RLX more complex for pedestrians as identified through the decision ladder and SAD analyses. Given that congestion is likely to continue to increase into the future, this issue requires the attention of RLX designers.

Further investigation of dynamism at RLXs could be performed through considering changes in the model of pedestrian behaviour developed in Chapter 10. Such research could apply real-time monitoring systems to collect data about pedestrian strategies exhibited at RLXs around the rail network. This could be achieved through CCTV monitoring with automated algorithms that identify particular behaviours and strategies, monitored by an analyst who validates this data and identifies emerging strategies to update the algorithm. The process would enable system stakeholders to continually manage risk through identifying patterns of emergence that are associated with risk and to intervene on a local level to try to improve the situation. An ongoing process of monitor-intervene-monitor would enable the overall system to respond more quickly and more sensitively to emerging issues.

Hierarchical structures

The tendency for systems to be organised in hierarchical structures is evident in the RLX domain. During the development of the WDA model a number of actors and organisations who are involved in RLX functions were identified including pedestrians, other road users, train drivers, RLX maintainers, road authorities, rail operators, government agencies and regulators.

At the uppermost levels of the RLX system sits the parliament who passes legislation that intends to affect behaviour at the RLX (e.g. rules that intend to prevent pedestrians crossing when the warnings are activated) as well as legislation that affects the way in which RLXs are designed (e.g. safety laws, regulations incorporating requirements to ensure accessibility of RLXs for people with disabilities, etc.). Exploration of the different actors and stakeholders was achieved through a stakeholder needs analysis conducted as part of the application of the CWA-DT. In many ways, the diversity of organisations with influence over RLX design and functioning is a core aspect of the complexity of this domain. Further research could conduct more detailed exploration of the interactions between actors at different levels through the application of other systems-based methodologies such as STAMP (Leveson, 2004).

12.2.2 Key recommendations derived from the research

In Chapter 11, the key aspects comprising the practical contribution of the research were presented. A number of novel recommendations were offered to improve the design of RLXs and reduce collisions involving pedestrians and trains. The recommendations, grounded in sociotechnical systems theory, relate to both RLX design and RLX management on an ongoing basis to support safe interactions in the domain. Further research is required to determine the conditions under which particular recommendations might be more or less effective, and to determine to what extent they represent an improvement on the existing situation. Overall, however, the application of the CWA-DT and sociotechnical systems theory has led to innovative design concepts that have the potential to improve safety performance at RLXs.

12.2.3 Future research directions

These findings demonstrate the necessity for systems-based approaches to be used more widely to understand a broad range of safety issues. Our modern world is complex and there are many public safety concerns, similar to collisions at RLXs, for which systems-based approaches such as the CWA-DT could provide benefit. For example, the CWA-DT could be applied to prevent road collisions involving pedestrians (and other vulnerable users such as cyclists), collisions involving trespassers on the railway, drowning deaths occurring in public waterways or household swimming pools, or deaths due to crowding and crushing at major events. Further research could even extend to exploring whether systems-based methods and / or the CWA-DT can be effectively applied to prevent deaths and injuries associated with intentional behaviours such as violent crime or suicide.

There is also further opportunity to explore RLX functioning from a systems perspective. For example, through the use of methods such STAMP, as noted above, to understand the control and feedback loops currently operating with the system as well as other techniques emerging from systems dynamics such as causal loops applied in accident analysis (Goh, Brown & Spickett, 2010).

12.3 Implications for design practice based on CWA

The translation of analysis outputs and findings into design has been a longstanding challenge for CWA (e.g. Jenkins, Salmon, Stanton, & Walker, 2010; Lintern, 2005; Mendoza, Angelelli, & Lindgren, 2011), and indeed for HFE more generally (Dul et al, 2012). While there have been successful design applications in the past, including using approaches such as EID, the lack of guidance for using CWA in design more broadly has potentially affected its usability, accessibility and its uptake in practice. This may represent a lost opportunity to reap the benefits of powerful approach which has the potential to make gains in safety, efficiency and effectiveness in today's complex sociotechnical systems. Therefore, the CWA-DT fills an important gap in CWA practice and has the potential to improve the translation of the systems approach in real world design. Indeed, the toolkit suggests that approaches such as EID be used as part of a broader design strategy using the CWA-DT. Implications for design practice are discussed in the following remarks.

The use of the design thinking perspective in the CWA-DT raised an interesting question about the role of professional designers in HFE design. Both design thinking and the sociotechnical systems theory approach to design involve non-professional designers in a process that helps them to think creatively and to produce innovations. Design thinking is based on the notion that anyone can be creative, however, it must be recognised that designers have years of specialised training and experience and possess skills in creating products and environments that are functionally useful and aesthetically pleasing. Such skills and experience cannot be simply provided to non-designers by guiding them through a design process. Accordingly, it is important to establish a collaborative design process involving experts spanning the areas of HFE and design, as well as specific areas relevant to the design scope (e.g. engineering, organisational design, etc.). Collaboration was seen as essential by a number of CWA users who responded to the survey (described in Chapter 4) and is therefore encouraged in the CWA-DT guidance document (see the section on ‘Participation and Engagement’ at page 19 of the Appendix).

A related issue raised by the use of CWA in design processes is whether the outputs generated from the analysis process such as the AH, CAT, decision ladders, etc. should be shared with design participants who have no CWA experience. It was determined that the CWA-DT should provide an option for bringing the outputs into design sessions, to enable design teams to choose this activity if they think it would be appropriate, based on the background of participants. The ‘constraint crushing’ tool was developed and has since been successfully used in an intersection design context with a participant group including both experienced CWA users and individuals unfamiliar with the CWA approach (Read, Salmon & Lenné, in press). Optimally, in addition to using CWA outputs in the design process, users and stakeholders would also contribute to the initial development of CWA outputs with appropriate support from researchers. This would be most advantageous for learning and provide a common ground for beginning the design process.

A final implication for design practice arises from the success of the toolkit structure adopted for the CWA-DT. This provides appropriate levels of flexibility to the design team to run the process in a way that best meets their particular needs. This was important as the goal was to support CWA users rather than control them or restrict them to a particular methodology. The format of the CWA-DT is intended to ensure that it can be used for many design purposes in any domain to which CWA might be applied. Whether this intention is achieved will require further applications, which are currently underway (e.g. Read, Salmon & Lenné, in press).

12.4 Implications for sociotechnical systems theory

Sociotechnical systems theory has a long-standing record of success in improving the design of organisations (e.g. Eason, 2014; Mumford, 2006) and this thesis has responded to calls for its use to be extended to new domains (Davis, Challenger, Jayewardene & Clegg, 2014). In particular, there have been increasingly frequent appeals for a systems approach to improve public safety issues, including in road transport (e.g. Larsson, Dekker & Tingvall, 2010; Salmon

& Lenné, 2015; Salmon, McClure & Stanton, 2012). CWA and the sociotechnical systems theory approach have provided a means to apply the systems approach to the RLX domain.

It is acknowledged that many aspects of the sociotechnical systems theory approach underlie modern HFE practice. For example, HFE is concerned with human wellbeing as well as system performance and safety (IEA, 2015). Furthermore, HFE takes a user-centred approach and promotes the use of participatory design techniques. The contribution of the CWA-DT, over and above existing HFE practice, lies in the explicit reference to, and use of the sociotechnical systems theory values and principles in conjunction with the use of CWA. The innovation is in taking these concepts and methods and aligning them with appropriate participatory design approaches. It is envisaged that the CWA-DT could make CWA and the sociotechnical systems theory approach accessible to a wider range of HFE practitioners.

A further contribution of the research to sociotechnical systems theory and to CWA has been its application beyond industrial or organisational settings. The existing literature has not provided explicit consideration of whether the values and principles of sociotechnical systems theory are appropriate for design in public safety contexts. There are key tensions between sociotechnical systems theory and the traditional safety management approach usually applied in these contexts, as described in Chapter 10 of this thesis. For example, the value of humans as assets suggests that humans in the system should be given control over their decisions and the principle that the means for undertaking tasks should be flexibly specified suggests that humans should be supported to exhibit flexibility and adaptability in their behaviour. However, the safety management approach encompasses concepts such as the hierarchy of control which are focused on separating humans from hazards and which, when applied within transport systems, tend to focus on limiting performance variability rather than supporting adaptive variability.

An overall trend in public opinion away from individual responsibility for safety towards government responsibility is being experienced (Leveson, 2004). Where public protection fails, those harmed are becoming more likely to take civil proceedings against organisations and government arguing a breach of duty of care. In the RLX context, it would appear anecdotally that if active RLX protection is in place where a collision occurs and the equipment has operated as designed (i.e. has provided a warning), the public attributes the incident to the individual road user involved in the collision as they have breached the road rules. However, if the equipment has failed to operate to warn of a train, the railway company and / or government are deemed responsible. This situation is not conducive to innovation and has stifled the implementation of low-cost innovations at RLXs (Road Safety Committee, 2008). Further, this underlying philosophy of blame permeating the road transport system is in direct opposition to the 'shared responsibility' approach that is being adopted and promoted by road safety agencies across Australia (Salmon, Read, Lenné & Stanton, 2013). However, none of the road safety strategies promoting the safe system approach attempt to deal with the law reform issues that would be required to facilitate its implementation.

To truly incorporate a sociotechnical systems theory approach in public safety domains many changes to the wider system would be required. For example, the operation of the legal system and the interventions of regulators need to be considered in relation to what organisational behaviour (such as innovation) it reinforces and punishes. Further, the underlying assumptions and focus of investigations on blame requires reform as it limits the information and data collected and consequently the ability to learn from past events.

However, can we be assured that the proposed paradigm of sociotechnical systems theory would be more successful in preventing accidents than the existing situation? This is an important question and its answer lies in finding a way to compare the traditional safety management approach and the sociotechnical systems theory approach in an appropriate manner to determine which is most successful in preventing accidents. System designs that are aligned with each of these approaches could be tested through avenues such as simulation and agent-based modelling to determine the effect on behaviour and potential emergent behaviours. However, such methods would not as easily capture the impacts of wider changes such as amendments to legal processes. Potentially, a hybrid approach incorporating agent-based modelling as well as systems dynamics-based approaches could be useful, to determine the effects of broader, structural changes that influence RLX operation (Hettinger, Kirlik, Goh & Buckle, 2015). Alternatively, a means of reconciling the two apparently conflicting approaches could be sought which could combine the protective aspects of the safety management approach while meeting the values and principles of sociotechnical systems theory. Significant further research is required to answer these questions.

12.5 Contribution to the discipline

Overall, this thesis has demonstrated contributions to each aspect of the HFE discipline identified by Karwowski (2005). The contributions are shown in Figure 12.1. In relation to philosophy, the work has adopted the sociotechnical systems theory values to underpin the development and application of the CWA-DT. It is proposed that these values represent the values of HFE and the explicit use of them may assist to address calls for a more comprehensive consideration of ethics and values in HFE (Dekker, Hancock, & Wilkin, 2013). Reflecting next on contributions to theory, this thesis has applied systems theory and demonstrated its utility for understanding sociotechnical systems used by members of the public. Although the research has demonstrated the practical value of the sociotechnical systems theory approach for design, it has also raised important questions that should be addressed to determine the effectiveness of sociotechnical systems theory for design for public safety. An additional theoretical contribution lies in the model of pedestrian behaviour at RLXs developed which could be tested through future research.

Continuing through the aspects of the HFE discipline shown in Figure 12.1, contributions to practice and education have included the development and evaluation of the CWA-DT as well as the multidisciplinary learning and education that occurred during the application of the CWA-DT with a diverse range of transport users and stakeholders. In relation to management, this thesis has contributed recommendations for the ongoing management of RLX design processes, from a sociotechnical systems theory perspective. A major contribution of the work has been to design. The CWA-DT provides an accessible and usable resource for HFE practitioners to use in conjunction with the CWA framework. Further, design recommendations for improving the performance of transport ticketing systems and RLXs have been provided. Finally, the work has contributed to the understanding of how RLX technology and the environment constrain pedestrian behaviour. It has also led to innovative recommendations for how technology and the environment can be modified to achieve better adaptive capacity within the RLX system.

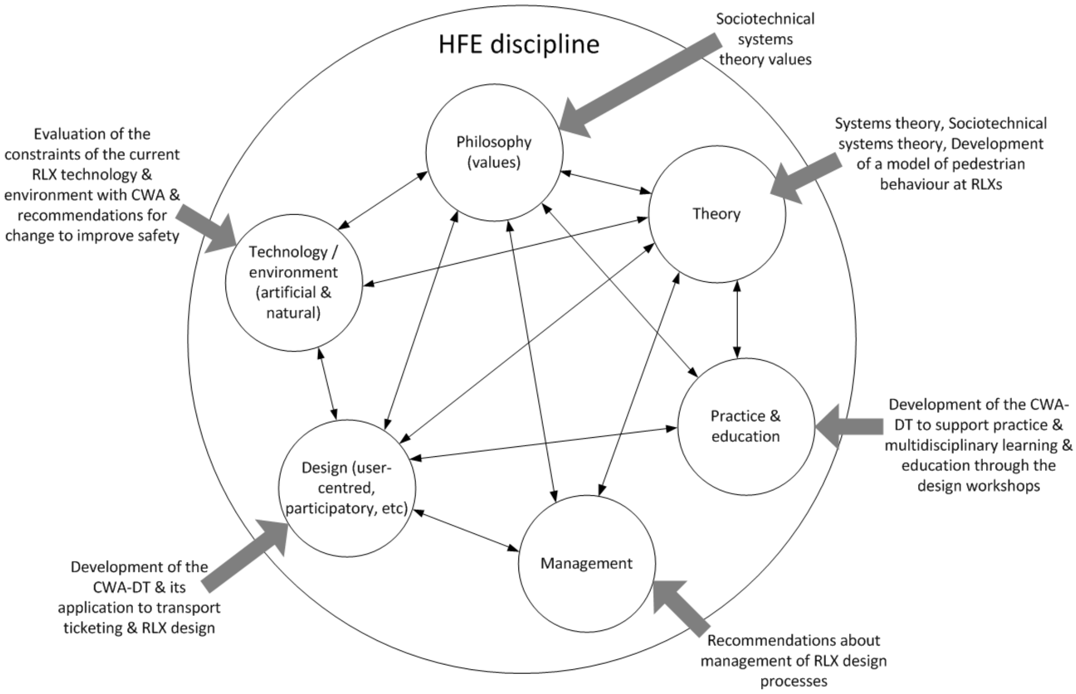

Figure 12.1. Contribution of the thesis to the HFE discipline.

12.6 Limitations and future research needs for the CWA-DT

There are limitations of the research described in this thesis that should be acknowledged. Firstly, the evaluation processes undertaken only formally tested the early stages of the CWA-DT (i.e. up to the development of initial design concepts). Processes associated with detailed design, detailed evaluation and design refinement, implementation and testing and verification were not evaluated. The rationale for this was that the decisions made early in the design process, and especially in defining the design concept/s to be subjected to detailed design and evaluation processes are the most important to influence. According to the sociotechnical systems process principle of 'design choices constrain subsequent choices', decisions made in design are interdependent and early decisions will constrain the degrees of freedom available for latter decisions (Clegg, 2000). Therefore, it is important to focus on providing a comprehensive process in the early stages where the most important decisions are made. It is, however, acknowledged that further research is required to evaluate and refine the subsequent stages of the CWA-DT and to explore how iteration can occur following the selection of design concepts. Preferably an end-to-end evaluation of the toolkit would occur without input from the developer, to determine the performance of the toolkit when applied by other users. It is intended that the toolkit will be provided as an online resource to enable the HFE community to download the guidance, tools and templates for direct use in design processes. A wiki or blog feature will be incorporated to enable users of the CWA-DT to provide feedback and to suggest additions, amendments or variations to the toolkit. The website would also provide an avenue for collecting data about the toolkit and its use over time via online survey forms. This initiative will enable the CWA-DT to be evaluated and optimised over time based upon the experiences of the users and facilitate adaption of the toolkit for emerging uses and requirements.

Secondly, the research was limited as the RLX designs created by stakeholders (described in Chapter 10) were not subject to a full testing, beyond evaluation by HFE experts. The evaluation by HFE experts was unable to demonstrate whether or not the designs produced are valid in real-world contexts nor was the evaluation sufficiently sensitive to explore the potential effectiveness of the designs in the short-term (i.e. at first implementation) as well as over the long-term. Unanticipated and emergent consequences of the designs cannot be fully predicted on the basis of desktop evaluation and must be considered as part of a longer-term monitoring and evaluation process following implementation. While a more thorough evaluation of the RLX designs was unable to be achieved within the scope of this thesis, further research involving simulation-based testing and additional expert evaluation is planned to occur to better understand their potential in improving safety. In addition, the specific design recommendations for pedestrians, provided in Chapter 11, should be subject to further evaluation and testing to support their potential implementation into practice.

In relation to methodology, one area of criticism could be the failure to engage fully in an action research paradigm with the design participants as part of the use of the CWA-DT. Action research has a strong tradition within the sociotechnical systems theory approach and was the methodology used by the Tavistock researchers in developing the approach. It can involve the direct contribution of the researchers in solving the problem at hand and can even involve inquiry that the researcher undertakes into their own action or situation. In the research undertaken in this thesis, a compromise approach was taken to balance the need to avoid researcher bias without affecting the validity of the outcome of the design process. This was achieved by maintaining the independence of the facilitator (the CWA-DT developer). For example, during design workshops, the facilitator did not suggest design ideas directly nor provide opinion on the merit of those proposed by design participants. The facilitator’s role was to ensure that the process supported the design brief, that participants understood the design activities and were encouraged to take part, and that design participants were afforded an environment in which they could freely express their views and opinions and debate these in a constructive manner. Potentially, if the purpose of the CWA-DT use did not involve its evaluation, the facilitator and wider researcher team could have had more direct involvement.

While the CWA-DT guidance does not comment upon the strengths and weakness of taking an action research approach, it is important to acknowledge that if it is adopted, the researchers' views might be given unreasonable weight due to their position of authority in the group. This must be managed as the benefits of the participatory approach are lost if participants simply acquiesce to the views and suggestions of the researchers.

A final limitation was the lack of a comparison between the CWA-DT and another CWA-based design approach or design approaches generally. This type of evaluation was found to be unattainable due to the lack of any standard, existing approaches for the translation of CWA outputs into design concepts, apart from detailed design involving EID (as discussed in Chapters 3 and 4). While the CWA-DT could have been compared with another approach described in the CWA literature, the detail provided in the published literature was generally too scant to enable replication of the process. With the CWA-DT now developed to meet this gap (with associated guidance to enable use by practitioners other than the developers), other design approaches developed for use with CWA could use it as an exemplar for evaluative purposes.

A future direction for the CWA-DT would be to explore whether it can be extended to support design based on the insights gained through other methods for systems-based analysis such as STAMP (Leveson, 2004), the Event Analysis of Systemic Teamwork (EAST) methodology (Walker, Gibson, Stanton, Baber, Salmon & Green, 2006) or FRAM (Hollnagel, 2012). The flexibility of the insight process for translating the findings uncovered during the analysis process into participatory design activities makes it a good candidate for use with many varied methodologies. However, any methodologies used should be underpinned by the systems approach to maintain theoretical validity. The use of an extended version of the CWA-DT with a range of systems-based methodologies could assist the values and principles underpinning the sociotechnical systems approach to reclaim a pivotal place in HFE practice.

12.7 Conclusion

The CWA-DT represents an exciting innovation for the HFE discipline. The toolkit represents a novel approach that explicitly draws together CWA and the sociotechnical systems theory approach to support HFE practitioners to negotiate the gap between analysis and design. In addition to the methodological contribution of a useful resource for HFE practitioners, this thesis has provided contributions to practice with the provision of innovative recommendations for improving the safety and performance of RLX systems and improving ticketing system design. Further, from a theoretical perspective, the research has demonstrated the need to determine the potential benefits of a paradigm shift in public safety from safety management to the sociotechnical systems approach. Such a shift could be facilitated through further applications and research to demonstrate the utility of the sociotechnical systems approach, as encompassed within the CWA-DT, in public safety contexts.

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Xu, W., Dainoff, M. J., & Mark, L. S. (1999). Facilitate complex search tasks in hypertext by externalizing functional properties of a work domain. *International Journal of Human-Computer Interaction, 11*, 201-229.

Young, M. S., & Birrell, S. A. (2012). Ecological IVIS design: Using EID to develop a novel in-vehicle information system. *Theoretical Issues in Ergonomics Science, 13*, 225-239.

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Appendix

The CWA Design Toolkit

The CWA Design Toolkit

2015

Contents

Purpose of the toolkit

The toolkit has been developed to assist users of the cognitive work analysis framework (CWA) to apply the outputs of the framework to the design of sociotechnical systems.

The toolkit intends to support the creative process of designing elements of a sociotechnical system (such as equipment, environments, processes, organisational structures, strategies, etc.) in an integrated manner that takes account of human factors and ergonomics (HFE) considerations. The particular philosophy underpinning this creative process is sociotechnical systems theory. This approach is concerned with the joint optimisation of human and technical aspects of the system and the design of sociotechnical systems that have adaptive capacity. A sociotechnical system which has the property of adaptive capacity can respond to the changing demands and variances imposed by its environment, whilst continuing to achieve its goals.

The toolkit is intended to be flexible, so you are encouraged to apply those aspects that are most useful for the purposes and scope of your design activity.

Intended users

The guidance is intended for those wishing to use CWA to support the design of sociotechnical systems. Toolkit users may have varying levels of knowledge and experience of the areas underpinning the thesis which are:

- Systems theory and systems thinking approaches
- The sociotechnical systems approach
- Cognitive work analysis
- Participatory design process

Given that readers have varying background knowledge levels, some readers may read this document from beginning to end while others will not. You may find that you are interested in certain sections or tools that might improve your usual process. It is recommended that users refer to, and utilise those aspects of the toolkit that they find are useful and relevant for the scope of their work.

If you have no or little experience with CWA, you should read this toolkit in conjunction with the further reading recommended in the various parts. For example, the toolkit provides some advice regarding the analysis process, however this cannot replicate or replace authoritative texts that provide comprehensive information and guidance for completing the analysis. References are provided in the toolkit to assist beginners to get started in reviewing the CWA literature.

Intended use

This toolkit is intended to assist design or re-design activities involving open sociotechnical systems. Sociotechnical systems are those in which humans and technology must work together for the system to achieve its goals. Open systems are those that do not have closed boundaries and are affected by changes in their environment. For example, a manufacturing company must respond to changes in customer demand for the product being produced, as well as changes to regulations that affect its business (i.e. in relation to employee relations, environmental protection, occupational health and safety, etc.). If the organisation cannot adapt to changes, it will fail to survive. Sociotechnical systems are open systems because interactions between humans and technology occur in a changing context.

This toolkit is intended for design projects where there is an existing system that is either being re-designed, or is the basis for the new design. This is required because the process is underpinned by the application of CWA and the use of the insights gained to feed into the design process.

Further, CWA is often applied in the design of ecological interfaces for supervisory control of a domain (i.e. process control systems such as nuclear power generation). Where this is the aim of your design activity, you may find that the ecological interface design approach is better suited to your needs rather than the application of this toolkit. However, ecological interface design can be used in conjunction with this toolkit. For example, the toolkit would be useful where the design scope includes an interface that is coordinated with the design of team roles, the physical environment, organisational strategy, etc. Further information about ecological interface design can be found in the following sources:

- Burns, C.M. and Hajdukiewicz, J.R. (2004). *Ecological Interface Design*. Boca Raton, FL: CRC Press.
- Bennett, K.B. and Flach, J.M. (2011). *Display and Interface Design: Subtle Science, Exact Art*. CRC Press: Boca Raton, FL.

Terminology

Throughout this guidance terms such as ‘analysts’, ‘designers’ and ‘design teams’ are used. In an optimal process, these groups would be not be differentiated. For example, analysts who conduct the CWA work would also contribute to design and would consider themselves ‘designers’ and part of ‘design teams’. Similarly, professional designers would be involved in the development of the CWA outputs and thus be ‘analysts’. However, the different terminology is used to acknowledge that in real world projects which may extend over months and years it may not be possible for all team members to be involved in all aspects of the analysis, design and evaluation processes.

Cognitive work analysis was developed in industrial settings hence the use of terminology around ‘work’ within the framework. Given the large and growing number of applications of the framework beyond work contexts (e.g. in road transport and driving, social networking, urban design), we tend to refer to ‘human’ rather than ‘operator’ or ‘worker’ throughout the toolkit. We also interpret the term ‘work domain’ to include domains other than those in which humans are employees within the system.

Background to systems thinking

Whether you are designing a product, a service, a physical environment, social environment or organisation it is important to think about it from a systems perspective. This provides a holistic understanding of the domain and, even if you are designing only a small aspect, enables you to understand the wider impacts of the change. It is particularly important to be sensitive to the possibility of unintended negative consequences of design changes as changes to a complex system will often not result in predictable effects.

Sociotechnical systems (in which humans interact with technology or other artefacts to achieve goals) are open systems. This means that they are affected by changes in their environment and must be able to adapt to these to continue to achieve their goals.

Some things that need to be taken into account in designing sociotechnical systems, or elements that will be introduced into a sociotechnical system, include:

They exhibit emergent properties. An emergent property is something that is the result of an interaction between system components, rather than a property of a single component. Emergence relates to the idea of the whole being more than the sum of its parts. For example, a person is made up of millions of cells but display properties (such as movement or consciousness) that cannot be explained by examining the cells themselves.

They organise in hierarchical structures. System components tend to self-organise and to organise into hierarchical structures. For example, birds form flocks, ants form colonies and humans form households, suburbs and cities.

There is variability in performance. In open sociotechnical systems, goals can be achieved in many different ways. For example, if you are driving to the supermarket you can usually choose between a number of routes. Further, because the road is shared with other cars and road users, you will have to respond to their actions as well as to other dynamic factors such as traffic lights. Therefore, the actions you will take on vehicle controls such as the steering wheel, brake and accelerator will be at least slightly different each time each time.

They are dynamic. Sociotechnical systems have inputs that are transformed to outputs, and because of changing external pressures, behaviour and performance of the system changes over time. Consider for example, the domain of news media and how it has changed over the years from hardcopy bulletins to radio and television, and now to online news delivery including web copy, videos and interactive social media. Journalists working in the modern age require very different skills to the past and are also working within new funding streams that impact the way work is done.

In summary, the approach taken to the design needs to account for the complexity, flexibility and dynamism of modern sociotechnical systems. This can be achieved through the application of CWA and the sociotechnical systems approach as described in this toolkit.

Further reading about systems theory and systems thinking

- Skyttner, L. (2006). *General Systems Theory: Problems, Perspectives, Practice (2nd Ed.)*. Hackensack, NJ: World Scientific.

About CWA

The CWA framework is unique in its formative, constraint-based approach in that it models the possibilities for behaviour within the constraints imposed by the system, rather than describing actual behaviour (i.e. how work is done), or prescribing normative behaviour (i.e. how work should be done) (Vicente 1999).

CWA has its origins in studies at the RISØ laboratory in Denmark beginning in the 1960s. The research program was concerned with designing safe nuclear power installations and, following work to ensure the technical reliability of a nuclear power plant, the researchers realised the need to consider to the role of the human operator. A key finding of their investigations was that accidents were likely where the operator was faced with situations unanticipated by the designer (Vicente 1998). The studies culminated in the emergence of the cognitive systems engineering approach, including the CWA framework of tools to assist in the design of adaptive systems that enable the worker to 'finish the design' (Vicente 1999).

To support such design, CWA provides a formative approach to the analysis of human activity by identifying and analysing the constraints within the system that shape behaviour (Vicente, 1999). The framework encompasses five phases of analysis. The first phase, work domain analysis, describes the environmental constraints on behaviour within the domain. Secondly, control task analysis considers the tasks that need to be achieved. Thirdly, strategies analysis identifies the various strategies that can be used to fulfil the tasks. The fourth phase, social organisation and cooperation analysis, is used to allocate functions amongst human and technological actors and to identify communication and collaboration requirements. Finally, the competencies required by actors operating within the domain are identified through the final phase, worker competencies analysis (Vicente, 1999).

CWA has been applied in many domains and there is a substantial literature around the process for conducting the phases of analysis (key texts are indicated below). Importantly, the framework encourages analysts to think about the system being investigated from new perspectives (i.e. from different levels of abstraction) which can prompt insights about the functioning of the existing system and insights about innovations that could be introduced. This toolkit promotes the documentation of insights during the analysis process, and provides guidance on how these insights can be used in participatory processes for concept design.

Further reading about CWA

- Vicente, K.J. (1999). Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work Mahwah, NJ: Lawrence Erlbaum Associates.
- Jenkins, D.P., Stanton, N.A. Salmon, P. M., & Walker, G. H. (2009). *Cognitive Work Analysis: Coping with Complexity*. Surrey: Ashgate.
- Sanderson, P.M. (2003). Cognitive Work Analysis. In Carroll, J. ed. *HCI Models, Theories, and Frameworks: Toward an Interdisciplinary Science.* New York: Morgan-Kaufmann.
- Naikar, N. (2013). *Work Domain Analysis: Concepts, Guidelines and Cases*. Boca Raton, FL: Taylor & Francis Group.

- Lintern, G. (2009). *Foundations and Pragmatics of Cognitive Work Analysis: A Systematic Approach to Design of Large-Scale Information Systems*. Available to download from: www.CognitiveSystemsDesign.net

About sociotechnical systems theory

Sociotechnical systems theory has its origins in the studies of the Tavistock Institute in the 1950s following the introduction of mechanisation in the UK coal mining industry (Trist and Bamforth 1951). The approach is aligned with systems theory and underpinned by notions of participative demography and humanistic values; being as concerned with the performance of the work system as with the experience and well-being of the people performing the work (Clegg 2000, Walker et al. 2008). Many years of action research implementing innovations in organisations have led to the evolution of principles of sociotechnical design (e.g. Cherns 1976, Davis 1982, Clegg 2000, Walker et al. 2009). These principles are intended to support the design of open sociotechnical systems that can adapt to changing external pressures.

As well as being open systems, sociotechnical systems comprise social and technical sub-systems which exhibit purposeful, goal-directed behaviour. The interaction of these sub-systems create conditions for either successful or unsuccessful system performance (Walker et al. 2008). A core assumption of sociotechnical systems theory is that joint optimisation (as opposed to optimisation of either the social or technical aspects) is required for successful system performance (Badham et al. 2006). Being open systems, sociotechnical systems undertake processes that convert inputs to outputs, they contain part-whole relationships where the whole is more than the sum of the parts, they possess the quality of equifinality; having many means of achieving goals, and they adapt to changes in the external environment (Badham et al. 2006, Walker et al. 2008, Waterson 2009).

A set of values and principles drawn from the sociotechnical systems theory literature is outlined on the following page. The values underpin the design process as well as the outcome of the design (e.g. the designed system). The process principles underpin the design process, and these were used in the development of this toolkit. The content principles should be evident within the designed system.

Further reading about sociotechnical systems theory

- Trist, E.L. (1981). *The evolution of sociotechnical systems: A conceptual framework and an action research program*. Ontario: Ontario Quality of Working Life Centre
- Clegg, C.W. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*, 463-477.
- Cherns, A. (1976). The principles of sociotechnical design. *Human Relations, 29*, 783-792.
- Cherns, A. (1987). Principles of Sociotechnical Design Revisited. *Human Relations, 40*, 153-161.
- Mumford, E. (2006). The story of socio-technical design: reflections on its successes, failures and potential. *Information Systems Journal, 16*, 317-342.

Values	Process principles	Content principles
- Humans as assets - Technology as a tool to assist humans - Promote quality of life - Respect for individual differences - Responsibility to all stakeholders	- Adoption of agreed values & purposes - Provision of resources & support - Adoption of appropriate design process - Design & planning for the transition period - Documentation of how design choices constrain subsequent choices - User participation - Constraints are questioned - Representation of interconnectedness of system elements - Joint design of social & technical elements - Multidisciplinary participation & learning - Political debate - Design driven by good solutions - Iteration & planning for ongoing evaluation and re-design	- Tasks are allocated appropriately between & amongst humans & technology - Useful, meaningful and whole tasks are designed - Boundary locations are appropriate - Boundaries are managed - Problems are controlled at their source - Design incorporates the needs of the business, users & managers - Intimate units & environments are designed - Design is appropriate to the particular context - Adaptability is achieved through multifunctionalism - System elements are congruent - Means for undertaking tasks are flexibly specified - Authority and responsibility are allocated appropriately - Adaptability is achieved through flexible structures and mechanisms - Information is provided where action is needed

About design

This toolkit adopts a human-centred design approach. Both CWA and the sociotechnical systems perspective place humans at the centre of the design process. Human-centred (or user-centred) design focusses design activity on understanding the needs and preferences of users, as well as their limitations, and designing to suit these. The International Standard for user-centred design for computer-based interaction systems incorporates the following principles (which could also be usefully applied beyond computer-based systems):

- The design is based on an explicit understanding of users, tasks and environments
- Users are involved throughout design and development
- The design is driven and refined by user-centred evaluation
- The design process is iterative
- The design addresses the whole user experience
- The design team includes multidisciplinary skills and perspectives

These principles align well with the sociotechnical systems approach and are supported within the toolkit.

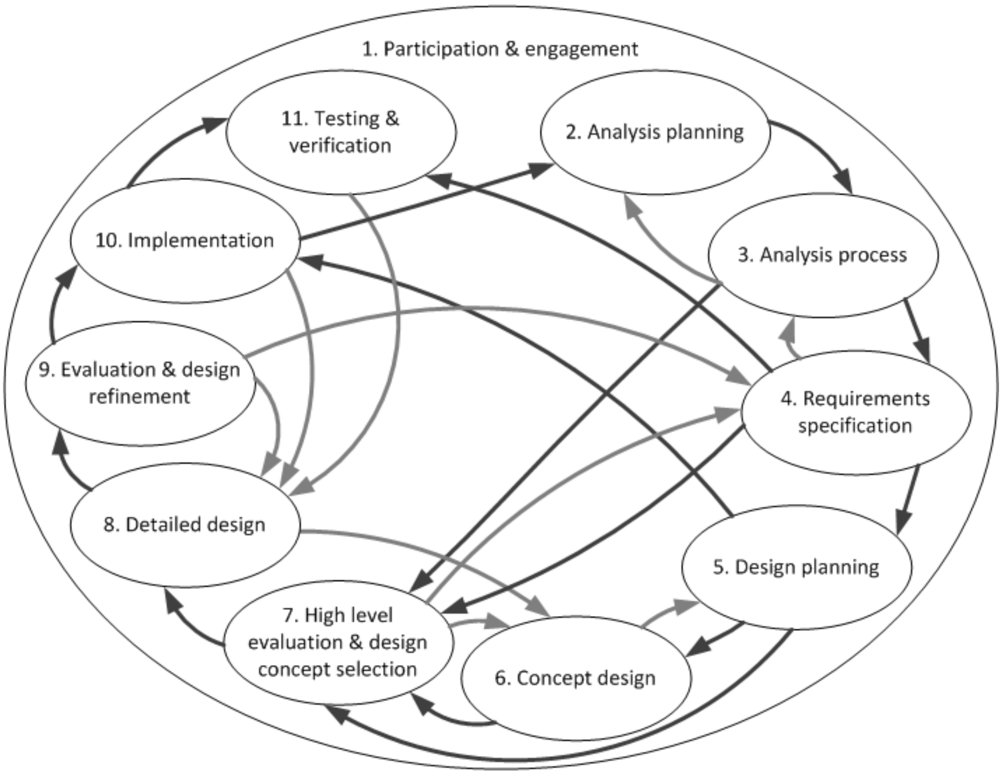
Further reading about human-centred design

- ISO 9241-2010: 010 – *Human Centred Design for Interactive Systems*.
- IDEO. (2009). *Human Centered Design Toolkit Second Edition*. Available to download from: www.ideo.com/work/human-centered-design-toolkit.

Structure of the CWA Design Toolkit

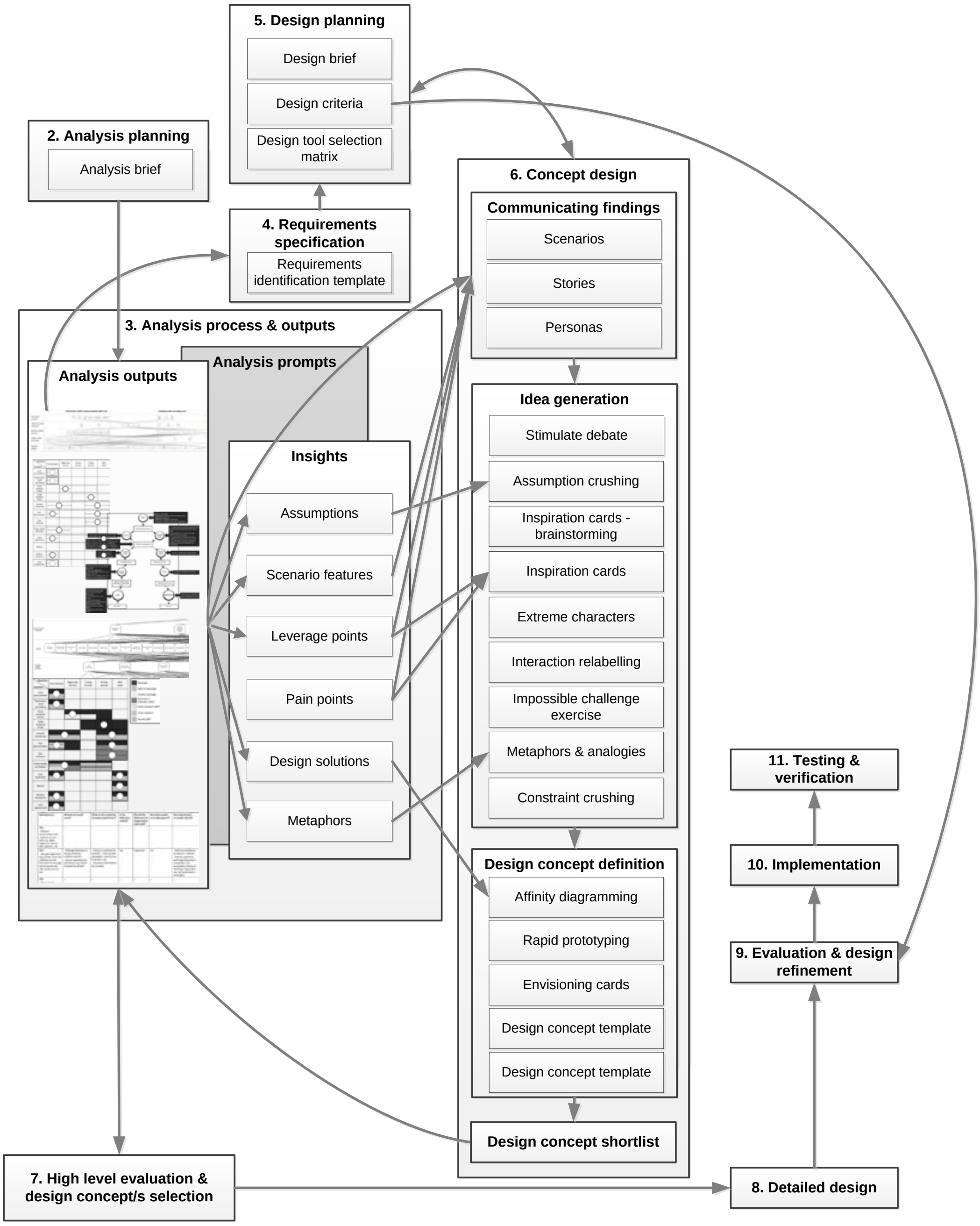
This toolkit provides guidance, templates and tools for 11 steps associated with CWA-based design. The steps are numbered but as the example arrows in the diagram below suggests, there should be iteration within the process. The process recognises analysis, design and evaluation as part of an iterative process of learning about the domain, considering potential changes and their impact, and improving knowledge throughout.

Further, the diagram shows that the aspect of participation and engagement, which is central to the sociotechnical systems approach and human-centred design, should permeate through the entire process.



Another way of representing the design process advocated within this toolkit is provided in the following diagram. This shows further details about the tools available in each step and how the outcomes of each step contribute to other steps.

As noted previously, you may choose to use all of the steps within the toolkit, or only the tools and templates that you think will be beneficial for your design purposes. However, the key aspects of the toolkit that should be used as a minimum are the *Analysis brief*, the application of CWA (at minimum the WDA phase), the use of the Design brief and Design criteria documentation, as well as at least one tool to communicate the findings of the research, to generate design ideas and to define design concepts.



The remainder of the toolkit is structured in relation to the 11 steps. The following sections will outline each step as well as the tools and templates available to assist in following the process.

1. Participation & engagement

The sociotechnical systems approach acknowledges that design is not a 'one-off' process that is finished when the design is implemented, but rather an extended process where users continually refine and adapt the design to suit their changing needs, or find new ways to exploit the functionality.

If it is the users and system stakeholders who will be responsible for the on-going adaptation and re-design of the system, they must have ownership throughout the design process. Ownership requires more than participation in the design process, it requires genuine engagement. Further, control over the process and decision making authority should remain with the users and stakeholders (rather than the design 'experts') as they are the ones who must live with the design in the longer term.

This toolkit envisages a workshop approach to engagement with users and stakeholders for design. However, engagement may take other forms such as a series of meetings, webinars, or other types of engagement. If using alternative types of engagement, simply adjust these materials to ensure they suit your process. Further, consider the need for engagement over the longer-term to enable design participants to learn about and embrace sociotechnical systems thinking prior to being involved in design. Mediums such as websites and newsletters enable researchers to keep in touch with research stakeholders and share findings over the course of the project.

There are some practical considerations about engaging design participants for workshops which are discussed in this section. These considerations are associated with selecting a facilitator, creating an appropriate physical and social environment for participation, involving the right participants and agreeing upon the values underlying the design process.

Bring together a diverse design team

The sociotechnical systems approach emphasises the need for multidisciplinary collaboration and learning. Therefore, your design team should be diverse. Consider bringing together HFE professionals, design professionals (i.e. industrial designers, human-computer interaction designers) and engineers as well as computer programmers, architects, urban designers, sociologists, etc. – whoever you think will add value to your project. The design team will be a core group involved throughout the entire design process, so you will also need to ensure that they can dedicate time to the project. Alternatively, subject matter experts can be called upon as needed, for example to participate in design workshops.

Selecting a facilitator

A good facilitator is vital to a successful process. The facilitator should have excellent communication skills, and be especially skilled in active and reflective listening. They need to be able to fulfil the following responsibilities:

- Focus on the process rather than the content
- Create a setting where participants are comfortable to share their views and opinions

- Encourage participants to share from their knowledge and learn from one another during the session/s
- Appropriately intervene in discussions to keep participants on track
- Identify and take action to control potential dysfunctional group behaviour (such as emotional disagreements, physical aggression / conflict, participants who withdraw from the process, participants who block others' ideas)
- Ensure all participants have the opportunity to contribute, rather than discussions being controlled by dominant individuals
- Encourage respectful debate and dissention to ensure that controversial issues are fully understood and canvassed during design
- Accurately summarise discussions and conversions to create a shared understanding
- Bring closure to the session

Preferably select someone who has extensive experience and / or training in facilitation or send one of the research team to get some training! Alternatively, you could hire an external facilitator to run particular sessions however it is important that they are briefed on the design approach and philosophy adopted.

Create an appropriate environment

An experienced facilitatorwill be aware of the environments that get the best out of people, but here are some tips that relate particularly to design. These tips take into account the physical environment as well as the social environment.

Physical environment	• Seat people at syndicate tables with 5-7 per table • Use a room with plenty of natural light (Imber, 2009) • Bring nature into the room (using pot plants, pictures, etc.) (Imber, 2009) • Use bright colours, particularly yellow to enhance creativity (Imber, 2009) • Provide diverse stimuli in the room to improve creativity (e.g. unrelated objects such as toys, pictures or posters, magazines or articles on unrelated topics, etc.) (Imber, 2009)
Social environment	• Encourage participants to define specific rules for workshops and participatory sessions (i.e. one person speaks at a time, everyone to have an opportunity to contribute, respecting one another's opinions, etc.) • Use ice-breaker exercises to assist participants to become familiar and comfortable with one another at the beginning of a session • Provide a fun activity, use jokes or screen a comedy show at the beginning of sessions to put participants in a good mood to enhance creativity (Imber, 2009) • Create intimacy and comfort between group members by providing an unexpected event at the beginning of a session (i.e. organise a fire-eater to perform or for a confederate to arrive and kidnap the facilitator) (Imber, 2009) • Create group cohesion by the facilitator engaging in unconventional behaviour (e.g. standing on the table to deliver material, providing instructions for activities on the back of T-shirts, etc.) (Jaussi & Dionne, 2003)

Involve the right participants

You may not have much choice as to who will be involved in the design process as in many situations the design participants may be selected for you by the project sponsor. However, optimally, you would gain support to involve:

- Representative end users
- Stakeholder representatives (e.g. supervisors, managers, maintainers, union representatives, regulators, etc.)
- Subject matter experts (SMEs, e.g. HFE professionals, engineers, computer programmers, lawyers, etc.)
- Professional designers

If you have the opportunity to select individuals for involvement in the process, there are certain attributes that Tim Brown from IDEO (2008) has suggested as making a good design thinker:

- Empathy: the ability to see problems from multiple perspectives
- Integrative thinking: the ability to go beyond selecting between current options and to instead create novel solutions that surpass and dramatically improve on existing alternatives
- Optimism: the belief that a new and better option than the existing is possible
- Experimentalism: the ability to be explorative in investigating the functioning of the existing system and exploring constraints in creative ways that proceed in entirely new directions
- Collaboration: the ability to work in an interdisciplinary manner and preferably having varied qualifications or experience across multiple disciplines (such as being both a psychologist and designer, or engineer and urban planner).

You could ask your project sponsor or project manager to consider these attributes when selecting who will be involved. It is also important, however, that representatives are respected by those they are representing and will represent the views of the group appropriately.

Prepare participants for a new approach

For many design participants the sociotechnical systems approach to design will be a novel approach and it may in fact conflict with the principles and underlying philosophies usually applied in that field. It is important for the research team to consider the existing design processes applied by design participants and to anticipate how they may best be introduced to the new paradigm. The stakeholder needs analysis conducted as part of the analysis planning stage can assist to consider the various beliefs and mindsets held by key stakeholders that may affect the overall process. Tools within this toolkit can assist to introduce the sociotechnical values and principles, but as a general point it is important to be sensitive in acknowledging that you are introducing a new paradigm which has a strong theoretical basis, but may be somewhat different to existing approaches.

Prepare participants for creativity

As ideas may need time to incubate, consider providing participants with activities prior to the workshop, or between workshops if they extend over multiple days, to ensure that they are able to capture design ideas that occur spontaneously outside of formal workshops. This can also engage participants outside of formal workshops could help to increase the variety of ideas generated. Participants could be provided with notebooks to take down ideas as they arise, or encouraged to take photographs of things in their everyday life that have inspired ideas or even asked to discuss the design problem with family and friends and bring their ideas to the workshop.

Adopt agreed values

For the design participants and design team to work well together, it is important to gain agreement on the values that will underpin the process. It is recommended that the values of sociotechnical systems theory be adopted; however, this would need to be negotiated with the design participants. One means to do this is to introduce the values and facilitate a process where participants discuss their relevance and provide their agreement for their use or adapt them as they see fit. The values may appear unusual to design participants, depending on their background and previous involvement in participatory design, so the facilitator may wish to spend some time to explain the sociotechnical approach and its benefits prior to introducing the values. A tool for introducing the values is provided on page 24.

Sociotechnical systems theory values	
Humans as assets	Rather than characterising humans as unpredictable, error-prone and the cause of problems in an otherwise well-designed technological system, sociotechnical systems theory acknowledges that no technical system is perfect and that people are assets as they are capable of identifying the need for change and of learning and adapting; making them effective problem solvers (Clegg 2000, Norros 2014).
Technology as a tool to assist humans	Technology should be viewed as a tool to assist people to meet their goals, rather than an end in its own right (Clegg 2000, Norros 2014). This value aims to avoid the common scenario where a technical solution is implemented as a panacea to a problem, with little or no consideration of the goals of people's work or the social system required to make the technology work within an open system (Clegg 2000). Eason (2014) suggests that the aim of technology should be to promote human adaptability and learning, rather than requiring the human to adapt to it.
Promote quality of life	This value is associated with promoting the quality of working life for employees and designing tasks which have meaning for people. It advocates that people cannot be considered as simply machines or extensions of machines (Robinson 1982). Quality work is challenging, has variety, includes scope for decision making and choice, facilitates ongoing learning, incorporates social support and recognition of people's work, has social relevance to life outside work and provides a feeling that the work leads to some sort of desirable future (Cherns 1976, Cherns 1987). Instead of humans being allocated those tasks that cannot be performed by technology, humans should only be allocated those tasks that justify the use of humans and utilises human skills and judgement. Technology should be designed to fulfil the remaining functions (Hendrick 1995).
Respect for individual differences	This value refers to the fact that people have different needs and wants. For example, some people may prefer high levels of autonomy and control in their work, while others may not. The design process should recognise and respect these differences and should aim to achieve a flexible design that incorporates different preferences, acknowledging that meeting all needs may not always be possible (Cherns 1976, Cherns 1987).
Responsibility to all stakeholders	In line with open systems principles, the effects of changes to the system on all stakeholders should be considered (Cherns 1987). Stakeholders could include end users, manufacturers, unions, industry bodies, government bodies and the wider community. Potential negative effects on these groups is broad and could include physical damage or injury to individuals (e.g. through accidents), economic loss, social harms or environmental harms (Cherns 1987). Impacts on stakeholders should be considered throughout all stages of the system lifecycle including design, construction and implementation processes, as well as system operation, maintenance and decommissioning.

Further reading about participation and engagement

- Clegg, C.W. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*, 463-477.
- Imber, A. (2009). *The creativity formula: 50 scientifically proven creativity busters for work and for life*. Caulfield: Liminal Press.
- Brown, T. (2008). Design Thinking. *Harvard Business Review (June)*, 84-92.
- Jaussi, K.S. and Dionne, S.D. (2003). Leading for creativity: The role of unconventional leader behavior. *The Leadership Quarterly, 14 (4–5)*, 475-498.

Values cards to promote discussions

Background	The importance of human values in design is emphasised in sociotechnical systems theory. Design often requires values to be traded-off and it is preferable for this to occur explicitly. Prior to beginning the design process, it is important that design participants explore their own values and those underlying the current system and how these relate to the sociotechnical approach. Once values are elicited they can be discussed and debated openly throughout the design process.
Materials	• Cards with each sociotechnical value printed on the front, and questions on the reverse side: 1. How would you describe this value to a colleague? 2. Do you believe this value is important? 3. In what way is this value currently supported in X domain? 4. In what way is this value not supported in X domain? 5. How can we incorporate this value in our session/s? • Worksheets for individual working • Whiteboard for group brainstorming
Format	Individual brainstorming followed by group discussion.
Steps	• Introduce the sociotechnical systems approach and its underpinning values • Introduce the values cards (ensure have enough duplicates for each participant) • Randomly distribute 1-2 cards to each participant (ensuring all cards are distributed) • Ask participants to answer the questions on the card/s individually • As a group, discuss each value and the key ideas raised by individual consideration of them. Record on whiteboard • Prompt for contradictions and trade-offs across the values • Document a final set of agreed values (these may incorporate changes to the original sociotechnical values)
Time requirements	Approx 1 hour
Recommended for	All design projects
Further information	Clegg, C.W. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*, 463-477. Cherns, A. (1987). Principles of Sociotechnical Design Revisited. *Human Relations, 40*, 153-161

2. Analysis planning

Introduction

Planning is important to ensure the successful completion of projects. Plans may not always be delivered exactly as they were envisaged, but they build common ground about what will occur and to manage expectations. This can be especially important if you have a large team or multiple sponsors, clients or stakeholders involved in the project. Plans should be flexible, they can and should be updated as things change during the project.

Planning for the application of CWA is important because of its status as a framework rather than a strict methodology. It is well-accepted in the literature that analysts should choose the phases and tools best suited to their purposes. Therefore, the planning process will assist you to consider which CWA phases and tools might be most useful for your project. Optimally, you would complete all five phases as each provides different perspectives on the domain. However, even within each phase there are decisions regarding the appropriate tools to use. If you are a CWA beginner, you will need to do some reading in conjunction with using the tools in this section. Some references to get you started are provided on page 44. You could also try searching the literature for CWA projects that have focussed on similar issues or has been conducted in the same domain as your project.

Context / problem analysis

If you already have good knowledge about the domain and the reason for the project commencing, you might want to consider the following questions (adapted from ISO 9241-2010: 010 – Human Centred Design for Interactive Systems) as a starting point:

- Who are the users and key stakeholders of the system?
- What are the characteristics of the users and stakeholders? (e.g. their goals and motivation, their core beliefs or mindset regarding the system or issue, their key concerns and the level of influence they have over the project. The stakeholder needs analysis template on page 27 can be used to assist with this).
- What are the key tasks undertaken in the system?
- What technology is used in the system?
- What is the environment in which tasks are undertaken? (e.g. the physical environment as well as the social and cultural environment)
- What is the background to the design process being commenced? Are there issues with the existing system? What are they?
- Are stakeholders / project sponsors expecting a revolutionary design (i.e. designing from scratch, unrestricted by existing technology) or an evolutionary design (i.e. working within the constraints imposed by previous design configurations)?

If the team cannot readily answer these questions it is suggested that some pre-planning work may be of benefit. Pre-planning activities could include reviewing key documents or speaking to the project sponsor or key stakeholders. Preliminary interviews could be conducted with one or two domain SMEs about the domain, its history, and the issues or opportunities that they believe the design should focus on.

Determine system type and appropriateness of CWA & STS

Once you know enough about the domain and the needs of its users and stakeholders, it is important to consider the appropriateness of applying CWA and the sociotechnical systems approach. CWA can be a time consuming exercise and it should be applied where there the effort expended is outweighed by the benefits to the project. CWA is particularly useful for complex systems, where normative and descriptive approaches cannot cope with the emergence and performance variability that is exhibited by the system.

Complex systems can be characterised by the following attributes (Skyttner, 2005):

- Containing a large number of elements
- Many interactions between the elements
- Attributes of the elements are not predetermined
- Interaction between elements is loosely organised
- The system is subject to behavioural influences
- The system is largely open to the environment and is affected by changes in its environment

If the system meets most or all of these attributes it is likely that CWA will add benefit to your process, especially if there are substantial risks associated with system dysfunction (i.e. safety, financial, reputational risks). If not, CWA may still be useful, but you may choose to use fewer phases (work domain analysis at least is recommended) and the amount of effort you give to ensuring the accuracy and completeness of the analysis may reflect this also.

Identify appropriate phases & analysis tools

The particular questions or areas of interest for the analysis and resulting design will be different for different projects. As CWA can be used to address many design problems, we have identified a range of areas of interest for system design from the immediate physical interactions between humans, technology and the environment, to organisational design. These areas are:

1. Interface design (including information displays, alarms, etc.)
2. Function allocation
3. Job / task design
4. Team design
5. Physical environment design (including workplace layout)
6. Support materials / procedures / rules / training design
7. Management system design (including monitoring & review processes, design of policy, etc.)

Some of the tools of CWA will be more useful for certain design questions and issues than others. The analysis tool selection matrix can assist you to choose which phases and tools would be most useful. Instructions for using the matrix are found on page 28.

Stakeholder needs analysis

Stakeholder	Goals	Core beliefs / mindsets	Key concerns	Influence on the project
Government / regulators				
Company management				
Supervisors				
Technical experts				
Users / workers				
Customers				
Suppliers				
Members of public				

Analysis tool selection matrix

Step 1:

- Determine the relevance of each design question / interest for your project – highlight across the row of the relevant questions.
- Count the number of X symbols for each column representing analysis tools and write the total at the end of the column, in the final row.

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	**Design question / interest**	**Y / N**	**AH**	**DH**	**ADS**	**CAT**	**DL**	**FC**	**SAD**	**AH / ADS**	**CAT**	**DL**	**FC**	**SAD**	**SRK**
1.Interface design 1.1 Information displays	Is information needed? Why?		X		X										
	What information is required?		X		X		X								
	How can information / data be sensed?		X		X										
	When should information be displayed?					X		X							X
	Who should information be presented to?									X	X	X	X	X	
	How should information be represented?		X		X										X
	Where should information be displayed?					X	X				X				
1.2 Controls / input devices	Are control / input devices needed? Why?		X		X										
	What is to be controlled?		X		X										
	When would controls be used?					X									
	Who should use controls?										X				
	What form should controls take?		X		X	X									X

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	Design question / interest	Y / N	AH	DH	ADS	CAT	DL	FC	SAD	AH / ADS	CAT	DL	FC	SAD	SRK
	Where should controls be located?			X		X									
1.3 Alarms	Are alarms needed? Why?		X		X		X								
	What should be the subject of alarms?		X		X		X								
	When should alarms be activated?					X									
	Who should be alerted to alarm activation?										X	X			
	How should alarms be represented?		X		X	X									X
	Where should alarms be located?					X									
1.4 Products, equipment, vehicles, infrastructure	Are equipment, plant, tools, etc needed? Why?		X		X		X	X	X						
	What functionality should it have? What should it afford?		X		X										
	What level of reliability is needed?		X		X		X								
	When should it be used?					X	X								
	Who should use it?									X	X	X			
	What form should it take?														X
	Where should it be located?					X									
2. Function allocation	Is automation required? Why?							X				X			
	What should be automated?											X			
	When should automation occur?					X	X								
	Under what situations should automation take over?					X	X								
	How should the system inform the operator of the level of automation in place?														X
	Who should select the level of automation (during operations)?										X	X	X	X	

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	Design question / interest	Y / N	AH	DH	ADS	CAT	DL	FC	SAD	AH / ADS	CAT	DL	FC	SAD	SRK
	How should automation operate?						X								
	Where should automated equipment, controls, etc be located?			X		X									
3. Job / task design	Are tasks required to be performed? Why?		X		X	X	X								
	What tasks need to be performed?					X	X	X	X						
	When should tasks be performed?					X		X							
	What is the task flow?							X							
	How should tasks be scheduled?					X									
	Who will perform which tasks?										X	X	X	X	
	What skills and knowledge do operators need to have?														X
4. Team design	Is a team required? Why?					X	X								
	How can work tasks be best allocated within a team?										X	X	X	X	
	When is communication / coordination required?										X		X		
	How can workload be managed?										X				
	How many team members are required?					X									
	Where should team members be located?										X				
	Will team members be co-located or distributed?										X				
	How will team members communicate / coordinate? (e.g. verbal / non-verbal, electronic messaging, telephone, etc.)									X					

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	**Design question / interest**	**Y / N**	**AH**	**DH**	**ADS**	**CAT**	**DL**	**FC**	**SAD**	**AH / ADS**	**CAT**	**DL**	**FC**	**SAD**	**SRK**
5. Physical environment design 5.1 Workplace layout	Does the layout of the workplace need to be optimised? Why?					X		X	X						
	What is the best layout to support collaboration?										X		X	X	
	What is the best layout to support task flow?							X							
	What layout would support goals, promote good and minimise negative variability?								X						
	When should the layout be optimised?					X									
	Who should the layout be optimised for?										X	X	X	X	
	How can the layout be optimised?					X		X	X						X
	Should the layout be adjustable / flexible for different circumstances?					X									
	Where should different physical components be located?		X	X	X	X									
5.2 Environmental factors (e.g. ambient noise levels, lighting, temperature, ventilation, humidity, vibration, shelter from weather	Do environmental factors need to be optimised? Why?		X	X	X	X	X								X
	What environmental factors should be optimised?		X	X	X	X	X								X
	When should environmental factors be optimised?					X									
	Who should the environment be optimised for?										X				
	How can environmental factors be optimised?														X
	Where should environmental factors					X									

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	Design question / interest	Y / N	AH	DH	ADS	CAT	DL	FC	SAD	AH / ADS	CAT	DL	FC	SAD	SRK
conditions)	be optimised?														
6. Support materials / procedures / rules / training design 6.1 Rules & procedures	Are procedures required? Why?		X		X										
	What should procedures cover?						X	X	X						
	When should procedures be relevant (i.e. in what situations)?					X		X	X						
	Who should be subject to procedures?										X				
	How should procedural information be presented?		X		X										X
	Where should procedures be accessible?					X									
6.2 Training	Is training required? Why?														X
	What should be trained?		X		X		X	X	X						X
	What knowledge is required?		X		X		X								X
	What technical skills are required?						X	X							X
	What non-technical skills are required?						X		X						X
	When should training occur?					X									X
	Who should be trained in what?									X	X	X	X	X	
	How often should refresher training be delivered?														X
	How should training be delivered?		X		X										X
	Where should training be delivered?		X		X										X
7. Management system design[1]	Are staff required? Why?									X	X	X			
	What selection criteria should be used?														X
	When should recruitment occur?										X				

[1] Requires CWA to be conducted with a focus on the organisational level of the system

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	Design question / interest	Y / N	AH	DH	ADS	CAT	DL	FC	SAD	AH / ADS	CAT	DL	FC	SAD	SRK
7.1 Staffing	Who should conduct recruitment?														X
	How should recruitment occur?						X	X	X						
	Where should information about recruitment be available?					X									
7.2 Business planning / asset management	Is budget allocation required? Why?		X		X										
	What assets and activities should be considered for funding?		X		X										
	When should planning occur?					X									
	Who should be involved in the budget allocation process?									X					X
	How should budgets and funds be allocated?		X		X	X									
	Where should information about business planning / asset management be accessible?					X									
7.3 Communication & consultation	Is communication required? Why?									X	X				
	What should be communicated?									X	X				
	When should communication occur?					X									
	Who is the audience of the communication?									X	X				
	How should communication be delivered?									X					X
	How should management communicate & consult with employees?									X					X
	How should communication / collaboration occur across teams & the organisation?									X	X				X

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	Design question / interest	Y / N	AH	DH	ADS	CAT	DL	FC	SAD	AH / ADS	CAT	DL	FC	SAD	SRK
	Where should communication materials be accessible?									X	X				
7.4 Monitoring & review	Are monitoring and review processes required? Why?		X		X										
	What should be monitored and reviewed?		X		X										
	When should monitoring occur?					X									
	What performance measures / indicators are most appropriate?		X		X										
	What data should be reported and analysed?		X		X										
	What should be investigated and how?		X		X		X								
	Who should be involved in the monitoring process?									X					X
	How should the monitoring be conducted?							X	X						
	Where should information about the results of monitoring and reviews be accessible?									X	X				
7.5 Organisation structure design	Does the structure of the organisation need to be optimised? Why?		X		X										
	What organisational structure would be most effective?									X	X				
	When should the structure be implemented?					X		X							
	Who should be involved in determining the structure?										X				X
	How should the structure be						X	X	X						

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	Design question / interest	Y / N	AH	DH	ADS	CAT	DL	FC	SAD	AH / ADS	CAT	DL	FC	SAD	SRK
	determined?														
	Where should information about the organisation design be accessible?									X	X				
7.6 Policy	Are policies required? Why?		X		X										
	What should be the subject of policy?		X		X		X								X
	What reward and discipline structures would be most effective?		X		X				X						X
	What processes should be used to prioritise research and development activities?						X	X	X						
	When should policies be relevant (i.e. in what situations)					X									
	Who should be involved in policy development?									X	X				
	How should policies be developed?							X	X						
	Where should policies be accessible?									X	X				
7.7 Risk management	Do risks need to be managed in this context? Why?		X		X										
	What risks & hazards are associated with the operations?					X	X	X	X			X		X	X
	What potential unexpected interactions are possible between system components?		X		X				X					X	
	When should each risk be controlled?					X									
	How should risks be prioritised?		X		X										
	Who should be involved in the risk management process?									X	X	X	X	X	X

		Relevant?	WDA			ConTA		SA		SOCA					WCA
Category	**Design question / interest**	**Y / N**	**AH**	**DH**	**ADS**	**CAT**	**DL**	**FC**	**SAD**	**AH / ADS**	**CAT**	**DL**	**FC**	**SAD**	**SRK**
	Who is responsible for controlling risks?									X	X	X	X	X	X
	How should risks be controlled?		X		X										
	Where should information about risks be accessible?									X	X				
7.8 Interface management (interface with other organisations / departments)	Is interface management required? Why?		X		X										
	What interfaces should be managed?		X		X					X					
	When should interfaces be managed?					X									
	Who should be involved in the interface management process?									X					
	What activities affect, or are affected by, other stakeholders										X	X	X	X	
	How should interfaces be managed?						X	X	X						
	How should management communicate & consult with others? (clients, customers, public)		X		X										X
	Where should information about interface agreements / management be accessible?									X	X				
		TOTAL													

Step 2:

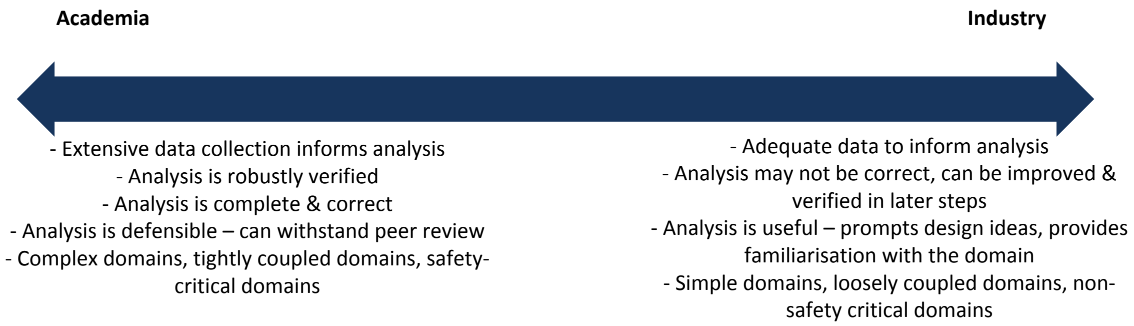
- Transpose the total score from each column to the fifth column in the following table.
- Consider the general recommendation, resource requirements and total score for each tool.
- Consider the importance of each tool for your analysis purposes, taking into account any resource constraints. Document comments or considerations leading to a decision.
- Document decision to use the tool, to not use the tool, or to consider further during the analysis and design processes.

Phase	Tool	General recommendation	Resource requirements	Total score from Step 1	Comments / considerations	Use tool? (Y/N/maybe)
Work domain analysis	Abstraction hierarchy (AH)	Recommended for all analysis purposes	High			
	Part-whole decomposition	Recommended where complex technical system	High			
	Abstraction-decomposition space (ADS)	Recommended where part-whole decomposition completed	Low (assuming abstraction & decomposition hierarchies already developed)			
Control task analysis	Contextual activity template (CAT)	Recommended for all analysis purposes	Medium			
	Decision ladder	Recommended for all analysis purposes	High			
Strategies analysis	Information flow chart	Recommended for interface design & detailed design	Medium			
	Strategies analysis diagram (SAD)	Recommended for concept design	High			
Social organisation & cooperation	SOCA – AH / ADS	Recommended for analysing actor responsibilities at a high level	Low			

analysis (SOCA)	SOCA – CAT	Recommended for analysing actors in relation to situations	Low			
	SOCA – Decision ladder/s	Recommended for analysing actors in relation to decision making requirements	Medium			
	SOCA – Flow charts	Recommended for interface design & detailed design	Medium			
	SOCA – SAD flowcharts	Recommended for concept design	High			
Worker competenc-ies analysis	Skills, rules, knowledge taxonomy	Recommended for detailed design	Medium			

Identify required resources & support

The analysis tool selection matrix provides only a basic estimate of time requirements for each CWA tool. Once the tools are identified, the project team should consider what approach will be taken to conduct the analysis. For example, is it important that the analyst/s is able to publish the results in peer reviewed journals? Or is it more important to move through the initial analysis step efficiently, and to continually update and verify the outputs as the design process progresses. There are no right or wrong answers. It will depend upon the setting in which CWA is being used, the requirements and concerns of project sponsors or stakeholders (as identified in the stakeholder analysis template), the domain within which design occurs, etc. The diagram below shows a continuum between an approach that may more likely be adopted in an academic setting (although not necessarily so) and an approach that may be adopted in an industry setting. It is important for the design team to consider where they fit on this continuum in the planning phases of the project and to consider what resources are required (e.g. number of analysts, time requirements, technical / software requirements, access to SMEs, etc.).



Complete the analysis brief

Now that the context has been explored, the analysis tools have been selected and analysis approach has been considered, the *Analysis brief* (page 40) can be completed. This document is intended to provide an agreed approach to the analysis activities. In the template, the grey italic text provides guidance for what to include in each section.

The project team should agree upon the content of the analysis brief and may choose to have it endorsed or approved by the project sponsor or client. The analysis brief should not, however, constrain the analysis process if discoveries are made that change the direction of the process or suggest that benefits may be gained from the addition of other tools. The brief may be used as a 'living document' throughout the analysis step and indeed throughout your design process.

Further, the project team may choose to supplement the analysis brief with additional project management tools such as project schedules, depending on the size and scope of the project. Project schedules should provide sufficient time to enable iteration during the analysis process, rather than assuming that once a phase of analysis is conducted, that it has been completed.

Analysis brief

Issue / need	*Provide some background to the project and its rationale.*
Deliverable / product	*Document the expected deliverable of the overall project (e.g. a new design for X domain that addresses X need). Additional deliverables might be a report into the process, academic papers, a thesis, CWA outputs that can be used for future purposes, etc.*
Stakeholders & target users	*Identify the key stakeholders and target users and summarise their needs (this information can be taken from the stakeholder needs analysis template).*
Aspects of expertise or cognition to be revealed	*Document any particular areas of HFE interest central to the project (e.g. what information is best presented to users to deal with X situation, etc).*
Research settings / situations	*In what settings will data be collected (e.g. naturalistic observations in the workplace, simulator studies to replicate abnormal situations) and in what settings will CWA be applied (e.g. by a co-located team with a dedicated space for working, or a distributed team who will use technology to collaborate).*
Proposed CWA phases & tools	*Document the CWA phases & tools to be applied (based upon the outcomes of using the Analysis tool selection matrix)*
Project dependencies & constraints	*Does this work depend on other projects or matters, how will this be managed? Further, document constraints relating to time and resources.*
Project planning & resources required	*Document the activities or steps that are required for the analysis process (e.g. data collection activities, CWA application, analysis review activities, etc), as well as the resources required (e.g. the project team allocated to this project for three months, software for supporting the CWA analysis, travel costs for data collection, etc).*

Further reading about CWA to assist with analysis planning

- Vicente, K.J. (1999). *Cognitive work analysis: Toward safe, productive, and healthy computer-based work*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Jenkins, D.P., Stanton, N.A. Salmon, P. M., & Walker, G. H. (2009). *Cognitive work analysis: Coping with complexity*. Surrey: Ashgate.
- Sanderson, P.M. (2003). Cognitive Work Analysis. In Carroll, J. ed. *HCI Models, Theories, and Frameworks: Toward an Interdisciplinary Science.* New York: Morgan-Kaufmann.
- Naikar, N. (2013). *Work domain analysis: Concepts, guidelines and cases*. Boca Raton, FL: Taylor & Francis Group.
- Lintern, G. (2009). *Foundations and pragmatics of cognitive work analysis: A Systematic approach to design of large-scale information systems*. Available to download from: www.CognitiveSystemsDesign.net

3. Analysis process

Introduction

In this step, you will be applying CWA to the domain in which you are designing. This toolkit does not intend to replace the existing guidance available on how to use the CWA phases and tools, but it aims to point you to such guidance. If you are an experienced CWA user, you might prefer to skip through to 'Documenting insights' on page 45.

Conducting the analysis

There are a number of texts and examples in the published literature of the application of different CWA tools to different domains. Some key references and examples are provided in the table on page 44. These sources provide guidance on how to work through the phases and apply the tools of CWA. It is important to read text such as Vicente (1999) and Naikar (2014) to understand the theoretical and philosophical approaches, as well as guidance for the tools, but you may find examples of the application of the tools in the literature provide further guidance. Lintern (2009) also provides a very accessible introduction to CWA and practical guidance to conducting the phases. You may find some differences in terminology and tools across the different sources. We have generally adopted the terminology of Vicente, adapted in some cases by Naikar and other authors. You may choose to adopt different terminology, methods and tools however it is important that the underlying philosophy of CWA is retained.

Generally, it is suggested that your analysis would be performed on the current or existing system. However, because the design of the current system influences the way in which the system functions, it is important to focus on the invariant constraints of the system which provide a boundary within which actors can operate. This includes ensuring that the analysis captures not just how the system currently functions, but how it could potentially function. This is referred to in the CWA literature as taking a formative perspective. For example, in the contextual activity template (CAT) it is possible to model what functions are typically performed in each situation as well as what functions *could* be performed. When the CAT is used in the social organisation and cooperation analysis (SOCA) phase of CWA, it enables the identification of which actors currently perform functions within situations, as well as which actors *could* perform each function. These aspects of the analysis provide insights that can lead to revolutionary design ideas, rather than evolutionary changes or 'tweaks' to the existing design. However, if evolutionary design is your goal, then you analysis approach would focus in on what can be done within the constraints imposed by the current design.

There are some examples of the application of CWA to first-of-a-kind systems, that is, systems that have not previously existed (therefore there is no existing system to analyse). In such cases, CWA provides a powerful approach for exploring the goals and constraints of such systems. See Sanderson (2003) and Naikar and colleagues (2003) for a discussion of the use of CWA for such systems.

Phase & tool	Key references & some examples
Work domain analysis	
Abstraction hierarchy	• Naikar (2014) • Jenkins, Stanton, Salmon & Walker (2009) • Vicente (1999) • Hajdukiewicz, Burns, Vicente & Eggleston (1999) (for intentional domains) • Lintern (2009)
Part-whole decomposition	• Naikar (2014) • Vicente (1999) • Lintern (2009)
Abstraction-decomposition space	• Naikar (2014) • Vicente (1999) • Lintern (2009)
Control task analysis	
Contextual activity template	• Naikar, Moylan & Pearce (2006) • Jenkins, Stanton, Salmon & Walker (2009) • Stanton, McIlroy, Harvey, Blainey, Hickford, Preston, & Ryan (2013) • Lintern (2009) (terminology of Work Task Docket)
Decision ladder	• Elix & Naikar (2008) • Jenkins, Stanton, Salmon & Walker (2009) • Lintern (2009) • McIlroy & Stanton (2011) • Stanton & Bessell (2014)
Strategies analysis	
Information flow chart	• Jenkins, Stanton, Salmon & Walker (2009) • Stanton & Bessell (2014) • Cornelissen, Salmon & Young, 2012
Strategies analysis diagram	• Cornelissen, Salmon, McClure & Stanton (2013) • Cornelissen, Salmon, Jenkins & Lenne (2012)
Social organisation & cooperation analysis	
SOCA – AH / ADS	• Jenkins, Stanton, Salmon & Walker (2009) • McIlroy & Stanton (2011) • Vicente (1999)
SOCA – CAT	• Jenkins, Stanton, Salmon & Walker (2009) • McIlroy & Stanton (2011) • Stanton & Bessell (2014) • Stanton, McIlroy, Harvey, Blainey, Hickford, Preston, & Ryan (2013)
SOCA – Decision ladder/s	• Jenkins, Stanton, Salmon & Walker (2009) • Stanton & Bessell (2014) • Vicente (1999)
SOCA – Information flow charts	• Jenkins, Stanton, Salmon & Walker (2009) • Stanton & Bessell (2014)
SOCA – SAD flowcharts	• Cornelissen, Salmon, McClure & Stanton (2013)
Worker competencies analysis	
Skills, rules, knowledge taxonomy	• Kilgore, St-Cyr & Jamieson (2009) • McIlroy & Stanton (2011) • Stanton & Bessell (2014)

The analysis process should be somewhat explorative and you may find it takes some time to determine the best way to apply the tools to your domain and issue of focus. There may also be a number of iterations of the analysis before you feel it is complete or you have enough to continue on to the design steps. It is important to remember that as you go through this process you are gaining important knowledge and insight about the domain and how it functions. Consequently, even where an iteration of the analysis is found to not be correct or complete, it may still have provided an important contribution to your project. Guidance for documenting insights is provided later in this section.

Documenting the analysis

There are software tools available to assist in conducting the analysis. One is discussed by Jenkins and colleagues (2009) and can be obtained by contacting the developers (https://www.defencehumancapability.com/HFIDTCLegacy/CWAHome/TheCWATool.aspx).

The analyst/s should decide upon a versioning system to assist in the tracking of versions of the CWA outputs. Some software tools may do this automatically. It is a worthwhile effort as it will enable the team to return to previous versions if it is found that a particular way of progressing the analysis has not been successful.

Documenting insights

The purpose of documenting the insights as the analysis progresses is to capture thoughts and ideas as they arise. The insights can then be shared amongst an analysis team and can be used to input to the design process and workshop materials.

The *Analysis insights template* (see page 48) can be used for documenting insights. The following sections outline how you might use the template.

Describe the insight

Insights include both non-obvious inferences from the evidence provided in the analysis as well as more obvious findings about the system that the analyst considers an important contribution to the design process. The term is used broadly here and can include anything that the analyst feels could be useful for the design process. The insight description can be quite short (i.e. a single sentence) but should be clear enough to be understood by others in the project team.

Type of insight

Six types of insights categories have been identified and are presented in the table below. It is suggested that analysts categorise their insights according to these. However, additional categories should be proposed if the insight doesn't align with the current categories.

In some cases an insight could be viewed from different perspectives – i.e. an identified pain point could have an obvious design solution. In these cases multiple categories can be selected, or the analyst can choose the most relevant category.

Insight type	Description
Assumption	Assumptions relate to the underlying hypotheses, expectations and beliefs upon which the system, or part of the system is based. These assumptions could be about the way the system functions or how people are expected to behave within the system. Assumptions could be correct or incorrect.
Leverage point	An aspect within a system which if changed in a small way, could produce big changes across the system. There may be evidence within the analysis that suggests there is a leverage point that is under-utilised or an aspect of the system could be identified as a potential leverage point.
Metaphor	Metaphors and analogies are often used in design as they promote thinking about how to apply existing ideas in new situations. Metaphor involves the comparison, interaction or substitution of two subjects on a symbolic level. An insight might involve, for example, realising that there are similarities in two domains (i.e. scheduling in manufacturing and health care) or that something in the natural environment is similar to what is trying to be achieved through technology (i.e. aircraft wing and birds wing).
Scenario feature	The data collection and analysis activities will include rich contextual information about the domain being analysed. The intention of this insight is to capture the key features that the analyst thinks would be important to communicate in the design process or to ensure is considered in the design process. A feature of a potential scenario could include a type of actor, attributes of an actor, a type of task, an environmental disturbance or influence, etc.
Pain point	Pain points are problems or issues that are identified during the analysis. They may be points of frustration for users, conflicting goals between users or problems such as information bottlenecks in organisational systems.
Design solution	A proposed design or feature of a design identified by the analyst, by research participants, or reviewers. The solution does not have to be a well-developed idea to be documented.

How did it arise?

To provide a way to trace insights and any subsequent design activities back to the analysis activities it is important to document where the insight came from. Insights may come directly from the CWA outputs (i.e. the way that values and priority measures are traded off in the system may suggest an assumption), or they may arise from data collection activities (i.e. a participant might suggest a design solution). Further, insights may come from the overall knowledge the analyst has gained of the system through conducting the analysis.

As far as possible it would be useful if the analyst could document which CWA output/s related to the insight, any relevant constraints identified in the output/s, and details about their thought process as much as possible. If version numbers are used to track the analysis that would also be useful to include as the outputs are likely to change as the analysis proceeds.

Date of documentation

For general tracking purposes it is suggested that the date of the insight be recorded.

Who was involved in developing the insight?

Again for tracking purposes it is useful to know which analyst/s was involved in developing the insight. This is especially useful if separate documents are merged and there is a need to contact the team member to clarify the meaning of an insight.

How could it be incorporated in the design process?

This column of the table provides an opportunity for the analyst to suggest how they envisage the insight being used in the design process. For example, if the analysis is being conducted in the healthcare domain, a metaphor might be suggested around how scheduling is done in manufacturing. The analyst might suggest that an SME on manufacturing be invited to present on the processes used in that domain, followed by brainstorming on how this might translate to healthcare. This column is optional but any ideas will be useful for the designing planning process.

Insight examples from a transport ticketing system case study

- *Assumption*: The system is designed on the assumption that users do not want to pay and are not trusted to voluntarily comply with regulations
- *Leverage point*: Most functions occur at the beginning of a journey, with no functions occurring during the journey. The design could enable use of journey time to perform functions.
- *Metaphor*: Airlines provide facilities for passengers to check-in prior to arrival at the airport. Potentially there could be an option for early validation of a ticket.
- *Scenario feature*: Poor weather conditions – heavy rain and wind.
- *Design solution*: Enable people who no longer require their smartcard balance for travel (i.e. are moving overseas) to transfer it to assist others who have difficulty affording public transport travel.

Analysis insights template

Insight no.	Describe the insight	Type of insight *(Assumption, Leverage point, Metaphor, Scenario feature, Pain point, Design solution)*	How did it arise? *(phase of analysis, thought process, etc)*	Date of documentation	Who was involved in developing the insight?	How could it be incorporated in the design process?
1						
2						
3						
4						
5						
6						
7						

Identifying key constraints

As noted already, a key benefit of CWA is that it identifies the constraints of the system. Constraints are limits on behaviour. They represent the boundary between possible or acceptable behaviours and impossible or unacceptable behaviours (Naikar 2013). The representation tools of CWA, however, do not however, provide any summary of the constraints. By documenting the key constraints in a structured manner, such as by using the constraints template, we have a list which can be used in later design activities (e.g. the constraints crushing exercise).

The key constraints are ones that appear to have most influence. From the work domain analysis it might be laws or rules from the values and priority measures level of abstraction, or it might be some physical constraint, such as a barrier, that is most influential on behaviour.

What is a key constraint will be up to analyst judgement, based on the knowledge they have gained from conducting the CWA. You can choose to document as many as you wish, but it is expected there would be 2-3 key constraints for each function, from each tool used.

To assist in thinking about and documenting constraints, it is worth discussing the two types of constraints. The first type are causal constraints. These have their basis in physical or natural law. They can be regarded as hard constraints because they cannot be violated (Burns, Bryant & Chalmers, 2005). Hard constraints should be documented in the constraints template as 'actors cannot…' Intentional constraints stem from social laws, conventions or values. They can be regarded as soft constraints because they can be violated, although it would be socially unacceptable to do so (Burns, Bryant & Chalmers, 2005). Soft constraints should be documented as 'actors aren't supposed to…' In revolutionary design project, you might choose to focus on changing hard constraints, whereas if evolutionary design is the goal, you might look at changes to soft constraints, which will invariably be a cheaper and easier innovation to implement.

Constraints template

	Work domain analysis	Control task analysis (CAT)	Control task analysis (DL)	Strategies analysis	Social organisation & cooperation analysis	Worker competencies analysis
Function 1:						
Function 2:						
Function 3:						
Function 4:						
Function 5:						
Function 6:						

50

Identifying stakeholder object worlds

One of the tools of CWA that has not been taken up widely since proposed by Rasmussen and colleagues (1990) is the idea of stakeholder object worlds. This is a way to represent, based on the work domain analysis, how different stakeholders view the same (objective) world / domain (Naikar, 2013). For example, Burns and Vicente (2000) found that in the design of panels for a control room, various stakeholders involved in the design process had different objectives and were concerned with different process associated with the physical objects. For example, members of the ergonomics design team were concerned with meeting the objectives of visibility and operability of controls, while members of the structural design team were concerned with strength and stability. Differently again, upper management was concerned with market share, and delivery on time and on budget. So within the one work domain, there are many views and perspectives that can be captured.

Having completed a work domain analysis, this provides a good opportunity to expand upon the understanding of system stakeholders (i.e. beyond the original *Stakeholder needs analysis* completed in the Analysis Planning step). It also ensures that the design team is aware of the system constraints associated not only with operation or use of the system, but also with maintenance, management, etc. The *Stakeholder object world* template can assist to identify the unique object worlds of the various system stakeholders. Any insights arising should be documented for use in the design process.

Stakeholder object world template

Abstraction dimension	Government / regulators	Company management	Supervisors	Technical experts	Users / workers	Customers	Suppliers	Members of public
Functional purpose								
Values & priority measures								
Purpose-related functions								
Object-related processes								
Physical objects								

Analysis review

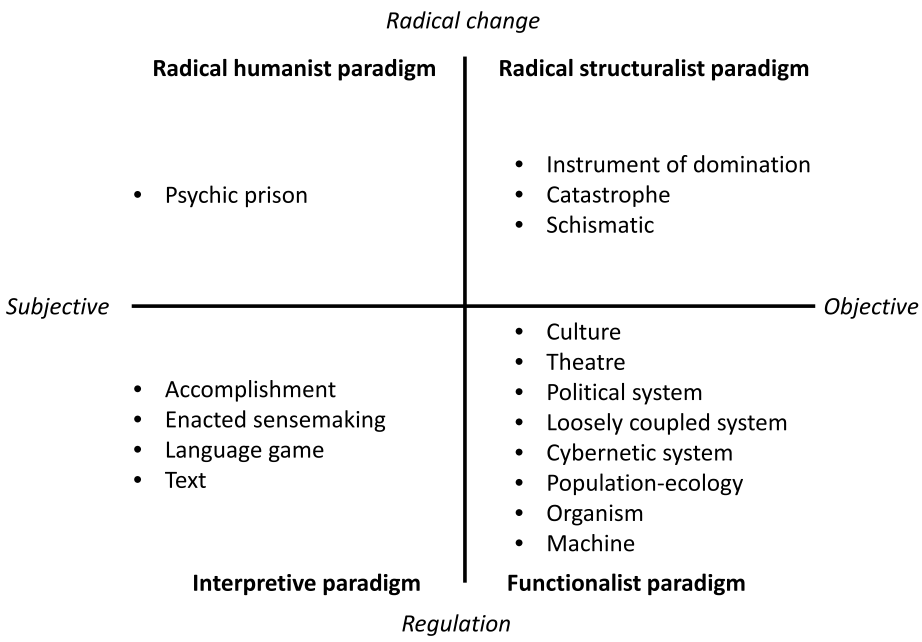
As noted in the *Analysis planning step*, different projects will require different levels of analysis review. It is recommended that there is at least one review is undertaken by an analyst who did not participate directly in the analysis process (preferably a CWA expert) as well as review by SMEs who did not participate directly in the analysis process. The extent of this review will differ between projects. A workshop-style review, where the analyst/s introduces their analysis outputs and the rationale for decisions, followed by a structured process of gaining feedback is recommended. Such a process could, for example, include the following questions (for a work domain analysis):

- Please review the physical objects we have identified.
- Have we used appropriate terminology for the physical objects? Would you change any of the terminology?
- What physical objects are missing?
- What physical objects should be removed from the WDA?

If a more rigorous validation of the analysis outputs is required, Naikar (2013) provides guidance for the validation of the WDA which involves testing that the model appropriately represents the reasoning processes undertaken by workers / users of the domain.

Prompting for insights

Insights will be generated during the analysis process however further insights may be gained through the use of prompts to apply to the final analysis outputs. In this toolkit, two sets of prompts are provided: CWA prompts (Appendix A) and Organisational metaphor prompts (Appendix B). These are intended to provide a comprehensive consideration of the functioning of the system from reviewing each tool within the CWA phases, as well as considering different metaphors through which organisational (or system) functioning can be viewed. They draw on a discussed by Morgan (1980). The organisational metaphors are shown in the diagram (adapted from Morgan, 1980). They are grouped according to the extent to which they align with views of the need to control and regulate systems versus openness to radical change. They also vary with the extent to which they are align with objective views of a system (i.e. the idea that there is one true and correct description of the system) or subjective views (i.e. that there are multiple interpretations of the system, all of which are valid and useful). While CWA and the sociotechnical approach would generally fit within the bottom right hand quadrant of the diagram, aspects of the approaches are relevant to the other types of metaphors. For example, the stakeholder object worlds consider the subjective perspectives of different actors in the system.



The insight prompting process is best done as a group, preferably involving both the project team and users or key stakeholders who may not have been involved in developing and / or reviewing the outputs. Applying the CWA prompts can be a good way for those who were not involved in the analysis to interrogate the CWA outputs and gain comprehensive knowledge about the purposes and constraints of the domain. It can assist to promote a shared understanding of the analysis outputs as well as the insights gained from them.

With the CWA prompts, the project team would only consider those related to the CWA tools used in the analysis process. With the organisational metaphor prompts, the team may decide to select particular metaphors to be applied (i.e. those that are most different to the current ways the system is seen) or they may choose the metaphors at random. There are two formats for using the organisational metaphor prompts. The first is as a table (Appendix B), and the second enables you to print / copy them onto thick paper (double-sided) and cut them out to use as cards (Appendix C). This enables random selection from the pack or some other interactive method of using them such as each team member selecting a card and facilitating the rest of the group through that metaphor.

Review & refine insights

By the conclusion of the analysis process, you are likely to have recorded a large number of design insights. The long list may seem unwieldy, and you may wonder which are the most important to take forward into the design process. Processes such as affinity diagramming can assist to categorise the insights into themes. It is recommended that this be done in a group process involving the design team as well as any users or key stakeholders who might be participating in later design processes. A good way to do this would be to post-it notes or cards with an individual insight or each. If you are using cards you could lay them out on a large table, post-it notes could be stuck onto a large wall area. Ask the team to work together to group the insights into themes. These themes will emerge during the process and do not need to be pre-defined. However, it would be beneficial if the person facilitating the process has thoroughly read through the insights and has considered some initial themes that could be used to get the group started, if necessary.

This will be an iterative process with multiple cuts of the themes undertaken. For example, after the first categorisation consider themes with large amounts of insights and ask if this would be better split into multiple themes. You may also find that something originally expressed as a pain point would be better expressed as a leverage point or design solution. Once you have a refined set of insights, these can be prioritised by asking the group to rank the insights in order of most importance / use within each type (e.g. rank the assumptions, rank the pain points, rank the metaphors, etc.). The team would discuss and decide what is most important in terms of the insights. However, for most design projects it would be beneficial to prioritise those insights that have the most potential to promote innovation so would be those that are most challenging or questioning of the existing design of the system, while still being relevant and useful.

Further reading

- Jenkins, D. P., Stanton, N. A., Salmon, P. M., & Walker, G. H. (2009). *Cognitive work analysis: Coping with complexity*. Surrey: Ashgate Publishing Ltd.
- Vicente, K. J. (1999). *Cognitive work analysis: Toward safe, productive, and healthy computer-based work*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Naikar, N. (2013). *Work domain analysis: Concepts, guidelines and cases*. Boca Raton, FL: Taylor and Francis Group.
- Rasmussen, J., Pejtersen, A.M., & Schmidt, K. (1990). *Taxonomy for cognitive work analysis*. Roskilde, Denmark.
- Morgan, G. (1980). Paradigms, metaphors and puzzle solving in organization theory. *Administrative Science Quarterly, 25*, 605-622.

4. Requirements specification

Introduction

Requirements are statements of need that the finished design should achieve. In many design projects, HFE specialists take the analysis products and findings that they have uncovered and use these to generate a set of user requirements. This is handed over to designers and the HFE team may have no further input. In this toolkit, it is suggested that while specifying requirements at this early stage of the design process is worthwhile, they should remain flexible. This is because further requirements will be generated within the design process as more is learned about the domain and what innovations could be possible.

Given this need for flexibility, it is recommended that at this stage, high level requirements be identified from the WDA. However, if your design process will conclude with the handing over of requirements to designers, it would be worthwhile to identify requirements from the latter phases of CWA. Examples from the literature may assist. For example, Jenkins et al (2011) describe how the decision ladder can be used to identify requirements for simulator design. Further, Naikar et al (2003) describe a process of identifying requirements for team design in a first-of-a-kind system.

A *Requirements identification template* is shown on the following page. To use the template, transpose the text from you WDA nodes into the first column. Then, if your project requires this, you may want to consider the relevance of the nodes to different stakeholders in your system, based on the stakeholder needs analysis. This would be done for key stakeholders important to your analysis (e.g. designing for a retailer who must consider requirements of customers as well as suppliers). Then document any design requirements which flow from the nodes of the WDA. In general, the new design would need to support the purpose/s identified in the WDA, support each of the functions within the WDA and support the object-related processes. There may or may not be need to include requirements around the physical objects. Not all nodes will lead to requirements. In fact, there may be nodes in the WDA for the existing system that may not be optimal. Further, requirements may relate to multiple nodes. For example, there may be multiple object-related processes which are supported by only physical object each (via the means-ends links). This may lead to a requirement that flexibility is provided by introducing multiple means of supporting critical object-related processes.

In some cases, the project team may decide to develop an 'optimal' version of the AH to assist them to determine design requirements. This could involve changing the purpose/s of the system to some ideal purpose and then considering the functions, processes and objects that could support this. The requirements identification could then be based on this optimal version.

In the final column of the template, document any comments about the nodes (e.g. a decision that the node should not have requirements associated with it). Further, if this exercise prompts further insights, document them in the final column and also in the insights template. Consider, with the project team whether these new insights should form part of the prioritised list of insights.

Requirements identification template

Nodes from the levels of abstraction	Applies to stakeholders:		Requirement/s	Comments / insights
	X	Y		
Purpose/s				
Functions				
Object-related processes				
Physical objects				

Sociotechnical systems theory requirements

In addition to the particular requirements of the system you are designing, there are general requirements that come from sociotechnical systems theory that should be included to ensure the design is underpinned by this philosophy. These would be stated in a general manner and could be viewed as 'aspirational' requirements, but having them documented increase the likelihood that they are taken into account throughout the design process. These could be stated as follows:

- The design promotes adaptive capacity
- The design values humans as assets within the system
- The design treats technology as a tool to assist humans
- The design promotes quality of life
- The design respects individual differences
- The design demonstrates responsibility to all stakeholders

These statements could be enriched with a description of the values (e.g. see page 79).

Further reading

- Jenkins, D.P., Stanton, N.A., Salmon, P.M., & Walker, G.H. (2011). A formative approach to developing synthetic environment fidelity requirements for decision-making training. *Applied Ergonomics, 42*, 757-769.
- Naikar, N., Pearce, B., Drumm, D. & Sanderson, P.M. (2003). Designing teams for first-of-a-kind, complex systems using the initial phases of cognitive work analysis: Case study. *Human Factors, 45*, 202-217.

5. Design planning

Introduction

As with planning for the analysis process, it is worthwhile to spend some time planning how the design process will occur, who will be involved and what resources are needed to support it. A number of templates are provided to assist in ensuring the success of your design projects.

Involving the right design participants

In the *Participation and engagement* step of this toolkit some advice is provided on the selection of design team members and stakeholders who are most likely to provide benefit within the project (see from page 19). You may also wish to involve other stakeholders to take part for other reasons. For example, a very influential stakeholder might be invited to take part not because they have many of the attributes discussed on page 21, but because if they perceive a sense of contribution to the design and preferably a sense of ownership, they are more likely to advocate for its adoption in practice.

Selecting design tools

This toolkit provides a number of tools (i.e. guidance for design exercises and activities) that can be used within the design process. These have been identified from the participatory design literature. Not all tools will be relevant to all projects and as resources are often limited there is a need to select the most appropriate tools. The *Design tool selection matrix* (page 63) provides a summary of each tool and can be used to identify those that will be most useful given the time constraints associated with the project.

There are four categories of tools that can assist to engage design participants and to gain the most from their participation. The categories are:

- Communicating the analysis findings. Most relevant where there are design participants who were not involved in the analysis process.
- Creativity boosting exercises. For engaging with design participants and encouraging them to think creatively, to question the current design of the system and be open to change.
- Idea generation. An assortment of tools that use the insights gained from the analysis to generate innovative ideas.
- Design concept definition. Methods and approaches for taking the range of ideas generated by participants, selecting those most promising and creating holistic design concepts.

The individual tools under each category can be found in Appendix D. Additional activities relevant to the aims of the design process can also be considered. For example, a period of initial brainstorming at the beginning of the workshop, prior to communicating the CWA findings to participants and introducing the sociotechnical systems values and principles, can assist to draw out pre-existing ideas held by participants, including ideas that are not aligned with the sociotechnical values. In fact, holding a large group brainstorm following by introduction of the sociotechnical values provides an opportunity to discuss as a group whether each idea is consistent or not with the sociotechnical approach. The values cards (page 24) could be used as part of such an exercise.

Design tool selection matrix

Tool	Materials required	Time required	Inputs required	Outputs provided	Recommended for	Use? Y / N	Comments
Communicating the analysis findings (select at least one tool to communicate the findings)							
Personas Personas are used to develop empathy with the users and stakeholders of the system. Analysts may develop empathy through data collection activities however design participants may not experience this directly. Empathy is important for achieving designs aligning with sociotechnical values.	- Pre-prepared descriptions of different actors in the system with prompting questions - Whiteboard for recording group insights	Approx 1.5 hours	- Knowledge about different types of users - May be based on user identified during data collection activities	- Design participant engagement & empathy	All design projects (personas can also be communicated through scenarios and stories)		
Scenarios Scenarios are a commonly used design tool. They involve documenting key situations of use in narrative form. Scenarios can be used to describe typical activities or to highlight problematic activities identified during the analysis. Narrative length will depend on the level of detail needed to communicate the key points and issues, and to develop a sense of empathy with the users in the scenario.	- Pre-prepared scenarios with gaps for participants to complete - Photos / pictures / videos to enrich the scenarios - Whiteboard to record group insights	Approx 1.5 hours	- Scenario features - Pain points	- Design participant understanding of pain points, different situations - Design participant engagement & empathy	All design projects		
Stories Stories can be used for communicating information uncovered during the analysis in a concrete, specific way.	- Pre-prepared short stories collected during the analysis. The stories should be real, personal stories that highlight key information. - Photos / pictures / videos to	Approx 1 hour	- Stories documented during data collection activities	- Design participant understanding of pain points, different situations	All design projects		

Tool	Materials required	Time required	Inputs required	Outputs provided	Recommended for	Use? Y / N	Comments
	enrich the stories - Whiteboard for recording group insights			- Design participant engagement & empathy			
Creativity boosting exercises							
Impossible challenge exercise A short exercise designed to shift the brain into a lateral thinking mode by encouraging participants to generate solutions to an 'impossible challenge' that are not logical or rational.	- A pre-prepared impossible challenge scenario - Paper for recording design ideas	Approx 10 minutes	n/a	- Design participants primed for lateral thinking - Design participant engagement	Design participants not usually involved in creative design activities		
Stimulate debate Political debate is an important of the design process to ensure that potential issues are discussed openly and do not remain hidden constraining creative thinking.	- Paper / whiteboard for brainstorming	Approx 40 minutes	- Insights about potential political / controversial issues (e.g. costs, differing beliefs or worldviews of stakeholders)	- List of issues / constraints affecting the design process & implementat-ion - Ideas for potential solutions	All design projects, unless teams consider that such information will be addressed during another activity such as assumption crushing.		
Idea generation (select at least one tool for idea generation)							
Inspiration cards – brainstorming This activity involves the pre-selection of inspiration cards, relevant to the design problem as uncovered by the analysis, which are used to prompt brainstorming in relation to opportunities or leverage points identified during the analysis.	- A set of pre-selected cards considered relevant to the design problem. Cards may be drawn from existing toolkits as well as from the analysis - Sheets of paper for recording design ideas (small group work) - Whiteboard for recording	Approx 3 hours	- Leverage points - Pain points	- Design ideas	All design projects		

Tool	Materials required	Time required	Inputs required	Outputs provided	Recommended for	Use? Y / N	Comments
	design ideas (whole group)						
Inspiration cards - sorting The activity is centered on creating design ideas from combining inspiration cards in order to realise the opportunities or leverage points identified during the analysis.	- Sets of cards, each representing a single concept or idea that can be combined to form design ideas. Cards may be drawn from existing toolkits as well as from the analysis - Sheets of paper for recording design ideas along with cards - Space on wall for displaying design idea sheets	Approx 3 hours	- Leverage points - Pain points	- Design ideas	All design projects		
Using metaphors & analogies The use of metaphors and analogies in design is common. They provide a means of seeing things in a new way which can prompt new ideas and innovation	- List of aspects of the system that prompted a metaphor or analogy documented in the analysis insights template - Cards of random pictures and words to prompt metaphors and analogies - Worksheets for individual brainstorming - Paper for small group brainstorming	Approx 4 hours	- Metaphors	- Design ideas based on metaphorical thinking - Change mindsets	All design projects		
Building on strengths This activity focuses thinking away from what is wrong with the system, or problems to be solved. It instead explores the strengths of the current system and how these could be further supported.	- List of some positive features of the current system, identified during the analysis - Worksheets for individual brainstorming - Whiteboard for brainstorming	Approx 4 hours	- Positive features of system – what's working well	- Design ideas that build upon current positive aspects - Evolutionary design	All design projects, particularly those involving stakeholder groups in conflict (focus on strengths		

Tool	Materials required	Time required	Inputs required	Outputs provided	Recommended for	Use? Y / N	Comments
					promotes more positive interactions)		
Assumption crushing Assumptions include theories, beliefs or hypotheses underpinning the structure of the system and the way things are currently done. They may not be consciously realized but can unconsciously restrict the type of design ideas that are considered.	- List of 4 to 6 key assumptions - Worksheets for individual brainstorming - Whiteboard for group brainstorming	Approx 2 hours	- Assumptions	- Change mindsets - Radical / revolutionary design ideas	All design projects		
Constraint crushing CWA identifies the constraints within the system. Constraints can limit openness to innovative design solutions. Challenging constraints can prompt innovative ideas and widen the thinking of design participants regarding what is possible.	- List of 6 to 10 key constraints identified during the analysis - Worksheets for individual brainstorming - Whiteboard for group brainstorming	Approx 2 hours	- Key constraints	- Design ideas	All design projects		
Interaction relabeling The use of an unrelated product to prompt ideas about interaction with the product to be designed.	- An unrelated product or range of products - Paper / whiteboard for recording design ideas	Approx 2-3 hours	- Pain points - Leverage points - Metaphors (relating to product/s)	- Design ideas	Design projects involving interaction design – including interface design and product design.		
Extreme characters While personas and scenarios tend to be based around prototypical users, extreme characters have exaggerated emotional attitudes and goals. Exploring design concepts for extreme characters	- A description of the character including text and pictures describing their goals and activities - Paper / whiteboard for recording design ideas	2 hours to full day	- The goals of the extreme characters would be drawn from decision ladders	- Design ideas based around non-typical users / uses	Situations where users may not share the goals of the overall system or there is the possibility of		

Tool	Materials required	Time required	Inputs required	Outputs provided	Recommended for	Use? Y / N	Comments
assists to uncover undesirable or antisocial emotions or goals and expand design ideas.	- Materials to create prototypes (if prototyping chosen)				unintended use.		
Design concept definition (select at least one tool to define design concepts)							
Affinity diagramming / combinatorial play Creativity arises from the combination of previously unrelated concepts. In design, combinatorial play is the term used to describe the process of putting together ideas from diverse areas. This tool aims to prompt further creative combinations of design ideas, including the introduction of ideas recommended by previous research, by other stakeholders, or implemented elsewhere.	- Outcomes of previous idea generation activities - List of design solutions from the analysis insights - List of leverage points from the analysis insights - List of design solutions proposed in previous research or solutions implemented in other jurisdictions - Post-it notes & available wall space	Approx 4 hours	- Design ideas from previous activities - Design solutions	- More sophisticated, combined design ideas	All design projects		
Rapid prototyping (mock-ups, models, etc) Design ideas can be given form early in the design process to prompt further ideas and to test assumptions about how people will interact with the finished design. Asking small groups to develop prototypes and mock ups of design ideas provides diverse solutions of which the best aspects can be combined.	- Materials for prototyping such as paper, clay, lego, cardboard, wood, etc	Approx 4-5 hours	- Design ideas from previous activities	- Models / prototypes for exploring physical designs - Prototypes can assist in communicating design ideas to others (e.g. project sponsors)	All design projects involving a tangible user interface		
Documenting design concepts The design ideas and concepts generated by design participants need to be documented to enable them to be	- Design concept template	Approx 1 hour	- Design ideas from previous activities	Documented design concepts	All design projects		

Tool	Materials required	Time required	Inputs required	Outputs provided	Recommended for	Use? Y / N	Comments
shared. Further, a documented form of a design idea, such as a sketch, enables refinement as the designer can engage in reflection on the design artifact created. This is not possible when ideas are discussed on verbally and do not take a tangible form.							
Envisioning cards for exploring design concepts Design requires values to be traded-off and this should occur explicitly. The envisioning cards can provide a prompt for considering the implications of the design concepts identified in relation to the themes of stakeholders, time, values, and pervasiveness.	- The envisioning cards - www.envisioningcards.com - Post-it notes	Approx 1 hour	- Design concepts from previous activities	- Design participant understanding of impact on values, ethical issues - Refined design concepts	All design projects		
Refining design concepts through sociotechnical systems principles It is important to place focus on the sociotechnical systems theory principles throughout the design process. One way to do this is to assess design ideas or design concepts against the principles and make appropriate changes and refinements.	- Sociotechnical systems theory content principles evaluation sheet (see Appendix E)	Approx 1 hour	- Design concepts from previous activities	- Refined design concepts - Improved design participant understanding of the sociotechnical principles	All design projects		

Complete the design brief

The *Design brief* is a template for documenting the proposed approach for the design and for ensuring a shared understanding within the project team and between the project team and user / stakeholder representatives as well as the project sponsor. The project team may choose to have it endorsed or approved by the project sponsor or client.

The design brief template is provided on page 71 and guidance for completing the sections of the design brief is provided in grey italic text.

The design brief assists to ensure that design process is appropriate for the project and that as the design process proceeds that it is driven by the sociotechnical philosophy. It also enables clear communication about the background and purpose of the design process which assists if additional stakeholders need to be briefed as the design process proceeds.

The design brief should be a summary of the approach rather than providing a large amount of detail. For simple projects it is expected to be only 1-2 pages in length, while for more complex projects it might extend to around 4 pages. As with the analysis planning process, the project team may choose to supplement the document with additional project management tools such as detailed project schedules and budgets depending on the size and scope of the project. Project schedules should provide sufficient time to enable iteration during design and should be flexible acknowledging that it is not possible to define the entire process upfront, and that ongoing learning occurring during the design process may change the course of the planned project considerably.

Complete the design criteria document

The key measures for determining the success of the design process should be documented in the *Design criteria* template (page 73). It is good practice to define up front the criteria that will be used to measure the success of a project and design projects are no different. The design criteria would be drawn from the values and priority measures identified in the work domain analysis phase of the CWA. They should also reflect the sociotechnical systems theory content principles. That is, the design outcomes could be considered successful if they exhibit the content principles (i.e. if tasks are allocated appropriately between and amongst humans and technology). Some standard text, including the sociotechnical systems theory content principles, is provided within the template. You may wish to alter this text if it does not align with the approach being taken in your project. Guidance for completing the other sections of the design criteria document is provided in grey italic text.

The design criteria document will be revisited in the *High level design evaluation and concept selection* step (page 81) and in the *Evaluation and design refinement* step (page 91).

Organise appropriate venue & invite participants

Now that the design team has decided who will be involved, what design tools will be used, and how long the collaborative session/s need to be, there is an administrative task of organising a venue and inviting your participants. Consider the guidance provided in the Participation and engagement step (page 20) regarding the selection of an appropriate physical environment for the session. Find out what is available in the room and ensure the venue can cater to your set up needs.

In relation to inviting participants, hopefully most will already be involved with the project and will be expecting your notification. For those you might be contacting for the first time, it would be beneficial to provide them with some information about the project and what you are trying to achieve (i.e. in the form of a brochure or website page where they can gain further information about the project).

Further reading

- Liedtka, J., & Ogilvie, T. (2010). *Designing for growth: A design thinking tool kit for managers.* New York: Columbia Business School Publishing.

Design brief

Project description	*Provide some background to the project. This may be similar to that documented in the Analysis brief but it should stand alone (so that a stakeholder interested in the design component would only need to read this document)*
Analysis outcomes	*Document the key analysis outcomes (e.g. what CWA outputs were developed) and a brief summary of the key findings of the analysis.*
Scope	*Identify the scope of the design process. For example: Is it to re-design an entire system or a particular aspect? Is it to create a design that could be implemented tomorrow, or in 20 years' time? Is it about implementing low-cost, simple innovations or a revolutionary design that will have wide-ranging effects? Include the need to ensure planning for the transition period and for on-going evaluation and re-design (a sociotechnical systems design process principle).*
Design requirements	*If requirements were identified for the design (i.e. through the use of the Requirements identification template), document them here,.*
Exploration questions	*Documenting any particular avenues that the project team wish to explore during design. These may arise from the prioritised insights.*
Target users	*Identify the target users for the design process?*
Design tools	*Document the design tools that are planned to be used (based on the outcomes of applying the Design tool selection matrix).*

Expected outcomes	*Document what is expected to be produced by the design process (e.g. design concepts, engagement with users & stakeholders to promote ownership of designs, etc).*
Success metrics	*How will you know if the design process has been successful (e.g. at least X number of design concepts are produced, user & stakeholder representatives indicated satisfaction with the process, etc).*
Project planning & resources required	*Document the activities or steps that will occur (e.g. five full-day workshops will be held or the project team will be co-located with the customer service team for three months and engage with them at times convenient to team members, etc), as well as the resources required (e.g. a professional facilitator for X hours, the project team allocated to this project for three months, a workshop area with appropriate materials for prototyping and mock ups, etc).*

Design criteria

Purpose	These design criteria are identified to provide a means to evaluate and measure the potential success of the design concepts created. For further information about the project, refer to the Design Brief.
Domain-specific values & priority measures	*Document the relevant values & priorities from the work domain analysis. If necessary to link to the requirements, these may need to be described in more detail than they were in the CWA.*
Sociotechnical systems criteria	A design concept could be considered potentially successful from the sociotechnical systems theory perspective if it meets the following principles: • Tasks are allocated appropriately between and amongst humans and technology • Useful, meaningful and whole tasks are designed • Boundary locations are appropriate • Boundaries are managed • Problems are controlled at their source • Design incorporates the needs of the business, users and managers • Intimate units and environments are designed • Design is appropriate to the particular context • Adaptability is achieved through multifunctionalism • System elements are congruent • Means for undertaking tasks are flexibly specified • Authority and responsibility are allocated appropriately • Adaptability is achieved through flexible structures and mechanisms (and undesirable behavioural adaptation is avoided) • Information is provided where action is needed
Project-specific criteria for the evaluation process	*Some design projects may have specific criteria that relate to the process of evaluation and testing of designs. For example, a performance measure that the design must meet to be acceptable to the regulator, a union, a key stakeholder, etc.*
Project constraints / requirements	*Describe any constraints associated with the use of the design criteria (e.g. issues around the measurement of particular criteria, limitations of funding) or requirements associated with the measurement (e.g. a requirement for a formal cost-benefit analysis of proposed design concepts).*

6. Concept design

Introduction

The concept design stage of this toolkit is principally concerned with engaging creative and lateral thinking, within a collaborative group process to create innovative design ideas. The process begins with expanding the design space and prompting divergent thinking. There will also be some narrowing and refining of ideas and concepts in attempts to ensure that they are integrated whole concepts rather than collections of ideas, however it is intended that formal evaluation and critique is left until the later steps such as the *High level evaluation & design concept selection* step (see page 81).

As noted previously, this toolkit envisages a workshop approach to engagement with users and stakeholders for design. However, engagement may take other forms such as a series of meetings, webinars, or other types of engagement. If using alternative types of engagement, simply adjust these materials to ensure they suit your process.

Conduct additional research

In many cases, the design insights will have raised more questions than answers. This is expected, and questions will continue throughout the design process. At the point of design planning however, it would be worthwhile to set aside some time and resources to conduct some desktop research on some of the key issues raised. For example, you may review HFE literature and standards relevant to a particular design solution, to see if it has been successfully implemented previously or if standards exist to provide guidance on how it should be implemented. This provides a stronger evidence base upon which to commence the design process.

Develop workshop materials

Use of the design tools collaboratively with users and stakeholders will require some preparation and often the preparation of bespoke workshop materials.

An important resource for the facilitator is a workshop or session plan. This plan provides an outline or overview of a session or series of sessions which is important to ensure that the activities can be achieved in the time set aside and that the resources required are available. It is also a valuable resource on the day for the facilitator who can use the plan to track activities and progress. A template for a workshop plan is provided on page 77.

Other materials include handouts for personas or written scenarios, cards to support brainstorming, etc. Set aside time for creating these materials as they may require some revisions to ensure they contain appropriate information and prompt the intended type of thinking from those participating in your process. Where time and resources permit, have different members of the project team review the materials or test them out to see how they might be interpreted and where you can make improvements.

The design concept template (see page 78) would be useful for most workshops / engagement sessions. It enables design participants to document their proposed design concepts. It is suggested that a template be developed for the project and printed in A3 size or larger where possible. The template should prompts the user to document a name for the concept, to provide a drawing or sketch of the design, to describe the expected benefits in the form of design hypotheses (e.g. how it is expected that the features influence behaviour or system functioning) and identify the sociotechnical values addressed. Additional information important to the particular project could be added to prompt its consideration in the concept design stage. For example, if it is important to ensure that the design is appropriate for a range of different types of users or stakeholders these could be named on a sheet with a check box to acknowledge where designs have or have not met the needs of all. For example, if using the template in a road design context you might include a prompt to indicate whether the design would be appropriate for car drivers, cyclists, motorcyclists, pedestrians and heavy vehicle drivers. This can serve as a reminder that, while it is easy to focus on a single user type (i.e. cars), concepts need to ensure appropriate design for all users.

Where the design concepts have not met all of the criteria, they may be shortlisted lower than others, or this information may contribute to design refinement activities whereby the designs are improved until they meet or come close to meeting the criteria.

Workshop plan template

Workshop introduction	Resources required	Start time	Time allocated
•	•		
Activity A			
•	•		
Break		11:00	10 mins
Activity B			
•	•		
Lunch		12:30	60 mins
Activity C			
•	•		
Break		3:00	10 mins
Activity D			
•	•		
Workshop close			
•	•		

Design concept template

Design concept name: ____________________

Description (text & sketch):

Values addressed:
- ☐ Humans as assets
- ☐ Technology as a tool to assist humans
- ☐ Promote quality of life
- ☐ Respect for individual differences
- ☐ Responsibility to all stakeholders

Design hypothesis - how will the design lead to the outcomes desired?

Other system changes required:

Possible unintended consequences:

Deliver workshop / engagement sessions

With the planning and materials development completed, it is time to run the workshops. As noted in the *Participation and engagement* step (see page 19), it is important that the sociotechnical values are incorporated in the process of the workshops. Examples of what this might look like for each value are provided below.

Value	Examples
Humans as assets	- Create a welcoming environment which is comfortable for the design participants, provide regular breaks. - Genuinely value the contribution of each design participant and demonstrate this through acknowledging their ideas and concerns and documenting them, even if you think they may not be relevant (you may in fact find that they are useful later in the process). - Respect the informed decisions of the group, even if you don't agree. They are the ones who will have to live with the outcomes.
Technology as a tool to assist humans	- If technologies are to be used, such as video conferencing or electronic interfaces, monitor how this impacts the cohesion of the group and the ability for all design participants to have equal opportunity to contribute. - Encourage participants to question the use of technology in the workshop, and ask them 'is this working well?' 'Would you rather work on paper?', etc.
Promote quality of life	- Let design participants know the reason for the project and the potential benefits it has so that they have a sense of meaningfulness of the work they are doing. - Use activities and exercises that provide design participants with a reasonable challenge - i.e. that are not overly simply nor overly complex, but which provides a sense of achievement and opportunity for learning. - Recognise the contributions of individual users when they suggest ideas, etc. and genuinely thank the group for their efforts.
Respect for individual differences	- After giving instructions to participants for a design exercise, ask if they are happy to do it in this way. - If a participant or group of participants wants to do a task in a different way (for example, they ask if their group can go outside and complete the activity in the park) be flexible to these requests. It will generally lead to better outcomes, especially in encouraging creativity.
Responsibility to all stakeholders	- Consider the materials you are using in the design process. Is recycled paper being used? Can recycled materials, rather than new, be used for prototyping activities? Is the coffee fair trade? Point out choices made to your participants to show that you are 'walking the talk' and considering your effect on wider society. Even better, point out some of the trade-offs you made (e.g. we wanted to hire the venue from a small, local business but could not justify the use of public research funds so went to a larger provider). This will help to raise awareness that the participants will have to make trade-offs in the design.

7. High level evaluation & design concept selection

Introduction

A key benefit of the CWA outputs (developed in the Analysis planning step) is in their power in providing a desktop evaluation of proposed design concepts. At this point in the process, you have design concepts from the *Concept design* step as well as criteria for judging the effectiveness of designs from the *Design planning* step.

The CWA outputs provide a means for ensuring that the impact or change relating to the new design concepts can be judged prior to further effort being spent on design refinement and detailed design. It enables the design team to focus efforts on the most promising concepts, as well as highlighting unexpected benefits as well as unanticipated negative consequences of the designs. The negative consequences may be able to be addressed through refinement of the design concepts.

Evaluation against the CWA outputs

We present a process for evaluating design concepts through the key tools of CWA, however, there may be additional or alternative means of doing this. Potentially the most powerful evaluation can be achieved through the use of the WDA (e.g. AH or ADS model). However, the latter phases can also provide useful information if time permits.

Work domain analysis

Take your WDA and the design concept. Preferably use a large hardcopy print-out of the WDA and annotate it. Alternatively you could do this in a drawing software program. As you work through annotating the WDA, record your findings using a table such as that provided on page 83. The first part of the table is intended for describing the changes to the existing WDA and also providing a count of the changes. In the second part, benefits, unanticipated risks, design refinement ideas, etc., coming out of the evaluation process can be documented. If you decide to compare the design comments based on numbers (e.g. which design concept would have the most influence on the WDA from a small or cost effective change). However, judgement will still need to be exercised in terms of determining not just how many new links are made but whether these relate to key nodes.

The following provides a step-by-step process:

- Add new physical objects into the WDA
- Highlight physical objects that are enhanced in the proposed design
- For each new and enhanced object, highlight:
    - The existing object-related processes that it would support
    - How these existing processes contribute to the functional purposes via the means-ends links

    - Any new object-related processes that the new or enhanced object would afford
    - How these new object-related processes contribute to the functional purposes via the means-ends links
- As you are overlaying the designs onto the WDA, document:
    - The assumptions being made about the design and the effect it will have on system functioning
    - The key benefits that are apparent from reviewing the effect on the WDA
    - The potential negative effects such as new risks introduced by the new design
    - Further investigation / research required to understand the impacts
    - Suggested improvements / refinements to improve its potential to achieve the desired benefits or to minimise the potential negative effects of the new design
- If required to compare concepts - count up the new nodes, the nodes that are enhanced / supported, the nodes that are appropriately restricted and the nodes that are negatively influenced
- If the design criteria are the values and priority measures of the WDA, you could create a comparison across concepts about which best support the measures most important in the context of the project

Some design concepts may incorporate more radical changes which add to / remove / or amend the functions performed by the system, the values and priority measures or the purpose or purposes of the system itself. In such cases, change these aspects of the WDA and determine the effects on the means-ends links up and down the hierarchy. If comparing concepts, the amount of change at different levels of the hierarchy may be an interesting metric. If a radical change is desired, a design concept that only leads to changes at the bottom levels of the hierarchy has not achieved this goal.

Latter phases of CWA

Similarly to the process for the WDA, the system changes proposed in design concepts can be overlaid on the other existing analysis tools of CWA. For example, for the contextual activity template, consider whether the functions have changed, as well as whether the situations within which activity can occur would be the same or different with the new design. Then, amend the contextual activity template as proposed by the design concept and determine if the constraints of the new design concept increase flexibility (i.e. functions can be performed in more situations), maintain current levels of flexibility, or reduce flexibility. Commentary about the benefits and potential introduced risks should again be documented.

The evaluation process should be able to be performed with all phases of CWA.

Design concept evaluation table

Concept name: ____________________

Effects on WDA	New nodes	Enhanced nodes	Nodes removed	Appropriately restricted nodes	Inappropriately restricted nodes
Physical objects					
Object-related processes					
Purpose-related functions					
Values and priority measures					
Purpose-related functions					

Assumptions	
Key benefits	
Potential negative impacts (e.g. new risks introduced)	
Further investigation / research required	
Potential refinements	

Evaluation against sociotechnical systems theory principles

Following evaluation with the CWA outputs, it is recommended to conduct an evaluation against the sociotechnical systems theory principles outlined in the design criteria document. A detailed description of each of the content principles, as well as indicators that can be used to judge whether or not the principle is 'present' in the proposed design, can be found in Appendix E (page 147). The intention is to consider the design concept as a whole and to judge the extent to which it aligns with the indicators provided in the appendix. If a design concept would meet all the indicators, it would be given a higher score (e.g. 3). If it does not align with any of the indicators it would be given a score of 1. Those concepts that somewhat meet the criteria would be given a rating of 2. This provides some basis for discriminating between different concepts, and also an indication of whether design concepts incorporate some principles strongly or weakly.

This evaluation process would be best conducted in a group setting to increase the chances that all aspects of the design concept are considered. Further, this process can prompt refinements to the design concept and these should be documented and / or incorporated where possible.

Other desktop evaluation methods

Depending on the scope of the project, you may wish to use other evaluation methods particularly if you have applied multiple methods to understand the domain. For example, task analysis methods. Different forms of evaluation can provide perspectives on system functioning and, while CWA will likely be most comprehensive, may provide additional evaluation information that will assist in shortlist selection and / or design refinement.

Further, if scenarios were developed in the design concept step, it would be beneficial to overlay the design changes onto these to demonstrate how the design ideas might influence the use of the system and the user experience. This can provide a useful means for communicating key evaluation findings to users and stakeholders.

Summarising the findings

The *Concept summary* template, adapted from (Liedtka and Ogilvie, 2010) is intended to provide a structured means for documenting the results of the evaluation. It enables the documentation of the key needs addressed by the design concept, the approach taken in the design concept (i.e. what are the overall changes and what philosophical underpinnings are associated with the change), the key benefits of the proposed design, the estimated costs of the changes, potential negative effects such as new risks or potential for human error and the assumptions made during the evaluation process. This concept summary can be taken back to the users and stakeholders (assuming they were not directly involved in the evaluation process) to inform discussions about selecting a particular design or shortlist of designs, and completing design refinements prior to moving into the detailed design stage.

Further reading on design concept evaluation with CWA:

- Read, G. J. M., Salmon, P. M., Lenné, M. G., & Jenkins, D. P. (In press). Designing a ticket to ride with cognitive work analysis. *Ergonomics*.

Concept summary

Concept name	
Key needs addressed	
Approach	
Benefits	
Estimated costs	
Potential negative effects	
Assumptions	

8. Detailed design

Introduction

In the detailed design step, the design concepts are fleshed out and decisions are made about the details of the design as it would be implemented. There are many ways in which the detailed design phase may proceed. It is recommended that a collaborative approach with users and stakeholders is continued. This could involve workshops or design sessions where activities such as prototyping are completed collaboratively. Alternatively, the design team might create some mock ups or scenarios of use that are presented to users and stakeholders for their feedback. The approach you take will likely depend upon the availability and interest of users and stakeholders to be involved in the detailed design step.

The use of prototypes and / or scenarios, coupled with existing guidance and standards from the HFE field which align with the sociotechnical principles, is proposed for the detailed design step.

Prototyping

Guidance on rapid prototyping in provided in Appendix D (see page 142). Basically, it involves building a model, mock-up, storyboard, video recording or other representation of the proposed design. Role play can also be used to test a process or experience. Prototyping gives form to the theoretical design and enables testing prior to the development of a final product. Prototypes should be low cost and so will often not demonstrate all of the functionality envisaged of the final product. Prototypes might include paper mock-ups of screens, computer simulations of new road environments, office layouts built with cardboard boxes, storyboards of customer interactions following a particular procedure, role plays involving teams coordinating using a new type of organisational structure, etc. Guidance for storyboarding for design has been documented by Stanton and colleagues (2013).

Prototypes enable quick learning about what will and will not work and allows for rapid and iterative design. They should be kept simple to encourage change and refinement, as where designs appear too finished there may be reluctance to suggest changes and refinements. Prototyping should occur for the key aspects of the design concept/s and should continue until an appropriate consensus is reached.

Scenarios

If scenarios were developed for the concept design step, these can be changed to reflect the new designs and to conceptually test how users may interact with or experience the proposed designs. Scenarios assist to provide a holistic view of the design concept, as it relates to use and user experience. Building scenarios can highlight where designs have inconsistent or incoherent aspects or where they do not align with the goals of users in different contexts.

A key contribution of scenarios would be to test how the design would operate under different conditions, including abnormal situations that can be envisaged by the research team and stakeholders. A set of scenarios could test how the design would perform across a range of situations as well as how they might perform over time where the external environment of the system changes. For example, one scenario could be set in a future time where funding for the system has been dramatically decreased and used to envisage how the design could cope with this disturbance, or how re-design might occur to adapt to this circumstances. Such scenarios can provide a stress-test for the designs and ensure they are capable of meeting the sociotechnical goal of adaptive capacity. Where designs are found to be inflexible to changing conditions or to re-design, refinements could be made to ensure these attributes are present.

Further information about developing scenarios can be found on page 121.

Existing HFE guidance

Participatory detailed design activities should be linked with existing literature and standards on best practice design that aligns with the sociotechnical approach. To assist readers new to HFE design, the table below provides some starting references and resources for different aspects of system design. This is by no means definitive but could provide a useful starting point. The design team will need to bring this expertise in to the process, unless users and / or stakeholders involved have a strong background in HFE design.

System aspect	Standards, HFE guidelines / guidance, useful references
Function allocation	• Stanton, N. A., Salmon, P. M, Jenkins, D. P., & Walker, G. H. (2009). *Human Factors in the Design and Evaluation of Central Control Room Operations*. CRC Press Inc. (Chapter 7)
Information systems / interface design	• Burns, C.M. & Hajdukiewicz, J.R. (2004). *Ecological interface design*. Boca Raton, FL: CRC Press. • Jenkins, D.P., Stanton, N.A., Salmon, P.M., & Walker, G.H. (2009). Cognitive Work Analysis: Coping with Complexity. Surrey: Ashgate. • (Chapter 3) • ISO 9241: Ergonomics of human system interaction – Part 11 • ISO 11064-4:2004 Ergonomic design of control centres • ISO 9355: Ergonomic requirements for the design of displays and control actuators • Stanton, N., Salmon, P., Jenkins, D & Walker, G. (2009): *Human Factors in the Design and Evaluation of Central Control Room Operations*. CRC Press Inc.
Job / task design	• Dul, J. & Weerdmeester, B. *Ergonomics for Beginners: A Quick Reference Guide*, 3rd Editition. CRC Press Inc. (Chapter 5) • Morgeson, F. P. and Humphrey, S. E. 2006. The Work Design Questionnaire (WDQ): Developing and Validating a Comprehensive Measure for Assessing Job Design and the Nature of Work. *Journal of Applied Psychology, 91*, 1321-1339.
Team design	• Stanton, N., Salmon, P., Jenkins, D & Walker, G. (2009): *Human Factors in the Design and Evaluation of Central Control Room Operations*. CRC Press Inc. (Chapters 2 & 6)
Physical environment design	• ISO 9241: Ergonomics of human system interaction - Part 500 – Workplace Ergonomics • ISO 9241: Ergonomics of human system interaction - Part 600 – Environment Ergonomics • ISO 11064-4:2004 Ergonomic design of control centres • Stanton, N., Salmon, P., Jenkins, D & Walker, G. (2009):

	Human Factors in the Design and Evaluation of Central Control Room Operations. CRC Press Inc. (Chapters 10 & 13) • Dul, J. & Weerdmeester, B. *Ergonomics for Beginners: A Quick Reference Guide*, 3rd Editition. CRC Press Inc. (Chapters 2 & 4)
Support materials / procedures / rules/ training design	• Grote, G. (2008). Rules management as source for loose coupling in high-risk systems. In E. Hollnagel, C. Nemeth & S. Dekker (Eds.), *Remaining Sensitive to the Possibility of Failure* (pp. 91-100). London: Ashgate. • Stanton, N., Salmon, P., Jenkins, D & Walker, G. (2009): *Human Factors in the Design and Evaluation of Central Control Room Operations*. CRC Press Inc. (Chapters 2, 3 & 4)
Management system design	• Molleman, E., & Broekhuis, M. (2001). Sociotechnical systems: towards an organizational learning approach. *Journal of Engineering and Technology Management, 18*, 271-294

Outcomes

The outcome of this step is expected to be one or more detailed designs to address the design brief. At this point, it would be beneficial to update the concept summary or summaries to reflect the details of the detail. This might now include photographs of models, detailed sketches of layouts, screen shots of interfaces, etc. Depending on the scope of the design problem, you may have created something close to the final product at this stage, or something only representative of the final product (such as a simulation). The level of fidelity will likely be driven by how you intend to evaluate and test the design in the following step.

Further reading about detailed design

- Nielsen, J. (1993). *Usability Engineering.* San Diego: Academic Press.
- Stanton, N.A., Salmon, P.M., Rafferty, L.A., Walker, G.H., Baber, C. & Jenkins, D.P. (2013). *Human factors methods: A practical guide for engineering and design* (2nd ed.). Aldershot: Ashgate.

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9. Evaluation & design refinement

Introduction

The evaluation step encompasses more rigorous testing than the high level evaluation conducted in Step 7. It is different to the previous steps in the toolkit in that it takes a research perspective, in contrast to a design perspective, on the proposed design concepts. This perspective is taken to provide objective evidence about the potential performance of the design concepts. Potentially, consideration should be made as to whether an external group or individual should be engaged to conduct or oversee the evaluation or if other measures can be introduced to ensure objectivity in the evaluation process.

In this step, you are interested in evaluating the proposed design/s to determine their performance against the design criteria. The empirical evidence gained from the evaluation can support the selection of a particular design over others or provide a case to make to funders to commit to constructing and / or implementing the proposed design.

There are a number of ways that evaluation of the design concept/s could be undertaken. We present some suggested processes however you may find there is an alternative evaluation methodology that would be useful for evaluating the designs for your project. Standard ISO/TR 16982:2002 identifies a range of usability methods that can be used to evaluate designs. It provides guidance to assist the choice of usability methods based on variables such as the constraints of the project (e.g. time available, budget available), the characteristics of users and whether they are available to participate in evaluation and the extent and importance of the change (e.g. whether it is a revolutionary or more minor change, whether it is a safety-critical change, etc.).

The methods presented in this step and in ISO/TR 16982:2002 are usually applied to one aspect of a design (e.g. a user interface). What is important to consider within your project is how these methods can be applied to a holistic design concept and to ensure that the evaluation takes into account the whole design, rather than simply user performance in response to one component of the design. Potentially this will involve the use of multiple methods, some evaluating components and others evaluating the full concept (where possible). Clegg (2000) advocates a pluralistic evaluation which incorporates a wide range of criteria (i.e. social, technical, operational and financial) and which takes account of different perspectives (e.g. different user types, stakeholders).

Inspection-based evaluation / expert review

Independent experts in HFE and / or usability can be engaged to provide an evaluation of the proposed design/s based on criteria or guidelines. For example, criteria for heuristic evaluation of user interfaces have been identified by Neilson (1994). These criteria include:

- Visibility of system status: The system should keep users informed about what is happening through appropriate and timely feedback

- Match between system and the real world: The system should speak the users' language, with words, phrases, and concepts familiar to the user, rather than system-oriented terms. Information should appear in a natural and logical order
- User control and freedom: Support users to recover from mistakes through clearly marked "emergency exits" without extended dialogue. Support undo and redo functions.
- Consistency and standards: Follow conventions so users easily understand the meaning of different words, situations, or actions.
- Error prevention: Design to prevent errors occurring.
- Recognition rather than recall: Make objects, actions, and options visible so that users do not have to rely on their memory. Instructions should be visible or easily retrievable whenever appropriate.
- Flexibility and efficiency of use: Accelerators can be used to speed up the interaction for expert users so that the system caters for both inexperienced and experienced users. Allow users to tailor frequent actions.
- Aesthetic and minimalist design: The interface should not contain information which is irrelevant or rarely needed. Every unit of information competes with relevant units of information and diminishes their relative visibility.
- Help users identify, diagnose, and recover from errors: Error messages should be expressed in plain language, should precisely indicate the problem, and constructively suggest a solution.
- Help and documentation: If documentation is needed it should be provided in a manner that is easy to search, focused on the task and list simple, concrete steps to be carried out.

Independent evaluators can rate interfaces against these criteria and provide a score which enables ranking of design concepts. These criteria could also be used beyond computer based interfaces with some thoughtful amendments. As well as evaluating the interface, evaluators can provide recommendations for improvements where the design scored poorly. While this approach does not directly involve users, it can provide information that is complementary to user testing.

This process could also, or alternatively, be used at the detailed design step. This could be done to identify issues and inform design refinements at that early stage of the process reducing the potential cost of re-design.

User testing against performance related measures

The commonly used quantifiable performance measurements related to effectiveness and efficiency are identified in ISO/TR 16982:2002 and are outlined below. These measurements are relevant for computer-based interfaces however you could identify similar performance-related measures based on the design criteria specified in the *Design planning* step.

Evaluation based on the measures below would require a working version of the design with which users would interact, and the data could be collected through user observation while they complete specified tasks. Nielson (1993) recommends that at least 10 real users would be needed to perform this type of evaluation.

The measures include:

- Time spent to complete a task
- Number of tasks which can be completed within a predefined duration
- Number of errors
- Time spent recovering from errors
- Time spent locating and interpreting information in the user's guide
- Number of commands utilised
- Number of systems features which can be recalled
- Frequency of use of support materials (documentation, help system, etc.)
- Number of times that the user task was abandoned
- Number of digressions
- Amount of idle time (it is important to distinguish between system-induced delays, thinking time and delays caused by external factors)
- Number of total key strokes

As noted above, it is important to ensure that your evaluation process considers more than performance on tasks in isolation and considers how tasks might interact when implemented in the real world as well as how tasks might be performed in different situations and contexts.

Simulation & modelling

Another way to evaluate a new design is to use simulation to understand human performance (i.e. to test error rates using a new interface linked to a micro-world simulator or how users respond to new road environments in a driving simulator) or to test system performance through methods such as agent-based modelling. To understand impacts on wider system functioning, such methods could also be combined with systems dynamics methods (as proposed by Hettinger, Kirlik, Goh & Buckle, 2015).

Prototypes can also provide a means for conducting experiments prior to implementation. In this case the prototype would be used differently to in previous steps. It would be a resource or tool within an experiment rather than a design tool. However, those participating in the experiment could still provide feedback and recommendations for design improvements.

Safe-to-fail experiments

Particularly when working in complex high-risk environments, even with rigorous evaluation prior to implementation, the effects of a new design on the system will not be known until put into practice. This is because cause and effect is not obvious in complex systems and features such as performance variability and dynamism means that it is not possible to predict outcomes. Safe-to-fail experiments are those in which small experiments are carried out in the real world and closely monitored to learn about the effects.

The idea is to implement small interventions over time that each have low risk and to check their progress and change strategy if things are not going to plan (Snowden & Boone, 2007). These experiments require a flexible and ongoing commitment to evaluation and thoughtful planning to ensure their appropriateness especially in high-hazard domains. Further, it is accepted and acceptable that many of these interventions will fail.

Further reading about evaluation processes and methods

- ISO/TR 16982:2002 Ergonomics of human-system interaction - Usability methods supporting human-centred design.
- Hettinger, L. J., Kirlik, A., Goh, Y. M.,& Buckle, P. (2015). Modelling and simulation of complex sociotechnical systems: envisioning and analysing work environments. *Ergonomics, 58*, 600-614.
- Mills, S. (2006). Heuristic evaluation. *In* Karwowski, W. ed. *International Encyclopedia of Ergonomics and Human Factors (Second Edition)*. Bocan Raton, FL: CRC Press.
- Nielsen, J. (1993). *Usability Engineering.* San Diego, CA: Academic Press.
- Nielsen, J. (1994). Heuristic evaluation. In Nielsen, J. and Mack, R.L. (eds) *Usability Inspection Methods*. New York: John Wiley & Sons.
- Snowden, D. J., & Boone, M. E. (2007). A leader's framework for decision making. *Harvard Business Review, 85*, 68-76, 149.
- Clegg, C. W. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*, 463-477.

10. Implementation

Introduction

If the final product or substantiation of the design has not yet been created, this step involves the construction and implement of the design into the real world. This toolkit will not focus on specific processes for creating the final design as it will vary so much between projects. Once the design is ready, it will be implemented.

Preferably, thinking about and planning for implementation has been considered in all of the previous steps. A key benefit of applying the sociotechnical systems approach is better implementation of innovations. Consequently, where strong participation and engagement with stakeholders has been achieved, as well as appropriate planning up front in the design process, implementation should be reasonably straightforward.

Implementation plan

While thinking about implementation and the transition process should be considered in many of the previous steps, at this point a concrete implementation plan will assist the process.

An implementation plan might consider the following issues:

- Which stakeholders will be affected (base on the stakeholder analysis)
- When stakeholders will be affected (i.e. all at once, or certain groups in some order)
- Whether aspects of the new design will be implemented simultaneously or incrementally over time
- Whether training / familiarisation is required and how this will occur (timing, resources, etc.)
- How communication will be maintained during the change
- How the change will be monitored in the early stages and over time
- How the effectiveness of the design, once implemented, will be monitored and tested initially and over time

The plan should include a proposed schedule which can be discussed amongst all stakeholders and should be agreed. It should be made clear however that, especially with large scale changes, schedules may need to change and that decommissioning of any previous design components be handled very carefully to ensure continuity.

Communication

The benefits of communication become quite important during change and resources should be dedicated to ensuring there is a good information flow between all parties during implementation. Chances are something will come up that is unexpected and knowing about this sooner rather than later will enable any problems to be resolved quickly which will minimise potential frustration experienced by users. If frustration is not dealt with this can encourage negative attitudes towards the change and a lack of trust in the new design.

11. Testing & verification

Introduction

This step involves testing whether the design, as implemented, has met the requirements specified in Step 3 via the criteria specified in the design criteria document (Step 4). It can encompass immediate testing as well as long-term monitoring and on-going testing and evaluation to ensure the design remains appropriate to the needs of the domain.

Methods for testing & verification

Test methods will vary considerably across projects but could include user subjective ratings of the design, incident and accident data, data on system reliability, absenteeism rates, naturalistic observations of the design operating in practice. Some of these measurements can be taken fairly soon after implementation but many will require monitoring over time. This ongoing monitoring process needs to be built into the design itself to ensure there are resources for it to occur and for re-design to be undertaken if required.

Depending on the scope of the design, there may be additional types of testing and verification including those conducted as part of engineering processes (i.e. testing of software code to ensure correct implementation). It is expected that this would occur as part of standard industry guidelines for the domain in which the project is conducted.

Monitoring testing & verification results

A simple template for recording the results of tests against the design criteria is provided on the following page. This would likely be a ‘living’ document with results being added as they become available. What is important is that the design participants will need to agree upon what is an acceptable test result. This is useful because it will provide a prompt for consideration of the need for re-design. For example, one of the sociotechnical systems theory design criteria is ‘Intimate units and environments are designed’. If more than 50% of users have responded to a survey and indicated that they believe the design to be isolating and that it makes them feel isolated, this would indicate the need to initiate a re-design process.

The testing and verification process, and the acceptability measures adopted, should be appropriate to the size and scope of the change, and the risk involved. For example, a design change in a high-hazard industry would involve closer monitoring and stricter acceptance criteria than the implementation of a new teaching initiative in a university.

Re-design

Where re-design is considered necessary, the design process is commenced again. However, whether CWA would be performed again will depend upon the time between the initial design and the re-design, whether the same or different people are involved, the extent of the design changes made rendering the initial CWA obsolete, etc. Thus, re-design may simply mean small modifications to designs, going back to previous prototypes, or starting all over again.

Design verification template

Requirement	Criteria	Acceptance measures	Test result/s

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Appendix A: Analysis insight prompts by CWA phase / tool

CWA phase	Prompt questions

Overall context	- What are the major factors in the organization's environment that influence the system's functioning?
	- Considering the inputs to the system:
	    o Where do they come from?
	    o Are there any potential issues with their supply?
	- Considering the outputs of the system:
	    o Where do they go?
	    o What wider purpose do they serve?
	    o What might happen if they were not produced?
	- Which parts of the system have the most interaction with the wider environment?
	- How could disturbances in the wider system affect the system?
	- What is the system's greatest strength?
	- What is the system's most obvious weakness?

Work domain analysis	- Are there multiple purposes specified for the system?
	    o Do these conflict?
	    o Could they potentially conflict? Under what circumstances?
	- What factors within the system most positively influence the purpose/s?
	- What factors within the system most negatively influence the purpose/s?
	- Are any purpose/s of the system not well supported?

	- Are there conflicting values & priority measures within the system? - Are the value & priority measures currently measured? - Are the value & priority measures currently achieved? - Do different value & priority measures exist in similar systems? - Do the value & priority measures have the potential to encourage functioning that doesn't support the purpose/s? How?
	- Are there any unexpected or unusual functions? - Could any other functions support the purpose/s of the system? - What functions are well-supported by the object-related processes? - What functions are poorly supported by the object-related processes?
	- Are there any unexpected or unusual object-related processes? - Could any other object-related process support each of the functions? - Which object-related processes are well-supported by the physical objects? - Which object-related processes are poorly supported by the physical objects?

	- Are there any unexpected or unusual physical objects?
	- Could any other physical objects support each of the object-related processes?
	- Which physical objects have the most influence / support the most object-related processes?
	- Which physical objects have the least influence?
	- Are any physical objects unreliable in their ability to support the object-related processes?
	    o What influence does this have on the system?
	- How are physical objects related to one another?
	    o Do they suffer common mode failures?
	    o Do any objects have the potential to conflict with, or affect the functioning of another object?
	- What influence do unreliable physical objects have on vulnerability?

Stakeholder object worlds	- What are the key similarities amongst stakeholder object worlds? - What are the key differences amongst stakeholder object worlds? - Can differences lead to issues relevant to achieving the purpose/s of the system? - Can differences lead to issues with communication and collaboration amongst stakeholders?
Contextual activity template	- Was it possible to use the functions from the WDA in the CAT? - Was it straightforward to define the situations for the CAT? - Do the situations have clear boundaries, or do they overlap? - For what situations is it possible to complete tasks, although they are not typically undertaken? Why are they not typically undertaken? - Are there situations involving high workload (many functions typically performed)? - Are there situations involving low workload (few or no functions typically performed)?

Decision ladders	- Which decisions are most important to achieving the system purpose/s?
	- Are the alerts for key decisions clear and unambiguous?
	- Do alerts require actors to respond in time pressured / difficult situations?
	    o Can alerts be improved?
	- Is the information required to understand system states and their consequences for key decisions clear and unambiguous?
	- What sensory modalities are used for information provision (i.e. visual, auditory, tactile, olfactory, gustatory, kinaesthetic)?
	- Is information gathering and synthesis required to occur in time pressured /difficult situations?
	    o Can information presentation / availability / clarity be improved?
	- Are all options known by actors?
	- Could some options be better supported?
	- Do any options conflict with the system purpose/s or values & priority measures?
	- Could goal selection be better supported by the system?
	- Are there any inconsistencies or conflicts between decision ladders (e.g. same alert for different decisions)?
	- What leaps and shunts typically occur?
	- What leaps or shunts should be supported?
	- Should any leaps or shunts be restricted?

Information flowcharts	- Were the beginning and end states for flowcharts straightforward to define? - Which flowcharts showed the most flexibility for completing tasks? - Did any flowcharts have limited options for completing the task? - Are certain strategies used more often than others? Why? - Which strategies are well-supported by the system? - Which strategies are reinforced or rewarded within the system? - Which strategies are not rewarded or punished within the system? - Do any strategies involve many steps (i.e. more steps than appears reasonable for the complexity of the task)? - Are there any inconsistencies or conflicts amongst different flowcharts?

Strategies analysis diagram & flowchart	- Which physical objects have the most interaction with actors in the system?
	- Can any interactions between actors and physical objects be improved?
	- How many strategies are available for each object-related process?
	- Could additional objects provide further flexibility?
	- Were any interesting or unusual strategies identified?
	    o Should these strategies be supported?
	    o Should these strategies be constrained?
	- For each function, what criteria are most important?
	    o How does the system support actors to apply appropriate criteria in situations?
	- Do any criteria represent time pressured or difficult situations?
	    o Can the system be changed to reduce time pressure or difficulty?
	- What are the relationships between the criteria and the values & priority measures?
	- Is there redundancy / multiple pathways through the SAD?
	- Are there critical points?
	- Are alternative pathways of equal value?
	- Are alternative pathways of equal workload?
	- Are there cascading patterns?
	- Are there emergent / not yet seen / new behaviours afforded?
	- Is there balance between all users?
	- Are strategies relevant to particular times / places?
	- Do any criteria represent non-time pressured / undemanding situations?

Social organisation & cooperation analysis	- To what extent are tasks currently completed by:
	    o humans?
	    o technology?
	- Would any tasks completed by humans be better completed by technology?
	- Would any tasks completed by technology be better completed by humans?
	- Do bottlenecks exist in relation to task or communication flow?
	- Are there points of high workload for an actor / group of actors?
	- Are there points of low workload for an actor / group of actors?
	- Where does the handover of tasks between actors occur?
	    o Are handover activities supported?
	- What are the key communication and coordination needs affecting system functioning?
	    o Are these supported?
	    o Are there areas of friction or conflict between actors?
	- To what extent is communication and coordination reinforced or rewarded within the system?
	- Do those responsible for tasks have access to information required for the task?

SRK taxonomy	- What are the key skill-based behaviours for achieving the system purpose/s?
	    o Are they currently supported by the system?
	- What are the key rule-based behaviours for achieving the system purpose/s?
	    o Are they currently supported by the system
	- What are the key knowledge-based behaviours for achieving the system purpose/s?
	    o Are they currently supported by the system?
	- What are the routine tasks? Does the system support these tasks through direct perception and action?
	- Does the system support problem solving activities for non-routine / unforeseen tasks and situations?
	- What high-consequence errors could occur?
	    o How does the system prevent errors?
	    o How does the system support error detection?
	    o How does the system support error recovery?
	    o How does the system support the mitigation of the consequences

	of error? - Are any positive SRK behaviours not currently supported by the system? - Are any negative SRK behaviours not currently constrained by the system? - Do those responsible for tasks have the necessary knowledge and skills for the task (including in non-routine / unforeseen circumstances)?

Appendix B: Analysis insight prompts by organisational metaphor

Metaphor category & description	Questions
Functionalist paradigm	
Cybernetic metaphor - Organisations viewed as patterns of information - Attention is given to which states of balance can be sustained through learning processes based on negative feedback	- What information flows are required to support the systems functioning? - How does information flow through the system? - Are there bottlenecks in information flow? - Are feedback loops in place? - Is feedback adequate for learning to occur?
Loosely coupled systems metaphor - Organisations viewed in a way that is counter to mechanical or organismic metaphors that suggest organisations are tidy, efficient, and well-coordinated systems - Loosely coupled elements are responsive, but each retains its own identity, separateness and independence and the attachment between elements may be infrequent, weak, unimportant or slow (Weick, 1976) - Loose coupling can promote localised adaptation and preserve more diversity - Where few variables are shared between two sub-systems, or between two actors or stakeholder groups, this can be indicative of loose coupling	- In what aspects is the system inefficient? - Where is coordination between system components, actors or groups of actors unsuccessful or lacking? - Are there situations where any one of several means will produce the same end? - Is there slack in the system (i.e. areas where there is an excessive amount of resources in relation to demand)? - To what extent is there decentralisation? - Does a breakdown or problem in one element of the system affect other parts of the system?
Population-ecology metaphor - Emphasises the importance of focusing upon competition and selection in populations of organizations, as opposed to organisation-environment adaption	- What are the system's main competitors? - What other options are available to users / customers / clients to achieve their goals? - How does the system interface with its competitors (e.g. intelligence gathering, communication, collaboration, etc)? - What activities are intentionally undertaken to maintain the system's niche? - What are the system's strengths in relation to its competitors? - What are the system's weaknesses in relation to its competitors? - What foreseeable environmental changes could affect the system's position relative to its competitors?
Theatre - Focuses upon how organisational members are essentially human actors - Actors engage in various roles as well as other official and unofficial performances	- What are the official roles of actors within the system? - What unofficial roles do actors undertake? - When are the official and unofficial roles congruent? - When are the official and unofficial roles in conflict?

Culture - Draws attention to the symbolic aspects of organisational life, and the way in which language, rituals, stories and myths embody networks of subjective meaning which are crucial for understanding how organisational realities are created and sustained	- What rituals are undertaken by actors? How did these arise? What meanings can be identified from rituals? - What stories and myths are shared between actors? How did these arise? What meanings can be identified from the stories and myths? - How are rituals, stories and myths communicated between actors? How are they passed on to others?
Political systems - Focuses attention upon the conflicts of interest and role of power in organisations French & Raven's bases of power (Raven, 1990): - Coercive power (through punishment) - Reward power (through granting something desireable or removing something undesireable) - Legitimate power (through position) - Referent power (through sense of mutual identity, draws upon the need for personal acceptance or approval) - Expert power (through expertise) - Informational power (through control of information)	- When is coercive power exercised? o Who is the target of coercive power? o Who exercises coercive power? - When is reward power exercised? o Who is the target of reward power? o Who exercises reward power? - When is legitimate power exercised? o Who is the target of legitimate power? o Who exercises legitimate power? - When is referent power exercised? o Who is the target of referent power? o Who exercises referent power? - When is expert power exercised? o Who is the target of expert power? o Who exercises expert power? - When is informational power exercised? o Who is the target of informational power? o Who exercises informational power? - What are the positive outcomes of the exercise of power within the system? - What are the negative outcomes of the exercise of power within the system? - Who (individual or group) holds a strong position of power? - Who (individual or group) holds a weak position of power?
Interpretative paradigm	
Language games - Focuses on organisational activity as little more than a game of words, thoughts, and actions - Organisational realities emerge as rule-governed symbolic structures as individuals engage their worlds through the use of specific codes and practices, in order to find meaning - Organisational realities rest in the use of different kinds of verbal and nonverbal language - Language is not simply communicational and descriptive; it is ontological. For example, being a manager in an organisation involves a particular way of being in the world, defined by the language game which a person has to	- What terminology is used by actors when talking about the system? - Is terminology or language common to particular actor groups? - Is different terminology used by different actors / actor groups? - Are there meanings or insights about underlying values or beliefs that can be drawn from the terminology used? - What nonverbal language or cues are used by actors? - What meanings or insights about underlying values or beliefs can be drawn from nonverbal language or cues?

play to be recognised and function as a manager - Organisations are created and sustained as patterns of social activity through the use of language	
Texts - Organisational activity is viewed as a symbolic document - Texts give form to particular kinds of language games and make use of metaphorical expressions to convey patterns of meaning - Existing text is interpreted and translated by others, who may find meaning or significance other than that intended by the author - Concern is given to understanding the manner in which organisational activities are authored, read, and translated, and the way in which the structure of discourse may explore certain key themes and develop particular kinds of imagery	- What terminology or language is used in official texts? - Are there contrasts or differences between the language used in official and unofficial texts? - Who authors texts used within the system? - What is the process for developing texts? - What are the key themes apparent in texts? - Have the language or themes changed over time? - What are the reasons for such changes? - What are the consequences of such changes?
Accomplishments - Focuses upon the way in which human beings accomplish and sustain social situations intelligible both to themselves and to others - Related to ethnomethodology which is concerned with "discovering the formal properties of commonplace, practical common sense actions, 'from within' actual settings, as ongoing accomplishments of those settings" (Garfinkel, 1967)	- What are the social rules or patterns that assist actors to successfully interact within the system? - How are these rules used? - What are the consequences if the rules are violated?
Enacted sense-making - Emphasises how realities are enacted by individuals through continuous after-the-event rationalisations as to what has been happening - Sensemaking is facilitated by action, which in turn affects the situation - Sensemaking is an issue of language, talk, and communication – situations are talked into being (Weick, 2005)	- How do actors make sense of key situations? - How do stakeholders make sense of key situations? - Does the system support sensemaking? - How do actions associated with sensemaking affect the system? - How does language and communication support sensemaking?
Radical humanist paradigm	
Psychic prisons - Focuses upon the way human beings may be led to enact organisational realities experienced as confining and dominating - The emphasis is on the process through which individuals over-concretise their world, perceiving it as objective and real, and something independent of their own will and action	- What is the ideology behind the design of the system? - Is there conflict between the goals or needs of the system, and that of actors or stakeholders of the system? - Do actors perceive the system to enable them to enact their own will and action? - Do actors over-concretise aspects of the system? Do they fail to explore alternative options or fail

- Emphasis is also placed on how modes of domination may be manipulated by those with power in pursuit of their own ends - Organisational members are effectively viewed as prisoners of a mode of consciousness which is shaped and controlled through ideological processes - Life at work constitutes an alienated mode of life in which individuals are shaped, controlled, and generally made subservient to the artificially contrived and reified needs of modern organisation	to break 'soft' constraints when this would be appropriate? - Do actors feel empowered and engaged by the system? - Do actors perceive the system to dominate and control their activities? - Do actors feel alienated by or subservient to the system? - Do actors feel manipulated by the system or by those exercising power in the system?
Radical structuralist paradigm	
Instruments of domination - Focuses on organisations as powerful instruments of domination understood as an integral part of a wider process of domination within society - Organisations can be viewed as machines and studied for their oppressive qualities - Encourages an analysis of the means by which modes of domination operate and are sustained - About understanding how the power structure within organisations are linked to power structures within the world political economy, and how societal divisions between classes, ethnic groups, men and women, etc., are evident in the system	- Do processes or aspects of the system dominate or control actors within the system? - Do processes or aspects of the system dominate or control stakeholders of the system? - What forms does domination take? - What are the consequences of domination? - Are actions taken to avoid or defeat domination? - What are the consequences of these actions to avoid or defeat domination? - Does the system produce or influence inequities between actors or members of the public?
Schismatic systems - Focuses on how organisations can fragment and eventually disintegrate as a result of internally generated strains and tensions - Counters the functionalist premise that organisations are unified entities seeking to adapt and survive, by considering the processes through which groups factionalise due to schismogenesis (Bateson, 1936) and focussing on the development of patterns of functional autonomy (Gouldner, 1959)	- Where are points of tension or conflict within the system? - To what extent do the parts of the system work in a coordinated manner? - Is there evidence of fragmentation or disintegration within the system? - What are the consequences of fragmentation / disintegration? - What foreseeable environmental changes could affect the system's ability to maintain unification between parts / sub-systems?
Catastrophes - The catastrophe metaphor has been used in Marxist theory to analyse internal contradictions of the world political economy (Bukharin, 1915, 1925) which set the basis for revolutionary forms of change - Relevant to the study of the role of organisations in the contemporary world economy, the labour process, and labour-management relations	- How is the system influenced by the politics? - How does the system influence politics? - How is the system influenced by the local, national and international economy? - How does the system influence the local, national and international economy? - How is the system influenced by the labour market? - How does the system influence the labour market? - What is the state of labour-management relations within the system?

Catastrophe theory - 'Catastrophe theory' (Thom, 1975) is a mathematical theory which enables the modelling of changes to equilibrium. Small changes in certain parameters of a nonlinear system can cause equilibria to appear or disappear, or to change from attracting to repelling and vice versa, leading to large and sudden changes of the behaviour of the system	- Did the analysis uncover any variables for which a small change led or could lead to large or sudden changes in the system's behaviour (i.e. a tipping point)?

Appendix C: Organisational metaphor prompts in card format

To create the cards, print the following five pages single sided, cut out the cards and stick them onto card so that on one side is the description of the metaphor, and on the other are the prompt questions.

<table>
<tr>
<td>Cybernetic metaphor
- Organisations viewed as patterns of information
- Attention is given to which states of balance can be sustained through learning processes based on negative feedback</td>
<td>Loosely coupled systems metaphor
- Organisations viewed in a way that is counter to mechanical or organismic metaphors that suggest organisations are tidy, efficient, and well-coordinated systems
- Loosely coupled elements are responsive, but each retains its own identity, separateness and independence and the attachment between elements may be infrequent, weak, unimportant or slow
- Loose coupling can promote localised adaptation and preserve more diversity
- Where few variables are shared between two sub-systems, or between two actors or stakeholder groups, this can be indicative of loose coupling</td>
<td>Population-ecology metaphor
- Emphasises the importance of focusing upon competition and selection in populations of organizations, as opposed to organisation-environment adaption</td>
</tr>
<tr>
<td>Prompts for the Cybernetic metaphor:
- What information flows are required to support the systems functioning?
- How does information flow through the system?
- Are there bottlenecks in information flow?
- Are feedback loops in place?
- Is feedback adequate for learning to occur?</td>
<td>Prompts for the Loosely coupled systems metaphor:
- In what aspects is the system inefficient?
- Where is coordination between system components, actors or groups of actors unsuccessful or lacking?
- Are there situations where any one of several means will produce the same end?
- Is there slack in the system (i.e. areas where there is an excessive amount of resources in relation to demand)?
- To what extent is there decentralisation?
- Does a breakdown or problem in one element of the system affect other parts of the system?</td>
<td>Prompts for the Population-ecology metaphor:
- What are the system’s main competitors?
- What other options are available to users / customers / clients to achieve their goals?
- How does the system interface with its competitors (e.g. intelligence gathering, communication, collaboration, etc.)?
- What activities are intentionally undertaken to maintain the system’s niche?
- What are the system’s strengths in relation to its competitors?
- What are the system’s weaknesses in relation to its competitors?
- What foreseeable environmental changes could affect the system’s position relative to its competitors?</td>
</tr>
</table>

Political systems - Focuses attention upon the conflicts of interest and role of power in organisations French & Raven’s bases of power (Raven, 1990): - Coercive power (through punishment) - Reward power (through granting something desirable or removing something undesirable) - Legitimate power (through position) - Referent power (through sense of mutual identity, draws upon the need for personal acceptance or approval) - Expert power (through expertise) - Informational power (through control of information)	**Culture** - Draws attention to the symbolic aspects of organisational life, and the way in which language, rituals, stories and myths embody networks of subjective meaning which are crucial for understanding how organisational realities are created and sustained	**Theatre** - Focuses upon how organisational members are essentially human actors - Actors engage in various roles as well as other official and unofficial performances
Prompts for the Political systems metaphor: - When is coercive power exercised? Who exercises it? Who is the target? - When is reward power exercised? Who exercises it? Who is the target? - When is legitimate power exercised? Who exercises it? Who is the target? - When is referent power exercised? Who exercises it? Who is the target? - When is expert power exercised? Who exercises it? Who is the target? - When is informational power exercised? Who exercises it? Who is the target? - What are the positive outcomes of the exercise of power within the system? What are the negative outcomes? - Who holds a strong or weak positions of power?	Prompts for the Culture metaphor: - What rituals are undertaken by actors? How did these arise? What meanings can be identified from rituals? - What stories and myths are shared between actors? - How did these arise? What meanings can be identified from the stories and myths? - How are rituals, stories and myths communicated between actors? How are they passed on to others?	Prompts for the Theatre metaphor: - What are the official roles of actors within the system? - What unofficial roles do actors undertake? - When are the official and unofficial roles congruent? - When are the official and unofficial roles in conflict?

Language games	Texts	Accomplishments
- Focuses on organisational activity as a game of words, thoughts, and actions - Organisational realities emerge as rule-governed symbolic structures as individuals engage their worlds through the use of specific codes and practices, in order to find meaning - Organisational realities rest in the use of different kinds of verbal and nonverbal language - Language is not simply communicational and descriptive; it is ontological, i.e. being a manager in an organisation involves a particular way of being in the world, defined by the language game which a person has to play to be recognised and function as a manager - Organisations are created and sustained as patterns of social activity through the use of language	- Organisational activity is viewed as a symbolic document - Texts give form to particular kinds of language games and make use of metaphorical expressions to convey patterns of meaning - Existing text is interpreted and translated by others, who may find meaning or significance other than that intended by the author - Concern is given to understanding the manner in which organisational activities are authored, read, and translated, and the way in which the structure of discourse may explore certain key themes and develop particular kinds of imagery	- Focuses upon the way in which human beings accomplish and sustain social situations intelligible both to themselves and to others - Related to ethnomethodology which is concerned with "discovering the formal properties of commonplace, practical common sense actions, 'from within' actual settings, as ongoing accomplishments of those settings" (Garfinkel, 1967)
Prompts for the Language games metaphor: - What terminology is used by actors when talking about the system? - Is terminology or language common to particular actor groups? - Is different terminology used by different actors / actor groups? - Are there meanings or insights about underlying values or beliefs that can be drawn from the terminology used? - What nonverbal language or cues are used by actors? - What meanings or insights about underlying values or beliefs can be drawn from nonverbal language or cues?	Prompts for the Texts metaphor: - What terminology or language is used in official texts? - Are there contrasts or differences between the language used in official and unofficial texts? - Who authors texts used within the system? - What is the process for developing texts? - What are the key themes apparent in texts? - Have the language or themes changed over time? - What are the reasons for such changes? - What are the consequences of such changes?	Prompts for the Accomplishments metaphor: - What are the social rules or patterns that assist actors to successfully interact within the system? - How are these rules used? - What are the consequences if the rules are violated?

Enacted sense-making - Emphasises how realities are enacted by individuals through continuous after-the-event rationalisations as to what has been happening - Sensemaking is facilitated by action, which in turn affects the situation - Sensemaking is an issue of language, talk, and communication – situations are talked into being (Weick, 2005)	**Psychic prisons** - Focuses upon the way humans enact organisational realities experienced as confining and dominating - Emphasis is on the process through which individuals over-concretise their world, perceiving it as objective and real, and independent of their own will and action - Emphasis is also placed on how modes of domination may be manipulated by those with power - Organisational members are effectively viewed as prisoners of a mode of consciousness which is shaped and controlled through ideological processes - Life at work constitutes an alienated mode of life in which individuals are shaped, controlled, and generally made subservient to the needs of modern organisation	**Instruments of domination** - Focuses on organisations as powerful instruments of domination understood as an integral part of a wider process of domination within society - Organisations can be viewed as machines and studied for their oppressive qualities - Encourages an analysis of the means by which modes of domination operate and are sustained - About understanding how power structures within organisations are linked to power structures within the world political economy, and how societal divisions between classes, ethnic groups, men and women, etc., are evident in the system
Prompts for the Enacted sense-making metaphor: - How do actors make sense of key situations? - How do stakeholders make sense of key situations? - Does the system support sensemaking? - How do actions associated with sensemaking affect the system? - How does language and communication support sensemaking?	Prompts for the Psychic prisons metaphor: - What is the ideology behind the system's design? - Is there conflict between the goals or needs of the system, and that of actors or stakeholders of the system? - Do actors perceive the system to enable them to enact their own will and action? - Do actors over-concretise aspects of the system? Do they fail to explore alternative options or fail to break 'soft' constraints when this would be appropriate? - Do actors feel empowered by the system? - Do actors perceive the system to dominate and control their activities? - Do actors feel alienated by or subservient to the system? - Do actors feel manipulated by the system or by those exercising power in the system?	Prompts for the Instruments of domination metaphor: - Do processes or aspects of the system dominate or control actors within the system? - Do processes or aspects of the system dominate or control stakeholders of the system? - What forms does domination take? - What are the consequences of domination? - Are actions taken to avoid or defeat domination? - What are the consequences of these actions to avoid or defeat domination? - Does the system produce or influence inequities between actors or members of the public?

Schismatic systems - Focuses on how organisations can fragment and eventually disintegrate as a result of internally generated strains and tensions - Counters the functionalist premise that organisations are unified entities seeking to adapt and survive, by considering the processes through which groups factionalise due to schismogenesis (Bateson, 1936) and focussing on the development of patterns of functional autonomy (Gouldner, 1959)	**Catastrophes** - The catastrophe metaphor has been used in Marxist theory to analyse internal contradictions of the world political economy (Bukharin, 1915, 1925) which set the basis for revolutionary forms of change - Relevant to the study of the role of organisations in the contemporary world economy, the labour process, and labour-management relations	**Catastrophe theory** - 'Catastrophe theory' (Thom, 1975) is a mathematical theory which enables the modelling of changes to equilibrium. Small changes in certain parameters of a nonlinear system can cause equilibria to appear or disappear, or to change from attracting to repelling and vice versa, leading to large and sudden changes of the behaviour of the system
Prompts for the Schismatic systems metaphor: - Where are points of tension or conflict within the system? - To what extent do the parts of the system work in a coordinated manner? - Is there evidence of fragmentation or disintegration within the system? - What are the consequences of fragmentation / disintegration? - What foreseeable environmental changes could affect the system's ability to maintain unification between parts / sub-systems?	Prompts for the Catastrophes metaphor: - How is the system influenced by the politics? - How does the system influence politics? - How is the system influenced by the local, national and international economy? - How does the system influence the local, national and international economy? - How is the system influenced by the labour market? - How does the system influence the labour market? - What is the state of labour-management relations within the system?	Prompts for the Catastrophe theory metaphor: - Did the analysis uncover any variables for which a small change led or could lead to large or sudden changes in the system's behaviour (i.e. a tipping point)?

Appendix D: Design tools

Communicating the findings

Personas

Background	Personas can be used to develop empathy with the users and stakeholders of the system. Analysts may develop this empathy through data collection activities however design participants may not experience this directly. Empathy is important for achieving designs that align with sociotechnical values. This exercise involves presenting a summary of selected system actors and stakeholders (real people or fictional), with personal information about the individual and their use of the system. Participants are then asked prompting questions which assists them to explore the individual's needs, concerns and values in interacting with the system.
Materials	• Pre-prepared descriptions of different actors in the system (see Nielsen 2012; 2014) with prompting questions (e.g. what difficulties might X experience with the current system design?) • A mix of users with prototypical as well as extreme attributes, needs and concerns is recommended • Photos should be provided to assist participants to connect with the individual • Whiteboard
Format	Presentation of each persona followed by individual work, then small group discussion.
Steps	• Introduce the activity • Present a persona • Provide handouts to participants and ask to complete the prompt questions • Participants discuss their answers in small groups • Repeat with subsequent personas (recommend at least 3 personas are presented) • At conclusion, each group shares 1 insight from the discussions • Insights raised by participants are recorded in the analysis insights
Time requirements	Approx 1.5 hours
Recommended for	All design projects
Further information	Nielson, L. (2012*). Personas-User Focused Design*. Springer. Nielsen, L. (2014). Personas. In M. Soegaard & R. F. Dam (Eds.) *The Encyclopedia of Human-Computer Interaction* (2nd Ed.). Aarhus, Denmark: The Interaction Design Foundation. Available from http://www.interaction-design.org/encyclopedia/personas.html.

Scenarios

Background	Scenarios are a commonly used design tool. They involve documenting key situations of use in narrative form. Scenarios can be used to describe typical activities or to highlight problematic activities identified during the analysis. They may range from quite short narratives (1 paragraph) to one page depending on the level of detail needed to communicate the key points and issues, and to develop a sense of empathy with the individual/s in the scenario. Scenarios can also assist to promote empathy with users or other stakeholders within the system, depending on the focus of the scenario. Scenarios should draw directly from the CWA outputs. The user goals represented in scenarios can be drawn from the decision ladder, the artefacts from the work domain analysis, the context from the situations in the contextual activity template, etc. Further, insights about scenario features should be incorporated where possible to ensure a strong link between the analysis and the scenario tools. To promote the development of empathy with actors it is recommended that scenarios are only partially specified. For example, the scenario may describe the situation of a user including their personal attributes, the goal they are working towards and how they interact with objects in the system. However, there may be gaps in the narrative for the participant to describe how the user feels at different points in the scenario (e.g. frustrated, pressured, delighted, etc.) and what they have learned about the system through their interaction.
Materials	• Pre-prepared scenarios with gaps for participants to complete • Photos / pictures / videos to enrich the scenarios • Whiteboard to record group insights
Format	Individual work followed by small group discussions
Steps	• Introduce the activity • Present a summary of a scenario • Ask participants to read the scenario and fill in the gaps • Participants discuss in small groups 1. What values were represented in the scenario? 2. What goals were represented in the scenario? 3. What issues or problems were apparent in the scenario? 4. What opportunities were apparent in the scenario? • Repeat with subsequent scenarios (recommend at least 3 stories are presented) • At conclusion, each group shares 1 insight from the discussions • Ensure any insights raised by participants are recorded in

	the analysis insights
Time requirements	Approx 1.5 hours
Recommended for	All design projects
Further information	Carroll, J.M., 2002. Scenario-based design. *In* Karwowski, W. ed. *International encyclopedia of ergonomics and human factors.* Second ed. Boca Raton, FL: CRC Press. Nielsen, L. (2014). Personas. In M. Soegaard & R. F. Dam (Eds.) *The Encyclopedia of Human-Computer Interaction* (2nd Ed.). Aarhus, Denmark: The Interaction Design Foundation. Available from http://www.interaction-design.org/encyclopedia/personas.html.

Stories

Background	Stories can be used for communicating information uncovered during the analysis in a concrete, specific way. Stories can also assist to promote empathy with users or other stakeholders within the system, depending on the focus of the story.
Materials	• Pre-prepared short stories collected during the analysis. The stories should be real, personal stories that highlight key information. Stories should cover who, what, when, where how and why. • Photos / pictures / videos to enrich the stories • Whiteboard to record group insights
Format	Presentation (slideshow recommended), with group discussion
Steps	• Introduce the activity • Present a story • Ask participants: 1. What values were represented in the story? 2. What goals were represented in the story? 3. What issues or problems were apparent? 4. What opportunities were apparent? • Repeat with subsequent stories (recommend at least 3 stories are presented) • Ensure any insights raised by participants are recorded in the analysis insights
Time requirements	Approx 1 hour
Recommended for	All design projects
Further information	Erickson, T., 1995. Notes on design practice: Stories and prototypes as catalysts for communication. In Carroll, J.M. ed. *Scenario-based design: Envisioning work and technology in system development*. New York: John Wiley & Sons Inc, 37-58. IDEO, 2009. *Human centered design toolkit second edition*. http://www.ideo.com/work/human-centered-design-toolkit.

Creativity boosting exercises

Impossible challenge

Background	Most people are unaccustomed to thinking laterally as much of what is done at work requires analytical, rational thinking. However, lateral thinking is important for generating novel ideas. This exercise can be used at the beginning of a workshop or idea generation session to 'warm up' participants brains in terms of their ability to think more laterally (Imber, 2009). An impossible challenge that cannot be solved through rational thinking is put to participants. Examples of challenges suggested by Imber (2009) include: • Cure cancer by lunchtime tomorrow • Stop global warming by midnight tonight • Raise Paris Hilton's IQ by 100 points by the end of the week • Give birth to an alien before dinner tonight • Marry Brad Pitt by noon tomorrow Any impossible challenge can be set. However, the goal to be achieved should be almost impossible to achieve with current technology and a very tight timeframe should be set to achieve the goal.
Materials	• Pre-prepared impossible challenge • Paper for recording responses
Format	Small groups (2-3)
Steps	• Introduce the activity • Set the challenge • Groups to brainstorm 3 solutions within 5 minutes • Report back to the wider group
Time requirements	Approx 10 minutes
Recommended for	All design projects
Further information	Imber, A., (2009). *The creativity formula: 50 scientifically proven creativity busters for work and for life*. Caulfield: Liminal Press.

Stimulate debate

Background	Political debate is an important of the design process to ensure that potential issues are discussed openly and do not hide under the surface constraining creative thinking, nor be raised at implementation where it is too late to make appropriate changes.
Materials	• Paper / whiteboard for brainstorming
Format	Small groups of 4-5 participants
Steps	• Introduce the activity • As a large group, brainstorm the issues or constraints that limit the possibilities for design (e.g. cost, public acceptance, standards / legislative requirements, etc.) • Add any further constraints identified by the researchers (e.g. assumption insights) • Ask small groups to think of ways that each constraint could be overcome (e.g. recover costs, engage with the public, change the standards, etc.) • Enable and encourage debate about the solutions and document all of the information for consideration in the detailed design phase • Wrap up the exercise explaining that the purpose is to avoid restricting ideas based on these constraints. That they should first generate design ideas and then consider how they can be refined to fit constraints, or how the constraints can be removed.
Time requirements	Approx 40 minutes
Recommended for	All design projects, unless teams consider that such information will be addressed during another activity such as assumption crushing.
Further information	Clegg, C. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*, 463-477.

Idea generation

Inspiration cards - brainstorming

Background	This activity involves the pre-selection of inspiration cards, relevant to the design problem as uncovered by the analysis, which are used to prompt brainstorming in small groups. The brainstorming will occur in relation to identified opportunities, leverage points or pain points.
Materials	• List of key opportunities, leverage points or pain points (2-3) arising from the analysis • Set of cards (4-6), that can each prompt design ideas. Cards could be drawn from: 1. Design with Intent cards (Lockton et al, 2010; ensure cards selected reflect design values) 2. IDEO Method Cards 3. Cards created for the purpose of the workshop • Sheets of paper for recording design ideas • Whiteboard for recording design ideas
Format	Small groups of 4-5 participants
Steps	• Introduce the activity • Describe an opportunity or leverage point from the insights • Present an inspiration card to the group • Individual idea generation for ideas for the opportunity or leverage point (5 minutes) • Small group idea generation (10 minutes) • Groups report back their design ideas • Individual idea generation (5 minutes) • Individuals report back – record on / build upon whiteboard • Repeat with an additional inspiration card • Repeat with an opportunity or leverage point, and inspiration cards (as time permits) • Review design ideas with whole group and build upon ideas further where appropriate Tip: to boost creativity, give participants a constraint which they must work to. For example, a budget of $20 or a solution that must be implemented within 24 hours. Change these around between the groups or the exercises.
Time requirements	Approx 3 hours
Recommended for	All design projects
Further information	Lockton, D., Harrison, D. & Stanton, N.A., 2010. The design with intent method: A design tool for influencing user behaviour. *Applied Ergonomics, 41*, 382-392. Toolkit available from www.danlockton.com/dwi/Main_Page IDEO Design Method Cards, available from www.ideo.com/work/method-cards/

Inspiration cards - sorting

Background	The use of cards and card sorting techniques are commonly used within user-centred design activities. The physical interaction with the cards assists the design process. The activity is centered on creating design ideas from combining inspiration cards in order to realize the opportunities, leverage points or pain points identified during the analysis.
Materials	• List of key opportunities, leverage points and pain points arising from the analysis • Sets of cards, each representing a single concept or idea that can be combined to form design ideas. Cards could be drawn from: 1. Design with intent cards (Lockton et al, 2010; ensure cards selected reflect design values) 2. IDEO Design Method cards 3. Technology cards (existing physical objects) 4. New technology cards (such as described in Halskow & Dalsgard, 2006) 5. Actor cards (actors identified in the analysis) 6. Random picture cards • Sheets of paper for recording design ideas along with cards • Space on wall for displaying design idea sheets
Format	Individual brainstorming followed by group discussion.
Steps	• Introduce the activity • Provide each participant with inspiration cards and sheets of paper for recording ideas • Describe an opportunity, leverage point or pain point arising from the analysis • Ask participants to sort through the cards, combining them to identify design ideas which are recorded on the design idea sheets • Participants to place completed sheets on the wall • Once ideas exhausted, participants introduce their ideas, the group discusses and builds upon the ideas • Repeat with other opportunities and leverage points (as time permits) Tip: to boost creativity, give participants a constraint which they must work to. For example, a budget of $20 or a solution that must be implemented within 24 hours. Change these around between the groups or the exercises.
Time requirements	Approx 3 hours
Recommended for	All design projects

Further information	Lockton, D., Harrison, D. & Stanton, N.A., 2010. The design with intent method: A design tool for influencing user behaviour. Applied Ergonomics, 41, 382-392. Toolkit available from http://www.danlockton.com/dwi/Main_Page Halskow, K. & Dalsgard, P., 2006. Inspiration card workshops. Proceedings of the 6th Conference on Designing Interactive Systems, 2-11. IDEO Design Method Cards, available from http://www.ideo.com/work/method-cards/

Using metaphors and analogies

Background	The use of metaphors and analogies in design is common. They provide a means of seeing things in a new way which can prompt new ideas and innovation. The use of metaphors can also assist the translation of conventions from one area to another, providing end users with a familiar model to understand the new system.
Materials	• List of aspects of the system that prompted a metaphor or analogy documented in the *analysis insights template* • Cards of random pictures and words to prompt metaphors and analogies (some may represent those identified during the analysis) • Worksheets for individual brainstorming • Paper for small group brainstorming
Format	Small group (3-4 participants) and individual brainstorming.
Steps	• Introduce the activity • Introduce metaphors and analogies and provide examples of the application to design • Present aspects of the system • Ask participants to form small groups • Allocate one system aspect to each group 1. Ask participants to work individually to brainstorm potential metaphors or analogies (refer to cards for prompts) 2. Small groups pool the metaphors and analogies 3. Small group brainstorming to identify design ideas • Report back to larger group • Repeat with other system aspects (as time permits)
Time requirements	Approx 4 hours
Recommended for	All design projects
Further information	Madsen, K.H., 1994. A guide to metaphorical design. The Communications of the ACM, 37, 57-62.

Building on strengths

Background	Drawing from the methodology of appreciative inquiry, this activity focuses thinking away from what is wrong with the system, or problems to be solved. It instead explores the strengths of the current system and how these could be further supported. Through a focus on current strengths and a desirable compelling future, change can be brought about without need for incentives, coercion or persuasion.
Materials	• List of some positive features of the current system, identified during the analysis • Worksheets for individual brainstorming • Whiteboard for brainstorming
Format	Large group and individual brainstorming.
Steps	• Introduce the activity • Begin the discovery phase 1. Ask participants to individually brainstorm strengths of the current system (i.e. what is done well? What works well?) 2. Ask participants to work in pairs to interview one anther 3. As a group, discuss the strengths and document on the whiteboard 4. If participants have difficulty identifying strengths, offer some from list and prompt for discussion (i.e. do the participants agree that these are strengths?) • Begin the dream phase 1. Ask participants to individually consider the system functioning at its best. What would this look like? What would it be like? 2. As a group, discuss this ideal state and document a shared statement, diagram, etc • Begin the design stage 1. Ask participants to identify concrete design ideas for bringing the system closer to the ideal state 2. As a group, brainstorm and discuss the design ideas • Recap the findings
Time requirements	Approx 4 hours
Recommended for	All design projects, particularly those involving stakeholder groups in conflict
Further information	Bushe, G.R. (2013). The appreciative inquiry model. In E. Kessler (Ed.) *The Encyclopedia of Management Theory*. Sage Publications. Available from http://www.gervasebushe.ca/the_AI_model.pdf

Assumption crushing

Background	Assumptions include theories, beliefs or hypotheses underpinning the structure of the system and the way things are currently done. They may not be consciously realized but can unconsciously restrict the type of design ideas that are considered. Crushing assumptions means to identify an alternative or opposite theory, belief or hypothesis and brainstorm design ideas in line with this.
Materials	• List of assumptions identified during the analysis 1. The *Analysis insights template* can be used to document assumptions 2. Select 4 to 6 assumptions that go to the core of the system • Worksheets for individual brainstorming • Whiteboard for group brainstorming
Format	Large group and individual brainstorming.
Steps	• Introduce the activity • Introduce the assumptions • Ask participants to individually brainstorm an alternative statement for each assumption • As a group, discuss and refine the alternative statements • Ask participants to individually brainstorm design ideas for the alternative statements • As a group, brainstorm and discuss design ideas • Recap the findings
Time requirements	Approx 2 hours
Recommended for	All design projects
Further information	Imber, A., 2012. Five ways to boost creativity. Melbourne: Inventium.

Constraint crushing

Background	CWA identifies the constraints upon behaviour within the system. These may be hard constraints (those that cannot be violated) or soft constraints (those that can be violated, although it would be socially unacceptable to do so). Constraints can limit stakeholder openness to innovative design solutions. Challenging constraints can prompt new ideas and widen the thinking of participants regarding what is possible.
Materials	• List of key constraints identified during the analysis 1. The *Constraints identification template* can be used to document constraints 2. Select 6 to 10 constraints that have the potential to open up thinking • Worksheets for individual brainstorming • Whiteboard for group brainstorming
Format	Large group and individual brainstorming.
Steps	• Introduce the activity • Introduce the constraints • Ask participants to individually brainstorm (for half the constraints): 1. What the system would be like without the constraint 2. The opportunities associated with removing the constraint 3. What functions or tasks could be undertaken with that constraint removed • Explain that only the positive aspects of constraint removal should be considered. Negative implications and costs will be identified in the evaluation phases. • As a group, brainstorm the three topics • Repeat for the other half of the constraints (individual brainstorming followed by collective) • Recap the findings • Highlight and record emerging design ideas
Time requirements	Approx 2 hours
Recommended for	All design projects
Further information	Stanton, N.A., McIlroy, R.C., Harvey, C., Blainey, S., Hickford, A., Preston, J.M., & Ryan, B. (2013). Following the cognitive work analysis train of thought: Exploring the constraints of modal shift to rail transport. *Ergonomics, 56*, 522-40.

Interaction re-labelling

Background	Interaction relabelling involves the use of an unrelated product to prompt ideas about interaction with the product to be designed. Design participants work in small groups to brainstorm ideas and physically handle the unrelated product to explore the interaction. The activity draws upon metaphorical design and can be used to assist designers to move away from prototypical interaction styles.
Materials	• A design opportunity uncovered during the analysis – i.e. a leverage point • An unrelated product or range of products from which groups can select (mechanical products with many moving parts are recommended) • Paper / whiteboard for recording design ideas
Format	Small groups of 4-5 participants
Steps	• Introduce the activity • Describe the interaction or product to be designed • Introduce the unrelated product (if multiple, ask each group to select one) • Encourage participants to handle the unrelated product and explore the functions and interactions • Ask participants to brainstorm how the interactions of unrelated product could be used for the product to be designed • Groups report back their design ideas
Time requirements	Approx 2-3 hours
Recommended for	Design projects involving interaction design – including interface design and product design.
Further information	Djajadiningrat, J.P., Gaver, W.W. & Frens, J.W. (2000). Interaction relabelling and extreme characters: Methods for exploring aesthetic interactions. *Proceedings of DIS 2000ACM Press*, 66-71.

Extreme characters

Background	While personas and scenarios tend to be based around prototypical users, extreme characters have exaggerated emotional attitudes and goals. Exploring design concepts for extreme characters assists to uncover undesirable or antisocial emotions or goals and expand design ideas. Role-playing each character within the workshop is recommended to provide richness and bring the character to life.
Materials	• A design opportunity identified during the analysis (e.g. a leverage point) • A description of the character including text and pictures describing their personalities, daily activities, etc. • Role play scenarios • Paper / whiteboard for recording design ideas.
Format	Small groups of 4-5 participants
Steps	• Introduce the activity • Describe the product or interaction to be designed • Introduce the extreme characters briefly to the whole group • Allocate a character to each small group • Ask each group to role play an interaction with their character • Ask participants to brainstorm design ideas for the product or interaction • Groups report back their design ideas
Time requirements	Approx 2 hours
Recommended for	Situations where users may not share the goals of the overall system or there is the possibility of unintended use.
Further information	Djajadiningrat, J.P., Gaver, W.W. & Frens, J.W., 2000. Interaction relabelling and extreme characters: Methods for exploring aesthetic interactions. *Proceedings of DIS 2000ACM Press*, 66-71.

Design concept definition

Affinity diagramming

Background	Creativity is driven by the combination of previously unrelated concepts. In design, combinatorial play is the term used to describe the process of putting together ideas from diverse areas. This tool aims to prompt further creative combinations of design ideas, including the introduction of ideas recommended by previous research, by other stakeholders, or implemented elsewhere. It will also assist to ensure that interventions are proposed across different levels of the system, and are holistic concepts that support integrated system design (i.e. are not focused on one aspect of the system alone).
Materials	• Outcomes of previous idea generation activities • List of design solutions from the analysis insights • List of leverage points from the analysis insights • List of design solutions proposed in previous research or solutions implemented in other jurisdictions • Post-it notes • Wall space for placing post-it notes
Format	Whole group activity and discussion

Steps	• Introduce the activity
	• Summarise the outcomes of the previous design activities and the design solutions proposed / implemented previously
	• Provide copies of all of the ideas and post-it notes
	• Participants transpose each idea onto an individual post-it note and place them on the wall
	• Participants move the ideas around on the wall so that similar ideas are located together in themes, with redundant / duplicate ideas removed during the process
	• Once ideas have been categorised into themes, they are labelled (write theme label on the post-it note)
	• Next, define different levels of the system on the wall, this may be a small circle (physical interaction), within a larger circle (organisational system), within a larger circle (socio-political environment). Place the ideas within this framework
	• Discuss gaps in terms of levels of intervention
	    1. Are all the ideas focused on the physical system?
	    2. Do the ideas relate to the leverage points identified?
	    3. Add any new ideas that arise
	• Create labels of the themes and place them down the wall (as rows)
	• Create labels of the different elements of the system and place them across the wall (as columns)
	• Move the ideas into this matrix
	• Brainstorm new ideas to fit an empty cells within the matrix
	• Each theme can then be documented and summarised as a

	design concept
Time requirements	Approx 4 hours
Recommended for	All design projects
Further information	Liedtka, J. & Ogilvie, T. (2010). *Designing for growth: A design thinking tool kit for managers.* New York: Columbia Business School Publishing.

Rapid prototyping

Background	Design ideas can be given form early in the design process to prompt further ideas and to test assumptions about how people will interact with the finished design. Asking small groups to develop prototypes and mock ups of design ideas provides diverse solutions of which the best aspects can be combined.
Materials	• Materials for prototyping such as paper, clay, Lego, cardboard, wood, etc.
Format	Small group work
Steps	• Introduce the activity • Introduce the materials available and any instructions or rules regarding the use of the materials (especially health and safety procedures if necessary) • Monitor groups and encourage them to work quickly and to focus on testing throughout the process and making changes to improve the design, rather than creating a perfect product • Ask each group to present their prototype to the larger group for discussion and critique. Groups should be encouraged to share information about the failures or difficulties they uncovered and how they overcame them.
Time requirements	Approx 4-5 hours
Recommended for	All design projects involving a tangible user interface
Further information	Erickson, T. (1995). Notes on design practice: Stories and prototypes as catalysts for communication. In J.M. Carroll (Ed.) *Scenario-based design: Envisioning work and technology in system development* (pp 37-58). New York: John Wiley & Sons Inc.

Documenting design concepts

Background	The design ideas and concepts generated by design participants need to be documented to enable them to be shared. Further, a documented form of a design idea, such as a sketch, enables refinement as the designer can engage in reflection on the design artifact created. This is not possible when ideas are discussed on verbally and do not take a tangible form.
Materials	• Design concept template (see page 78) • If using prototyping / modelling – polaroid or other instant photo of models, mock- ups, etc.
Format	Small group work or individual work if appropriate
Steps	• Introduce the need to document design concepts during or following activities such as affinity diagramming, or other points in a workshop where there is an opportunity to draw together design ideas • Introduce the design concept template • Encourage participants to draw sketches, write text or use the template with other materials being used such as physical models or prototypes • Towards the middle of the time allotted, remind participants to fill out all of the template (i.e. provide a name, identify the design hypothesis, etc.) • Ask each group to present their concept to the wider group for discussion and critique
Time requirements	Approx 1 hour
Recommended for	All design projects
Further information	See page 78 for the Design concept template

Envisioning cards for exploring design concepts

Background	The importance of human values in design is emphasized in sociotechnical systems theory. Design often requires values to be traded-off and it is preferable for this to occur explicitly. The envisioning cards can provide a prompt for considering the implications of the design concepts identified in relation to the themes of stakeholders, time, values, and pervasiveness.
Materials	• The envisioning cards • Post-it notes
Format	Individual brainstorming followed by group discussion.
Steps	• Introduce the activity • Introduce the envisioning cards • Distribute a card to each participant • Ask participants to consider the design concepts on the wall in relation to the issue prompted by the card • Participants write implications on post-it notes and add to the design concept/s • Participants describe the implications to the group • Group discussion regarding the implications, changes to design concepts made as relevant • Repeat with further cards (recommended to use at least two cards per participant)
Time requirements	Approx 1 hour
Recommended for	All design projects
Further information	Friedman, B. & Hendry, D.G., 2012. The Envisioning Cards: A toolkit for catalyzing humanistic and technical imagination. *Proceedings of CHI'12 - the SIGCHI Conference on Human Factors in Computing Systems.* New York: ACM Press, 1145-1148. Cards available from www.envisioningcards.com

Refining design concepts through sociotechnical systems theory principles

Background	While it is expected that the introductory activities and idea generation exercises will assist to promote design ideas that align with the sociotechnical systems theory approach, it is important to continue to place focus on the principles. One way to do this is to introduce, throughout workshops or design sessions, opportunities to assess design ideas or design concepts against the principles and make appropriate changes and refinements.
Materials	• Sociotechnical systems theory principles with definitions and criteria (see Appendix E)
Format	Small group work and discussion.
Steps	• Introduce the activity • Ask participants to consider a design concept or idea that they have generated and consider to be promising in meeting the design brief • Introduce the sociotechnical systems theory content principles evaluation template • Ask participants to work in small groups to rate their design concept against each principle and provide any comments regarding rationale for the ratings and any design refinements • Participants are encouraged to ask questions if they need clarity about the meaning of the concepts • Once the evaluation is completed, ask participants to review the low scoring principles and the design refinements and create a refined concept that better aligns with the principles
Time requirements	Approx 1.5 hours for a full concept, shorter time period for a less comprehensive idea.
Recommended for	All design projects
Further information	Clegg, C.W. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*, 463-477. Cherns, A. (1976). The principles of sociotechnical design. *Human Relations, 29*, 783-792. Cherns, A. (1987). Principles of Sociotechnical Design Revisited. *Human Relations, 40*, 153-161.

Appendix E: Sociotechnical systems theory content principles evaluation template

Content principle	Description	Indicators / measures	Rating (1 to 3)	Comments / reasoning / refinements required
Tasks are allocated appropriately between and amongst humans and technology	The design of work and equipment should be based on the complementarity of people and machines and not on competition between them. Recognition of the unique capabilities of humans as adaptive elements in systems of machines and people are essential to the design and effective functioning of organisations (Davis, 1982). Tasks involving unpredictable contexts and involving judgment should be allocated to humans rather than computers (Clegg, 2000).	• Users are provided with appropriate tasks, i.e. not monotonous tasks that can be performed by technology with human supervision, but those that provide appropriate challenge • Users are given tasks where there is unpredictability such that judgment and interpretation is needed		
Useful, meaningful and whole tasks are designed	A process perspective should be taken where people are responsible for conducting, supervising or managing complete processes. People should have the authority and resources to do this. A job should incorporate a whole task, rather than a fragmented part of whole (Clegg, 2000).	• Users are given whole tasks, rather than fragmented pieces of tasks to perform • Users perceive the tasks they are performing to be meaningful or useful		
Boundary locations are appropriate	Boundaries exist between functional units or groups. Core processes should not be split across these artificial boundaries (Clegg, 2000). Further, boundaries should not be drawn that impede communication and the sharing of knowledge, experience and learning (Cherns, 1987).	• Boundaries or divisions between users or user groups are based on whole processes • Boundaries do not impede sharing of knowledge and experience		

Content principle	Description	Indicators / measures	Rating (1 to 3)	Comments / reasoning / refinements required
Boundaries are managed	The focus of a supervisor or manager should be the management of boundary activities such as ensuring the group has sufficient resources, is coordinating with other groups, and predicting changes that may impact on their activities (Cherns, 1976). The supervisor provides the work group with a buffer to protect them from external disturbances or changing demands, and supports them through provision of resources and training (Davis, 1982). Boundaries may be created and managed by the work group itself, by defining the rules and processes that constrain their activities and participating in the ongoing revision and update of rules (Hirschhorn *et al.* 2001).	• The design facilitates supervisors, users or user groups to manage the boundaries or interfaces with other users or groups • Boundary management incorporates buffering from external disturbances or changes in the wider environment • The design empowers users to define the rules and processes that constrain their activities		
Problems are controlled at their source	Problems or variances (unprogrammed events that critically affect objectives) should be controlled as near to their point of origin as possible (Cherns, 1976). Problems include behaviours (errors) that can have negative consequences in the system. Designing to promote learning from problems or variances is beneficial (Sinclair, 2007). For example, inspections for variances in product quality should not occur once the product is finalised but should be incorporated in the production process to enable workers to check their own work and learn from their mistakes (Cherns, 1976). Users should have access to the means for controlling or resolving problems and the necessary authority or competency to do so	• The design facilitates the detection of, and recovery from problems (including negative behaviours) at the time and place at which they occur • The design provides people with the competency and authority to control problems		

Content principle	Description	Indicators / measures	Rating (1 to 3)	Comments / reasoning / refinements required
	(Davis, 1982).			
Design incorporates the needs of the business, users and managers	Consideration should be given to the goals of the business / the objectives of the overall system as well as to the goals of employees, managers and any other end users (Clegg, 2000).	• The design meets identified business needs • The design meets identified user needs		
Intimate units and environments are designed	Organisational and physical structures should provide smaller and more intimate environments for individuals and groups (Davis, 1982).	• The design creates a feeling of being in a small / intimate environment • Where teams or groups are created, these are small to provide opportunities for social interaction / social cohesion / a feeling of belonging		
Design is appropriate to the particular context	Design choices do not necessarily have universal applicability. Choices must be based on the context of operations, the goals to be achieved, the local context of implementation, etc (Clegg, 2000). The design should suit the specific situation and context and requires individualised design rather than imported or copied solutions.	• Local features / issues are taken into account in the design or the design can be customized for local implementation • The design is created for the specific design brief, rather than being an off-the-shelf solution		
Adaptability is achieved through multifunctionalism	There is a need for systems to adapt to ever changing environments. The system needs a repertoire of responses to environmental changes (Cherns, 1976, 1987). Ashby's Law of Requisite Variety proposes that it is people who have the knowledge, flexibility and agility to	• The design promotes multi-skilling of individuals • The design promotes collaboration between individuals with varied skills		

Content principle	Description	Indicators / measures	Rating (1 to 3)	Comments / reasoning / refinements required
	provide that response – providing organizational resilience (Sinclair, 2007). This can be achieved by training and multiskilling people to enable them to perform multiple functions and to assist in tasks outside of their normal area during unpredictable events, emergencies or when change occurs (Cherns, 1976). It may not be possible or desirable for all individuals to have all skills. In such cases dynamic collaboration is needed between those with different knowledge and experiences (Hirschhorn *et al.* 2001).	and experience		
Adaptability is achieved through flexible structures and mechanisms	Self-maintaining units or groups exist which have the capability to perform all the activities required to achieve its specific goals under a wide variety of contingencies. The unit is flexible and can adapt itself to changing environmental demands (Davis, 1982).	• The design incorporates units or groups which are multi-skilled and flexible to changing demands		
Information is provided where action is needed	Information systems should be designed to provide information where action on the basis of the information will be required (Cherns, 1976). It should provide information to those taking action rather than those controlling or monitoring the system (Davis, 1982). Information systems should provide the right type and amount of feedback to users to enable them to learn from experience and to anticipate events (Cherns, 1976).	• Information systems are consistent with the way work will be organised • Information is presented in line with the mental model of the decision maker, or any conflicts are resolved through additional methods such as training • The information gets to the person making the decision • The information gets to the person making the decision at		

Content principle	Description	Indicators / measures	Rating (1 to 3)	Comments / reasoning / refinements required
		the right time • The information provided is in an appropriate format and at an appropriate level of detail to enable the receiver to make the decision and take necessary action. The information is usable, not unnecessarily complex • Information is provided to users about what is expected of them and feedback is provided on their progress towards targets / measures		
Means for undertaking tasks are flexibly specified	While it is important to specify what is essential, no more than necessary should be specified. Design should make it clear what needs to be achieved (the ends) but it is often unnecessary to specify how it must be achieved (the means) (Cherns, 1976). The design may evolve over time. It can be initially implemented as a rudimentary design, and then developed as the needs of the operators become clear, and as their responsibilities develop (Clegg, 2000). The design should avoid over specifying how tasks must be performed as this limits adaptability. Users, as local experts, should be allowed to solve their own problems and develop their own methods of working, thereby incorporating scope for learning and innovation (Clegg, 2000).	• The design is not overly specified enabling it to evolve over time in line with changing user needs and preferences • The means for carrying out tasks and activities is not unnecessarily restrictive • The design empowers users to solve their own problems and develop their own ways of achieving outcomes		

Content principle	Description	Indicators / measures	Rating (1 to 3)	Comments / reasoning / refinements required
Authority and responsibility are allocated appropriately	Those who require access to equipment and resources should have the authority to access and command them. In return they accept responsibility for their prudent use (Cherns, 1987). Further, differentials in status and privilege should be minimized where they are unnecessary to the achievement of goals (Davis 1982). Finally, authority should be distributed so that people doing the work are empowered to make appropriate decisions according to their role (Sinclair 2007).	• The design places appropriate authority on users • The design engenders appropriate levels of responsibility • The design minimizes status differentials between groups or individuals		
System elements are congruent	A new design needs to be congruent with surrounding systems and practices to facilitate implementation. However, it may be that a new system requires some accommodation by the systems into which it is being placed. It may prove to be a catalyst for change (Clegg, 2000). Further, there needs to be compatibility between roles and goals (Sinclair, 2007).	• Elements of the design are in harmony with one another – users will not perceive a conflict • The design is in harmony with the existing system or changes to the existing system are planned to facilitate the implementation of the new design • Targets and measures are fair and reasonable and support the design of work. For example, if team working is part of the design, information and reward on individual performance is not appropriate • Designs are incorporated within, and consistent with, the wider management system		