# Application of Cognitive Work Analysis in early Phases of a Complex System Development Project

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**Abstract**. Systems engineering (SE) is applied to bring about complex systems, such as sociotechnical systems (STS), based on stakeholder requirements. The introduction of new technology into an existing STS may result in unexpected emergent behaviour when prevailing processes, procedures and information flows are challenged. Due to the complexity associated with emergence, the resultant system may fail to achieve the desired utility fully, or the work system produced may not be desirable. Cognitive work analysis (CWA) provides a framework for analysing, modelling, and designing STS. This study proposes applying CWA modelling to requirement analysis for new technology introduction as part of a validation workflow in aid of SE. Work domain analysis (WDA), the first step in the CWA framework, is applied to a test case and the resultant abstraction hierarchy (AH) models analysed to evaluate the perceived utility. This article shows how analysts were able to apply the method and uncover possible design emergence. We hope that the methods presented herein will aid more designers in the application of CWA as part of the SE life-cycle toward the successful implementation of complex STS.

## Introduction

A system can be loosely defined as any set of integrated components or elements that work together to accomplish a common objective (Kossiakoff et al. 2011, Walden et al. 2015). SE as a discipline is concerned with the successful production of systems that addresses defined user requirements, established development objectives, ideal performance in the application environment and the achievement of desired operating life. SE is commonly applied to the development of complex systems. Transforming and refining the mental vision and needs of the system stakeholders into a set of measurable requirements is one of the first steps of project execution. These requirements form a golden thread that ties any project together from beginning to end (Scribante 2019).

The development of complex systems requires multidisciplinary collaboration from a team that shares a common understanding of the design and user requirements. Sources of complexity may include the number and diversity of components, the degree of interaction between components, the integration of independently useful and locally optimised subsystems (Kossiakoff et al. 2011). Thus, the relationships between the components and subsystems, and their originating requirements must be captured early, communicated thoroughly and frequently revisited (London 2012).

The introduction of new technology, such as a human-machine interface (HMI), often leads to additional task possibilities that evolve user requirements and bring about new and emergent behaviour

(Carroll & Rosson 1992, Blanchard & Fabrycky 1990). These behaviours are in turn associated with an increase in unforeseen, complex and counter-intuitive consequences. The consequences may include valuable properties such as robustness, adaptability and flexibility; but may also afford undesirable capabilities such as the ability to undermine the safe operation of the system (Fromm 2006).

Predicting unintended emergent behaviour and anticipating potential challenges to adopting technology is invaluable to the transformation process. Unfortunately, few systems techniques exist for knowledge exploration and concept development that effectively envisions future operations and systems performance (Shadrick et al. 2005, Lintern 2008). Classic SE processes alone seem inept at addressing this. The application of STS modelling may provide an improved approach (Oosthuizen 2014).

CWA is used to analyse cognitive work to inform the design of information systems (IS). It provides a framework for the analysis, modelling, and design of STS. The application of CWA results in models that capture the structure of the problem and which functions provided by technology are associated with system requirements. Thus, CWA provides constructs that aid in the understanding of STS and informs design and requirements analysis (Naikar 2011, Lintern 2012a, Oosthuizen & Pretorius 2013).

At the onset of any project, design freedom is highest and diminishes as design decisions are made. As such, capturing a complete set of requirements early on is vital to achieving an STS that delivers on client requirements without disrupting existing operations (London 2012). This study evaluates the benefits of supporting the SE process through STS modelling by applying CWA to the early phases of system design for HMIs and requirement analysis. The following section will first discuss the issues surrounding the development of complex STS before proposing CWA as a modelling and development approach. This approach is then demonstrated in a real-world system. Finally, the implementation is validated through focus groups with subject matter experts (SMEs).

## Development of Complex Sociotechnical Systems

The elements that comprise a system may include people, products, processes, techniques, services and facilities alike (Walden et al. 2015). A key attribute of a system is that it exhibits a behaviour pattern or characteristic not shown exclusively by its constituents' inherent abilities and behaviours. These characteristics are known as emergent properties. These emergent properties drive systems development throughout the execution of projects (Blanchard & Fabrycky 1990, Kossiakoff et al. 2011, Walden et al. 2015).

Walden et al. (2015:9) indicate that the traditional and disciplined SE approach to the system development process kicks off with a complete set of clear user requirements. Scribante (2019) noted how vital a thorough set of requirements are for success in all phases of SE and the project as a whole. Equally important, these requirements should be a refinement of the combined mental image of all the stakeholders. The decisions during all phases of systems development should consider the impact on the stakeholders, who ultimately seek the benefit of the system, and should be traceable back to requirements established at the onset.

Complex systems are characterised by a high level of emergence. The interactions between the persons, products and processes give rise to emergent properties. Emergence is the perceived difference in properties and patterns of behaviour at the micro and macro levels (Fromm 2006, Oosthuizen et al. 2011). Not all emergent properties are by design, nor are they all beneficial. Engineering, however, aims to impose the function and purpose of the macro-level system by defining the micro-level element properties and processes. Therefore, autonomy, self-optimisation, and self-organisation stand in contrast to this fundamental goal (Stepney et al. 2006, Johnson 2006, Oosthuizen et al. 2011).

It has long been argued that consultation with cognitive engineers does not occur early enough during the design of large-scale systems. Their involvement is only sought out after human integration issues have already started to surface. Correcting these human integration problems after the fact tends to be very expensive. These expenses could be avoided if human integration is considered earlier in the SE process, preferably no later than concept development (Lintern 2008).

The term "sociotechnical" draws from the word socio, meaning people or society, and the word technical related to machines and technology (Walker et al. 2008). Thus, a system in which humans apply technology to perform work associated with processes within a social structure, such as an organisation or a firm, and which are intended to realise specific objectives, is known as an STS (Bostrom & Heinen 1977, Walker et al. 2009, Oosthuizen 2014). Fred Emery and Eric Trist first observed the relevance of the interaction between the human actors and the technological artefacts in the context of their research on work systems. Their work was undertaken during the 1950s when introducing new mining technology failed to have the expected efficiency and productivity improvements foreseen. This was due to a lack of consideration for the resulting changes to work practices which ultimately highlighted the need to consider behavioural changes during system integration (Trist 1981, Baxter & Sommerville 2011).

The STS theory is concerned with the joint optimisation of both systems and organisations' technical and social components (Walker et al. 2008). Trist (1981) explains that although independent in how their actions are governed, the social and technical systems correlate in the sense that one requires the other to fulfil the purpose of the joint system. Thus, the technical and social systems require joint optimisation since local optimisation is likely to result in suboptimal system performance and utility. It, however, remains primarily associated with the introduction of new technology, yet its influence on the way jobs are designed and work is organised cannot be refuted (Trist 1981, Baxter & Sommerville 2011).

The cognitive processes and procedures at work in an STS develop over time and become effective and robust. This is in part due to situated cognition and the self-organising nature of the STS. However, existing processes, procedures and information flows are challenged during the introduction of new technologies, concepts and methods and may lead to disruptions or even inability of functional performance (Shadrick et al. 2005, Lintern 2008). Therefore, understanding the dynamic interactions between the constituent components and processes within an STS and predicting the impact of new technologies on the cognitive process is vital.

Hollnagel and Woods (1983) first defined the concept of a cognitive system as "an adaptive system which functions using knowledge about itself and the environment in the planning and modification of actions". However, this definition was later adjusted to that of a system with the ability to "modify its behaviour based on experience to achieve specific anti-entropic ends" (Hollnagel & Woods 2005 as quoted by Hollnagel 2012). This adaptive ability is known as self-organisation and is associated with the emergence in cognitive systems. Thus, an STS invariably performs cognitive work and is a cognitive system (Hollnagel & Woods 1983, Hollnagel 2012, Lintern 2008).

New abilities emerge when tasks are undertaken within the constraints imposed by the cognitive structures. Thus, the introduction of new technology results in an emergence of affordances and constraints to the work domain, some of which are unexpected and unpredictable (Lintern 2008). Therefore, designs for human work need to focus on a functional work structure that shapes effective and robust work ways through goal-oriented constraints (Lintern 2008, Carroll & Rosson 1992, Lintern 2012b).

Due to the non-linear and dynamic interaction between people, technology and the environment, the complexity of work can increase. The development of STS often involves the introduction of new technology into the existing system. It also usually consists of the technocentric replacement of only components or subsystems. Due to the limited scope of such replacements, the influence on the greater STS is largely neglected. Although SE is applied during this endeavour, little attention is paid to the cognitive system aspects, resulting in unforeseen and sometimes unwanted affordances. The development of STS can be supported by effective modelling and analysis of the elements of the problem and solution spaces (Bostrom & Heinen 1977, Walker et al. 2009, Oosthuizen 2014, Oosthuizen & Pretorius 2015, Oosthuizen & Pretorius 2016).

## Cognitive Work Analysis

Modelling methods such as CWA aids in the development of user and design requirements to provide models that facilitate interdisciplinary communication and dialogue (London 2012, Birrell et al. 2012, Read et al. 2015). Walden et al. (2015) define human systems integration (HSI) as "the interdisciplinary technical and management process for integrating human considerations within and across all system elements". Although the criticality of HSI had long been known, it was only formally recognised as a crucial component of SE around two decades ago and has since seen real emphasis. The focus can be attributed to the counter-intuitive increase in workloads that modern operators experience due to high technology and automation. To achieve and maintain safe and reliable operations, process operators require effective HSI designs.

Studies have shown that early HSI-related design commitments may account for as much as 60% of systems life-cycle costs, most of which are irreversible beyond the early phases of development. Hardman and Colombi (2012) concluded that methods applied to object analysis early during the requirements development process inform better user interface designs (Walden et al. 2015, Lau et al. 2008, Hardman & Colombi 2012). SE processes often struggle with the design and integration of STS due to unpredictable and dynamic behaviour and the unintended consequences of new technology introduction. Sage & Rouse (1999) (as quoted by Hardman & Colombi 2012:173) list some of the "most deadly" transgressions in SE. These include the lack of consideration for the "cognitive style and behavioural constraints" that affect operators, the failure to design for human integration, and the failure to develop and apply appropriate methods in support of SE. Modelling that helps explore the operation, functional and structural elements of the problem and solution spaces may be applied to aid SE. Salmon et al. (2016) argue that systems thinking approaches such as CWA provide suitable methods for the development of safe and efficient systems (Hardman & Colombi 2012, Oosthuizen & Pretorius 2016, Lintern & Kugler 2017, Salmon et al. 2016).

Since STS are open and exposed to unforeseeable events that threaten their effectiveness, designs need to support operator adaptation. Furthermore, the actions workers require to cope with interferences from the environment could not be known a priori. As such, design should not prescribe the work but instead provide decision support for promoting problem-solving. CWA is a systems-based approach, ideally suited for the design of large-scale STS, that analyses how social humans perform tasks within an organisational structure while accounting for constraints within the environment (Naikar 2011, Naikar 2017). CWA aims to differentiate possible or acceptable behaviour from impossible or unacceptable conduct (Lintern 2008, Naikar 2011, Lintern 2012a, Oosthuizen 2014).

CWA is described as a formative framework aimed at establishing how an STS might reasonably function instead of normative or descriptive methods that aim to describe how a system should or does function (Fidel & Pejtersen 2004, Jenkins et al. 2008). Normative approaches to work design typically result in sequentially ordered actions that fail to equip workers for unexpected events. CWA's focus on constraints encourages design for adaptation, replacing rigid prescriptive workways with options that allow workers the flexibility to tailor their behaviour within the system limits. The freedom of creativity promotes job satisfaction and results in behaviour patterns that are better adjusted to deal with unforeseen circumstances. CWA provides valuable inputs to STS design, allowing the actors to 'complete' the designs (Lintern 2008, Sanderson 2003, Naikar 2011, Naikar & Lintern 2002, Jenkins et al. 2008). However, due to the formative nature of CWA and the dynamic nature of STS, the design is never really complete. Traditional engineering approaches seek complete design descriptions, while CWA draws on the utility of emergence in cognitive systems and specifically refrains from such complete descriptions (Fromm 2006).

The CWA framework can be broken down into five distinct phases known as work domain analysis (WDA), control task analysis (ConTA), strategies analysis, social organisation and cooperation analysis (SOCA), and worker competencies analysis (WCA). Each of the phases aims to describe one of the constraints that shape the functioning of the STS (Naikar 2011, Jenkins et al. 2008).

The WDA describe the work environment or domain, independent of activities or their associated goals. It seeks to capture the relationships between the overall STS purposes and its constituents. ConTA model recurring tasks identified during the WDA, focussing on the goals independent of the methods available for achieving them. This allows task evaluation within a specific system state to identify unknown constraints. Strategies analysis describes the different ways a cognitive state can be transformed into another. SOCA model task capabilities within an STS and how the system's constraints influence these to enhance system performance by the collaboration of technical and social factors. WCA determines actors' competency requirements within the STS (Jenkins et al. 2008, Lintern 2008).

Stanton and Jenkins (2017) show that CWA has been applied in nuclear power generation, aviation, healthcare, power distribution, rail transport, and urban planning. However, introducing new technology into existing sociotechnical environments are associated with complexity due to the interdependencies between the social and technical components. Moreover, new technology brings new affordances and new task abilities. The cognitive system responds in a self-organising fashion to re-establish a robust equilibrium within the new constraints (Lintern 2008, Lintern 2012b, Fromm 2006). New constraints may also reduce the efficacy of previously established behaviours. This complexity invokes the need to apply systematic methods to STS design to predict and manage the emergence. However, emergence is recognised as a bottom-up process that resists the traditional engineering design of top-down decomposition (Fromm 2006). Basic SE methods seem unable to address this problem effectively. As such, STS modelling is proposed as an aid to the SE process.

The non-prescriptive nature of the CWA framework releases operators from the cognitive strain of rigid prescriptive work ways and allow them to cope with abnormal conditions (Lintern 2008, Sanderson 2003, Naikar 2011, Naikar & Lintern 2002, Jenkins et al. 2008). Naikar and Elix (2016) criticise human factors methods that apply descriptive approaches of analysing organisational structures, indicating that the resulting designs are limited in their support of adaptation to only those reoccurring and familiar conditions. They also posit that this approach may not support adaptation, with the solution not providing the same possibilities due to a reduced possibility space.

CWA is ideal for high performing interface designs, providing varied methods for addressing engineering and human factor issues (Naikar 2017). This includes validation of designs introducing new technology into existing STS. In addition, Birrell et al. (2012) demonstrate that CWA can be applied to identify relationships between casual domain functions and objects and predict their mutual influences. Sanderson et al. (1999) further argue that CWA helps to make these connections and influences explicit. Therefore, it is a suitable gauge for whether a particular design will fulfil the intended functional purposes. Naikar (2017) further indicates that reliable determinations of validity, based on SME judgement of application-specific implementations, may increase the perceived value of CWA. As such, an SME judgement of a proposed validation method for introducing new technology in the process control domain may add value.

## Conceptual Model

The CWA framework for examining work possibilities within a constrained environment has been demonstrated to apply requirements analysis, function allocation, the design of interfaces, physical workplaces, teams, jobs and organisations (Sanderson et al. 1999, Read et al. 2012). The conceptual framework for this research study is presented in Figure 1. The successful introduction of new technology into STS is generally managed through the application of SE processes. Following the famous “V” model (Forsberg & Mooz 1991), stakeholder requirements for introducing new technology inform the development of design requirements and design concepts, the implementation of which will introduce new technology into an existing system.

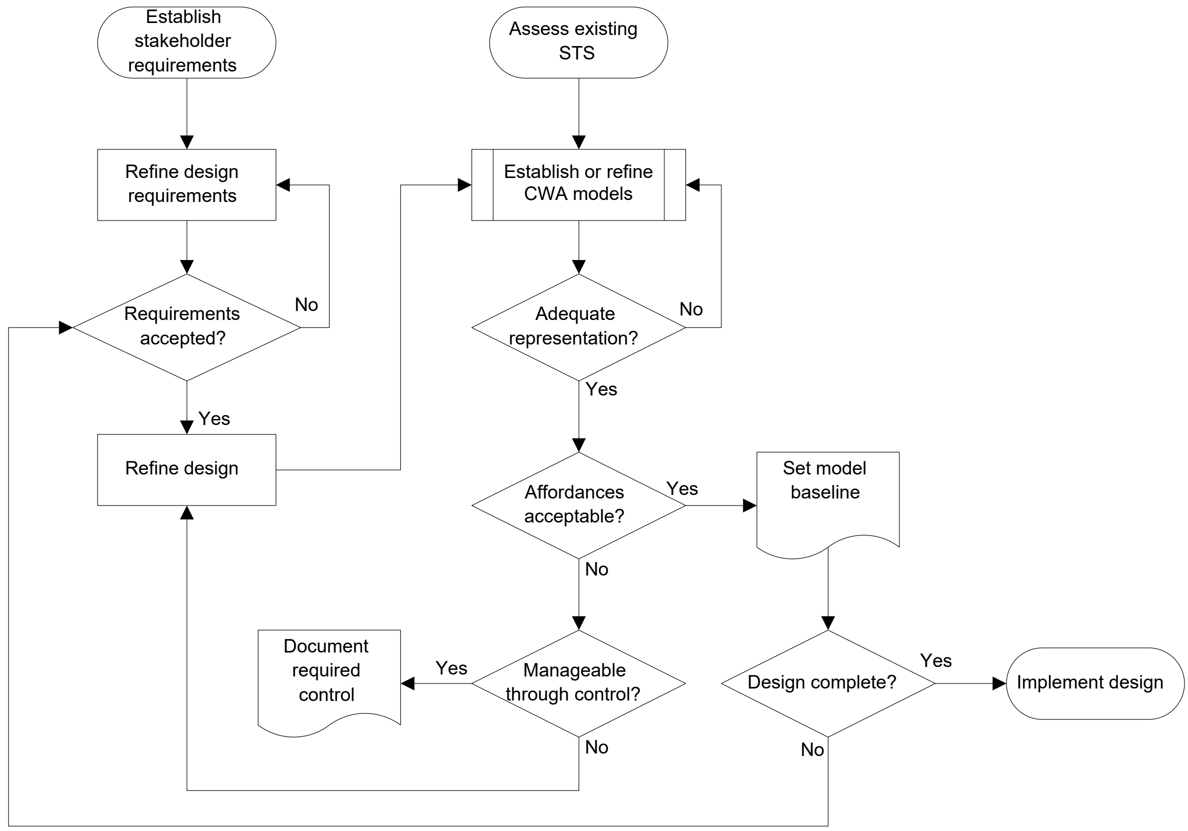


Figure 1. Proposed iterative validation process flow

Introducing new technology into an STS results in changes to the constraints of the work domain (Bostrom & Heinen 1977), leading to the emergence of new and sometimes unexpected affordances resulting from the self-organisational properties of the cognitive system (Carroll & Rosson 1992, Lintern 2008). Thus, the design needs to focus on providing goal-oriented constraints that will result in the emergence of robust and effective workways (Lintern 2012b).

CWA was identified as an appropriate method for modelling STS since it focuses on analysing constraints that shape behaviour within an STS (Naikar 2011). Therefore, expert practitioners with advanced knowledge of both the work domain and CWA techniques must assess the influences of design requirements on constraints and the effect of adjustments of constraints on STS (Jamieson 2003, Jamieson et al. 2007).

Oosthuizen and Pretorius (2016) indicate a tendency for the development of complex STS through piecewise introduction of new technology and warns that focussing only on the new technology addition could result in sub-optimal implementation when essential aspects of the existing STS get excluded (Oosthuizen & Pretorius 2016). For that reason, the framework proposes that both the new technology addition and the existing STS be analysed using CWA techniques. The proposition is that in-process validation using baseline models of the STS will allow for identifying changes to constraints brought about by proposed designs.

Thus, it may allow for the identification and evaluation of potential emergence to manage the effects (risks) of acceptable affordances and reject design propositions that lead to unacceptable affordances (hazards). This is intended to be an iterative process in which the baseline models are incrementally updated to incorporate approved designs. Requirement analysis aims to inform the design of systems that fulfil the stakeholders' intended purpose. If specific core requirements are not identified and met, the work system produced may not be desirable (Scribante 2019). Since the attainment of the requirements for an STS is invariably dependant on the constraints that shape it, CWA is well suited for supporting the identification and refinement of requirements for its design (Birrell et al. 2012).

Jenkins et al. (2008) stated that the structured methods of CWA aid requirements elicitation. This view is echoed by Read et al. (2015), who pointed out that CWA models help to evolve user requirements and that the application thereof is in line with the iterative approaches of SE. In addition, the CWA modelling processes provide for a common language among involved disciples that stimulates decisions and debate, which ultimately result in improved product designs (Jenkins et al. 2008, Birrell et al. 2012, Read et al. 2015, Horiguchi et al. 2013, Sanderson et al. 1999).

## Method Demonstration

The proposed validation method was applied to a test case to introduce new HMI technology into an existing STS. For this purpose, the researcher drafted an initial AH of the unaffected STS. The model was verified and refined using SME evaluation. The initial AH was subsequently altered to reflect the replacement of the existing display and input capturing devices from the HMI with the newly proposed technology.

The proposed solution would see the existing multi-monitor HMI display replaced with a single big-screen television (TV) display and the traditional keyboard and mouse interface with a tablet computer. The AH for new technology introduction was presented to a focus group to investigate the possible impact of the technology on the existing STS; to seek out new affordances and task possibilities.

The focus group method has been applied successfully to many areas of management research (Barry et al. 2008). A focus group may be defined as an organised assembly of people gathered to partake in an in-depth or focussed interview. Persons are selected to provide insight from their personal experience and expertise regarding the subject under investigation, which generates data through interaction and allows individual perspectives to surface (Blackburn & Stokes 2000, Barry et al. 2008).

Discussions typically involve six to twelve participants moderated by a facilitator and directed through preconceived, open-ended questions limited to the topic under review. This results in the required focus (Oosthuizen 2014). A significant advantage of focus groups is that they drive group interaction. Here, participants are encouraged to explain their views to contradict and challenge the opinions of others (Blackburn & Stokes 2000). This may aid in bringing forth tacit knowledge held exclusively in the mental models of SMEs (Oosthuizen 2014). Although participants are guided through the choice of questions, the interaction may have a snowballing effect which results in broader perceptions being investigated and captured (Oosthuizen 2014, Blackburn & Stokes 2000).

Oosthuizen (2014) indicates that focus groups have been used to aid in gathering data for CWA constructs. This is partly because the numerical data for statistical analysis is not readily available within complex STS. Furthermore, a focus group is a rich source of qualitative data and a valuable tool for exploration when the data available on the subject is limited. As a method, focus groups fall into a category known as judgement tasks. By selecting participants with appropriate experience and knowledge, the data gathered through focus groups may be generalised and can provide measurements with acceptable precision as an outcome (Oosthuizen 2014, Blackburn & Stokes 2000). Although there is difficulty demonstrating rigour with focus groups, it has been widely applied to considerable research and the social and behavioural sciences. Of late, focus groups have also been employed in IS as a knowledge elicitation and interrogation method in the design of HMIs (Oosthuizen 2014).

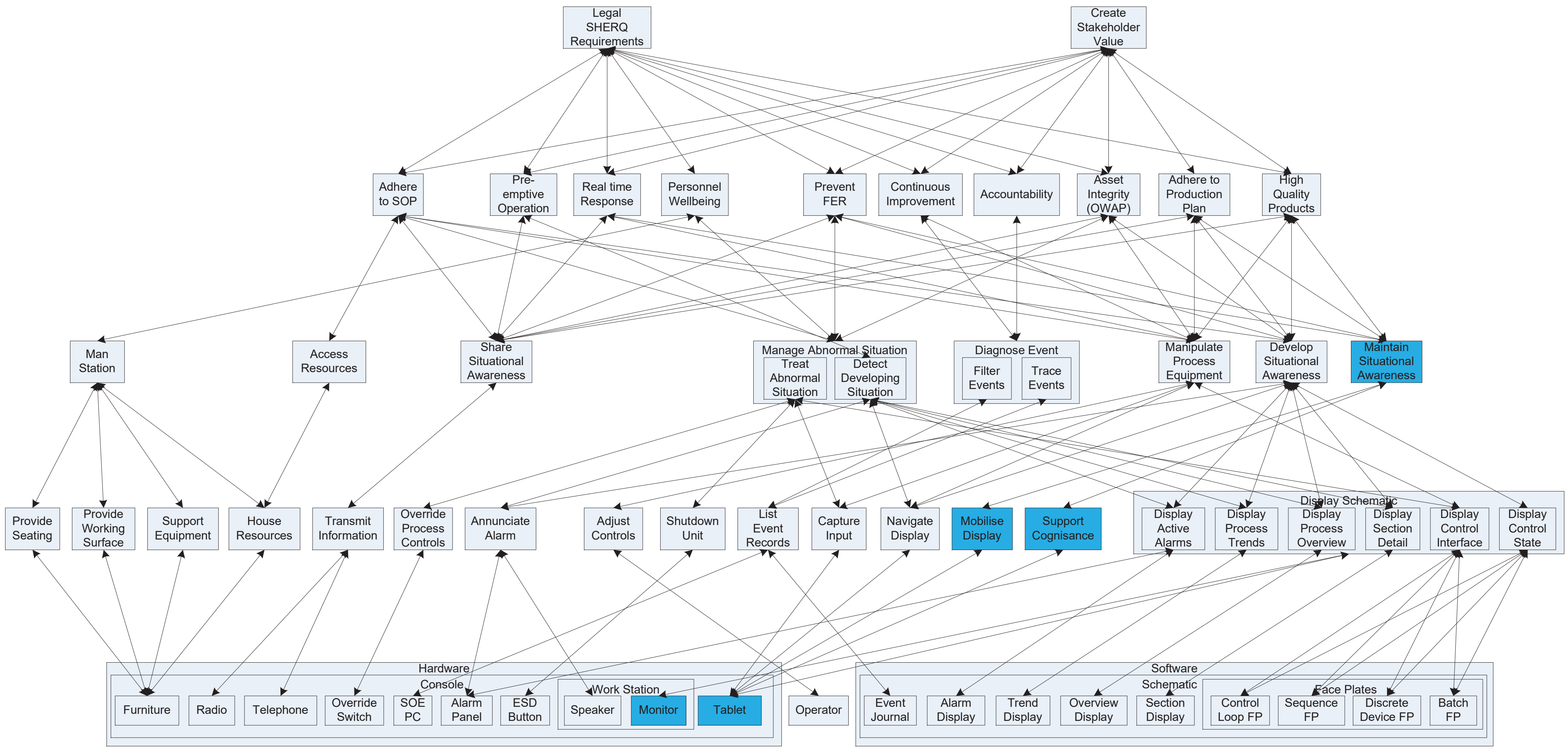


Figure 2. Abstraction hierarchy with identified affordances

Using the AH and documentation on the proposed technology, the focus group identified two additional technical functions (affordances) related to the use of the tablet computer, viz. “Mobilise Display” and “Support Cognisance”. “Mobilise Display” is linked to the ability of the proposed technology to support docking of the traditional display schematics onto the mobile device. “Support Cognisance” relates to the ability of the granular analogue adjustments to process control dials that are only available via the tablet (as compared to the existing keyboard and mouse).

These affordances were found to support a general function that had to date not been considered (i.e. “Maintain Situational Awareness”). The baseline AH, drafted at the end of that iteration of the validation cycle (Figure 2), shows the affordances highlighted. Affordances were also identified for the possibility to miss-use the reception capability of the TV monitor and the mobile connectivity of the tablet computer, both of which we found undesirable and did not correlate with known stakeholder requirements. These were not included in the AH since appropriate controls were identified and recorded.

## Discussion

The application and evaluation of the proposed validation technique were undertaken with a group of five engineers within the field of control and instrumentation (C&I) engineering. All interactions with the participants were virtual. The specific engineers were included for their perceived strengths (e.g. operations, project execution, HMI design) and years of experience. This was done since using domain experts as analysts are known to be beneficial to CWA modelling. However, the benefit to be had is reliant on the familiarity of the experts with the analysis technique (Jamieson 2003).

At the onset of the process, none of the engineers had knowledge of CWA or related concept of an STS. The engineers partook in individual semi-structured interviews to verify the initial AH, during which principle knowledge regarding WDA was conveyed. Verification of the initial AH and the analysis of the model for new technology introduction was somewhat laboured. This is perceived to be due to the participants' unfamiliarity with the WDA technique and, in part, due to existing domain knowledge.

Jamieson (2003) warns that a high familiarity with existing operations may lead an expert into contrasting current practices with the analysis process. This was observed, with experts repeatedly seeking to join domain functions to close a perceived design or feedback loops. Additional coaching in CWA remedied this problem. This phenomenon may also explain why no technical functions supporting the general function “Maintain Situational Awareness” were identified for the resident technology.

Jamieson (2003) further posits that partaking in the domain analysis is where most of the benefit of the AH lies. Thus, it was not surprising that both individually and as part of the focus group, the engineers were perceived to struggle with comprehending the AH models. However, the process was well-received, and the WDA allowed the researcher and analysts to capture and combine multiple perspectives into a descriptive model.

The focus group interviews did not generate as much discussion as was hoped. The risk that Barry et al. (2008) expressed that participants may not be forthcoming due to fear of providing “socially” unacceptable answers is thought to be one reason for this. All participants hale from the same engineering discipline and department and have significantly different levels of experience (range 6 to 18 years), which may have contributed to the drought in the discussion. On the positive side, the inclusion of changes to the AH models, resulting from recommendations made by the participants, were perceived to lift morale and achieve buy-in as the participants felt that their views were valued (Barry et al. 2008).

By applying the validation methodology, the AH models allowed the focus groups to identify previously unforeseen opportunities and affordances that require either engineering controls or further design considerations. These discoveries recorded on the new AH baseline model can be applied directly to inform user requirement identification (Birrell et al. 2012). The focus group expressed the opinion that the proposed workflow is viable and may add value.

Although the single iteration simulated by this research study is limited to the concept phase, the focus group identified several additional applications for the AH models supporting the SE life-cycle. First, it was proposed that the modelling methodology be applied during the pre-feasibility to test the technical viability of the solution and to tie physical objects to system purposes as a means of justifying the expenditure. Second, it was echoed that the models are ideal during the feasibility and concept phases to identify the physical components and the related function required to establish design requirements. Third, it was proposed that during detail engineering (construction and implementation), the models be applied to ensure that all the means-end links identified in the AH are present and functional in the design. Lastly, it was proposed that the baseline AH be updated after commissioning to reflect any lessons learned or unplanned changes to the design that were necessitated during commissioning and acceptance testing.

## Conclusion

In conclusion, this article describes the application of WDA as a validation method for the development of complex STS. The workflow application is useful as the case study implementation provides a material illustration of the application and utility of the proposed process and AH models as part of a requirements analysis for STS. WDA has proven helpful at combining different perceptions of an STS into a holistic representation. Although not ideal, even inexperienced analysts were able to apply the method and uncover possible design emergence. We hope that the methods presented herein will aid more designers in applying CWA as part of the SE life-cycle toward the successful implementation of complex STS.

## Future Research

This research study was limited to the application of WDA. Other modelling techniques from the CWA framework, such as ConTA and WCA, can conceivably be applied to inform the structuring of HMI displays is ways that provide novice operators of the information necessary to perform tasks effectively and safely while not constraining the efficiency of expert users. The focus group also provided good arguments for application of the validation process beyond that proposed for the concept stage. As such, future research may explore the benefit of applying other CWA techniques as the focus of the proposed validation process, and that of the application of the process to the later stages of systems development.

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## Biography

**Henk van den Heever** obtained a B.Eng (Comp & Elect 2008) from the North West University in 2008. In 2009, he joined SASOL Ltd. where he has been involved in the maintenance, engineering and governance of automation, process control and functional safety systems as part of the C&I fraternity. In 2015, he took up specialisation in functional safety and is a certified Functional Safety Engineer (FS Eng) with TÜV Rheinland. Henk is currently a Master of Engineering Management (MEM) candidate at the University of Pretoria.

**Rudolph Oosthuizen** joined South African Air Force in 1990, where he performed systems engineering roles in electronic warfare and Command and Control (C2). At the University of Pretoria, he obtained a B.Eng (Elec 1994), B.Eng (Hons) (Indus 1998), MEM (2002) and PhD in Engineering Management in 2015. In 2008 Rudolph joined the CSIR as a Systems Engineer on multiple C2 projects. Since May 2020, he has been appointed as a senior lecturer at the Graduate School of Technology Management at the University of Pretoria, where he teaches Systems Engineering and Systems Thinking. Lately, his focus is on Data Science and Artificial Intelligence for decision support and situation awareness. Rudolph is registered as a Professional Engineer with ECSA and is also a Certified Systems Engineering Professional (CSEP) with INCOSE.