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 paper explores the extent to which CWA and sociotechnical systems theory offer complementary perspectives and presents an abstraction hierarchy, based on a review of literature, that describes an ‘optimal’ CWA and sociotechnical systems theory design system. The optimal abstraction hierarchy 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.

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

Practitioner Summary: Cognitive work analysis 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 cognitive work analysis and sociotechnical systems design principles, recommendations for a design toolkit are specified.

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 et al. 2010a, 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). Further, 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 et al. 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
paper 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 and colleagues (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 organisations that exhibit open system properties and can thus cope better with environmental complexity, dynamicism, new technology and competition’ (p 480). In this paper 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. So, 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 paper aims to examine these two systems-based approaches with an emphasis on the synergies between them. The paper 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 will be 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 et al. 2008b), air traffic control (e.g. Ahlstrom 2005), disaster management (e.g. Jenkins et al. 2010a), healthcare (e.g. Miller 2004), road transport (e.g. Cornelissen et al. 2013) and rail transport (e.g. Stanton et al. 2013a). 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 et al. 2010a, Mendoza et al. 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. Further, 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 et al. 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 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).
Application of sociotechnical systems theoretical approaches to successful system design / re-design have been reported in the literature. For example, Pasmore and colleagues (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. Further, 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). Further, 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 et al. 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. Further, 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 and colleagues (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 and colleagues (2009).
### Table 1. Alignment of sociotechnical systems principles and the CWA framework

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<th>Sociotechnical systems principles (adapted from Walker et al. 2009)</th>
<th>CWA framework</th>
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<td>The technical system does not exist in isolation, rather the social and the technical system have to be designed together.</td>
<td>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 abstraction hierarchy 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.</td>
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<td>Top-down design approaches are appropriate for complicated, large scale problems, bottom-up approaches are appropriate for complex, emergent problems. Sociotechnical systems theory and human factors integration is about achieving the correct balance.</td>
<td>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 abstraction hierarchy 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 abstraction hierarchy 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.</td>
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<td>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.</td>
<td>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.</td>
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<td>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.</td>
<td>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.</td>
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<td>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.</td>
<td>As described above, 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.</td>
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<td>Design of systems should produce useful, meaningful, effects-based, whole tasks which enable people to see the</td>
<td>Vicente (1999) discusses the need to design for safety, productivity and worker health. Vital to supporting worker health is design that maximises decision latitude by</td>
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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 ongoing design, CWA outputs provide a useful medium for communication (e.g. Stanton and Bessell 2014).

Systems should be congruent with existing practices which may on occasion appear archaic compared to 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.

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 et al. 2013).

1.4 Design approach development

But what might such a design approach entail? This paper will attempt 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 paper will use 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 paper 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 for a 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 paper 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’, ‘sociotechnical’, ‘cognitive work analysis’, ‘human factors methods’, ‘ergonomics methods’, ‘methodological attributes’, ‘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 original 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 will firstly describe the boundaries of the analysis and will 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/s for which the system is intended to fulfil; it’s reason for being. As shown in Figure 1, the functional purpose 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 firstly, 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 fourteen generally accepted methodological attributes. These are outlined in Table 2 with some examples of supporting statements from the literature.
Table 2. HFE methodological attributes synthesised from the literature

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<th>Attribute</th>
<th>Definition</th>
<th>Selected supporting literature</th>
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<td>1. Creativity</td>
<td>Design process facilitates creativity and / or innovation</td>
<td>- Design is a creative process that should not be controlled by formal, normative procedures. Designers are inspired through the findings of the analyses (Rasmussen et al. 1990).&lt;br&gt; - Design problems require innovation and new perspectives. Needs to be an opportunistic and explorative process (Militello et al. 2010).&lt;br&gt; - Need to maintain creativity in the design process (Hajdukiewicz and Burns 2004).&lt;br&gt; - A challenge for HFE is supporting the creative features of the design process (Norros 2014).</td>
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<td>2. Efficient</td>
<td>Design process is efficient and / or cost effective</td>
<td>- Resources consumed in the analysis and design processes should be proportionate to the benefits gained (Potter et al. 1998).&lt;br&gt; - Criteria for evaluating HFE methods have included efficiency (Hoffman et al. 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).&lt;br&gt; - 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 et al. 1997).</td>
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<td>3. Holistic</td>
<td>Design process supports coordinated design of all system elements (e.g. interfaces, training, support materials, team structures)</td>
<td>- All aspects of a system should be designed in a coordinated fashion (Vicente 2002).&lt;br&gt; - 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).&lt;br&gt; - The discipline of HFE is holistic. Its outputs need to consider the impact on all stakeholders and should enhance multiple goals (Wilson 2014).</td>
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<td>4. Integrated</td>
<td>Design process can integrate with existing systems engineering processes</td>
<td>- It is important that design processes integrate with system design and development processes (Bisantz et al. 2003, Gualtieri et al. 2005) and are consistent with existing tools and methods (Clegg et al. 1996).&lt;br&gt; - 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).</td>
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<tr>
<td>5. Iterative</td>
<td>Design process facilitates iteration</td>
<td>- 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).&lt;br&gt; - 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).&lt;br&gt; - The boundaries of the system are continually reconsidered as the design process progresses (Edwards and Jensen 2014).&lt;br&gt; - Design processes need to be iterative to enable opportunism and innovation (Militello et al. 2010).&lt;br&gt; - Iteration enables decisions to be amended and re-evaluated as the process proceeds (Older et al. 1997).</td>
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<td>6. Reliable</td>
<td>Design process produces consistent results each time it is applied</td>
<td>- 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).&lt;br&gt; - A method cannot be valid if it is not reliable (Gawron 2000).&lt;br&gt; - Reliability is concerned with whether measurements are repeatable and accurate (Gawron 2000) between different analysts (Stanton and Stevenage 1998, Baber and Stanton 2002, Baysari et al. 2011) and within the same analyst over time (Annett 2002, Baber and Stanton 2002).&lt;br&gt; - Criteria for evaluating HFE methods have included evidence of reliability (Hoffman et al. 1998, Patrick et al. 2006, Stanton et al. 2013b).</td>
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<td>Attribute</td>
<td>Definition</td>
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| 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 et al. 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). |
| 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 et al. 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 et al. 1997).  
- Methods should be flexible (Clegg et al. 1996, Hoffman et al. 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 et al. 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 et al. 2011).  
- A method that is usable and straightforward to learn is more likely to be selected for use in practice (Older et al. 1997) and will promote better consistency amongst analysts and less errors than one which is difficult to use (Baysari et al. 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 et al. 1998, Koudek et al. 2003, Stanton et al. 2013b). |
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Selected supporting literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. Worker / user involvement</td>
<td>Workers / end users are involved in the design process</td>
<td>- 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 et al. 2002).</td>
</tr>
</tbody>
</table>
### 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, 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.** 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, Cherns 1987). As an underpinning principle, understanding and respecting different preferences and ways of working amongst those involved in the design process is also important.

**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 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 and implementation processes, as well as system operation.

### 3.3.3 Sociotechnical system 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 paper 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.
Table 3. Sociotechnical systems theory content principles.

<table>
<thead>
<tr>
<th>Content principle</th>
<th>Adapted from previously proposed sociotechnical systems theory principles</th>
</tr>
</thead>
</table>
| 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, Cherns 1987, Davis 1982)  
- Core processes should be integrated (Clegg 2000)  
- The workgroup creates boundaries (Hirschhorn et al. 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 et al. 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, Cherns 1987)  
- Multifunctionalism (Davis 1982)  
- Design entails multiple task allocations between and amongst humans and machines (Clegg 2000)  
- Dynamic complementarity (Hirschhorn et al. 2001)  
- Provide multi-functionality 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, Cherns 1987, Davis 1982)  
- Management support (Robinson 1982)  
- System components should be congruent (Clegg 2000) |
<table>
<thead>
<tr>
<th>Content principle</th>
<th>Adapted from previously proposed sociotechnical systems theory principles</th>
</tr>
</thead>
</table>
| Adapted from previously proposed sociotechnical systems theory principles         | - 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, Cherns 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, Cherns 1987, Davis 1982)  
- Core processes should be integrated (information systems should match the task) (Clegg 2000)  
- Feedback (Sinclair 2007) |
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 paper, 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 et al. 2010b). 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 system theory process principles and from generic system design processes.

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 the table.
<table>
<thead>
<tr>
<th>Process principle</th>
<th>Adapted from previously proposed sociotechnical systems theory principles</th>
</tr>
</thead>
</table>
| 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, Cherns 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)  
- Multi-disciplinary 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 redesign | - 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)
3.5.2 System design processes

In addition to the sociotechnical system 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.

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

The above 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). Further, 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. Further, 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.
 Functional purposes (see section 3.2)

Values & priority measures (see section 3.3)

Purpose-related functions (see section 3.4)

Object-related processes (see section 3.5)

Figure 2. ‘Optimal’ CWA-STS design system AH.
Figure 3. Representation of the AH focusing on the Design planning function.
Functional purposes

Values & priority measures

Purpose-related functions

Object-related processes

Support system design

Maximise creativity

Multidisciplinary participation & learning

Figure 4. Representation of the AH focusing on the Concept design function.
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. Firstly, to refine the values and priority measures within the ‘optimal’ CWA-STTS design system AH and secondly, to populate the fifth level of abstraction; the physical objects.

Having developed the optimal AH, it was considered that the number of values and priority measures (13 methodological attributes, five 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 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 respondents would generally use in design with CWA. The final section focused 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 sub-set 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 Appendix 1.

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 one year up to 30 years, with the majority of respondents having used CWA for ten 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 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).

5.2. Refining the value & priority measures of the AH

As shown in Appendix A, 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, Valid. These were identified as values and priority measures that should be incorporated in the refined AH, 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.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Average ranking</th>
<th>Weighted score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative</td>
<td>9.35</td>
<td>18</td>
</tr>
<tr>
<td>Efficient</td>
<td>9.15</td>
<td>12</td>
</tr>
<tr>
<td>Holistic</td>
<td>9.35</td>
<td>12</td>
</tr>
<tr>
<td>Integrated</td>
<td>8.2</td>
<td>3</td>
</tr>
<tr>
<td>Iterative</td>
<td>8.7</td>
<td>7</td>
</tr>
<tr>
<td>Reliable</td>
<td>6.95</td>
<td>11</td>
</tr>
<tr>
<td>Stakeholder involvement</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Structured</td>
<td>7.9</td>
<td>15</td>
</tr>
<tr>
<td>Tailorable</td>
<td>7.55</td>
<td>5</td>
</tr>
<tr>
<td>Theoretical</td>
<td>6.6</td>
<td>5</td>
</tr>
<tr>
<td>Traceable</td>
<td>5.7</td>
<td>3</td>
</tr>
<tr>
<td>Usable</td>
<td>7.35</td>
<td>9</td>
</tr>
<tr>
<td>Valid</td>
<td>6.25</td>
<td>12</td>
</tr>
<tr>
<td>Worker / user involvement</td>
<td>6.6</td>
<td>5</td>
</tr>
</tbody>
</table>
Figure 5. Refined AH, incorporating the prioritised values and priority measures.
5.3 Using the abstraction hierarchy 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. Within 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 & planning for the transition period or that focus on the system in operation to assist Iteration & 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 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 situations. Further, *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 et al. 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 et al. 2008a). 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 Mclroy 2012).
Figure 6. Representation of the AH displaying the physical objects supporting the Design planning function.
Figure 7. Representation of the AH displaying how the CWA outputs support the object-related processes and purpose-related functions of the AH.
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. Further, 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 et al. 2011).

6. Using the abstraction hierarchy 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 & 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.
Table 6. Design requirements for a CWA-STS design approach

<table>
<thead>
<tr>
<th>Design requirement</th>
<th>Description</th>
</tr>
</thead>
</table>
| 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 & design refinement and testing & 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. |

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

<table>
<thead>
<tr>
<th>Values &amp; priority measures</th>
<th>Evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative</td>
<td>The design approach facilitates creativity and / or innovation</td>
</tr>
<tr>
<td>Structured</td>
<td>The design approach provides structure to the design process</td>
</tr>
<tr>
<td>Holistic</td>
<td>The design approach supports coordinated design of all system elements, e.g. interfaces, training, support materials, team structures</td>
</tr>
<tr>
<td>Integrated</td>
<td>The design approach can integrate with existing systems engineering processes</td>
</tr>
<tr>
<td>Efficient</td>
<td>The design approach provides a process that is efficient and / or cost effective</td>
</tr>
<tr>
<td>Valid</td>
<td>The design approach does what it says it will do; i.e. produces effective designs / designs sociotechnical systems with adaptive capacity</td>
</tr>
<tr>
<td>Iterative</td>
<td>The design approach facilitates an iterative design process</td>
</tr>
<tr>
<td>Process aligns with sociotechnical values</td>
<td>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.</td>
</tr>
<tr>
<td>Outcome aligns with content principles</td>
<td>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).</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Object-related process</th>
<th>Current physical objects</th>
<th>Example potential physical objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adoption of agreed values &amp; purposes</td>
<td>Project stakeholders</td>
<td>- Guidance to introduce and communicate sociotechnical systems values and principles</td>
</tr>
<tr>
<td></td>
<td>End users</td>
<td>- Tools and technique/s to draw out &amp; test stakeholder values and assumptions (e.g. Mumford 1995)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Use of stories (e.g. Erickson 1995) to communicate values and assumptions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Analysis brief (e.g. Liedtka and Ogilvie 2010) documenting agreed values and purposes</td>
</tr>
<tr>
<td>Provision of resources &amp; support</td>
<td>Project stakeholders</td>
<td>- Project planning methodologies, e.g. Gantt chart can assist to estimate resources required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Analysis brief (Liedtka and Ogilvie 2010) outlining agreed resources for analysis phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Design brief (Liedtka and Ogilvie 2010) outlining agreed resources for design phase</td>
</tr>
<tr>
<td>Adoption of appropriate design process</td>
<td>Project stakeholders</td>
<td>- 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)</td>
</tr>
<tr>
<td>Design &amp; planning for transition period</td>
<td>Scenarios (focussed on transition issues)</td>
<td>- Statement of agreed values and purposes (documented in analysis brief) acknowledging the transition period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Design brief (Liedtka and Ogilvie 2010) acknowledging the need to design the transition period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Business process maps (Neumann and Village 2012) for the transition period</td>
</tr>
<tr>
<td>Constraints are questioned</td>
<td>N/A</td>
<td>- Statement of agreed values and purposes (documented in analysis brief) to outline support for questioning system constraints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Design brief (Liedtka and Ogilvie 2010) to outline support for questioning system constraints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Guidance for questioning constraints, e.g. for challenging assumptions underlying the current design</td>
</tr>
<tr>
<td>Iteration &amp; planning for ongoing evaluation &amp; re-design</td>
<td>Scenarios</td>
<td>- Statement of agreed values and purposes (documented in analysis brief) acknowledging ongoing evaluation and re-design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Design brief (e.g. Liedtka and Ogilvie 2010) should explicitly include this in the scope of the project</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Stories (Erickson 1995) that raise future needs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Agent-based modelling and simulation tools (e.g. Hughes et al. 2012) such as Brahms modelling software (Clancy et al. 1998, Lintern 2005)</td>
</tr>
<tr>
<td>Documentation of how choices constrain subsequent choices</td>
<td>Software tools</td>
<td>- Guidance for using the AH to evaluate the impact of choices</td>
</tr>
<tr>
<td></td>
<td>AH / ADS</td>
<td>- Template and guidance for documenting design choices and considering their impact</td>
</tr>
<tr>
<td>Stakeholder needs analysis</td>
<td>Stakeholder analysis documentation</td>
<td>- Stakeholder object world representations (Naikar 2013)</td>
</tr>
<tr>
<td></td>
<td>Subject matter experts</td>
<td>- Global organisational analysis documentation (Cummings and Guerlain 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Envisioning Cards for value sensitive design (Friedman and Hendry 2012)</td>
</tr>
<tr>
<td>Joint design of social and technical components</td>
<td>AH / ADS</td>
<td>- Statement of agreed values and purposes (documented in analysis brief) should state that design will not be technology-led</td>
</tr>
<tr>
<td></td>
<td>Scenarios</td>
<td>- Envisioning Cards for value sensitive design (Friedman and Hendry 2012)</td>
</tr>
<tr>
<td>Political debate</td>
<td>N/A</td>
<td>- Design brief (e.g. Liedtka and Ogilvie 2010), should build in time and flexibility to enable this to occur</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Stories (Erickson 2002) that raise issues for debate and promote understanding and empathy among participants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Envisioning Cards for value sensitive design (Friedman and Hendry 2012)</td>
</tr>
</tbody>
</table>
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, 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, 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 above.
The aim of this paper 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 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 cannot 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 system 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 if 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 et al. 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 and colleagues (2014).

Further research will be required to evaluate the effectiveness of the toolkit against the evaluation criteria specified in this paper. 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.
References


Appendix 1. Sub-set 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 ☐
- Skills, rules, knowledge (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.

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

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?