Optimising the Introduction of New Technology into Safety-Critical Environments: a Human Factors Study

Prepared by

Elise Geraldine Cathrina Crawford

This thesis is submitted in fulfilment of the requirement of the Doctor of Philosophy at

Central Queensland University

Centre for Railway Engineering
School of Human Health and Social Sciences

Date

March 2016

Abstract

User resistance toward new technology can be a symptom of poorly interacting system elements and is, therefore, a human factors concern. New technology can offer many benefits to organisations. However, before returns on investment can be realised end users must come to adopt the new technology. For organisations with safety-critical systems, this final adoption step is extremely important for the organisation's investment and for public safety where poor technology adoption can lead to events that result in loss of life at catastrophic levels. However, few studies have focused on how employees adopt technology in mandatory circumstances. In order to develop effective implementation strategies, scholars have suggested that it may be fruitful to investigate the underlying factors that influence user resistance and technology adoption.

With the aim to better understand how to introduce new technology into safety-critical environments, a two-phase study design was adopted. The first phase utilised mixed methods to explore underlying factors that influence end user technology adoption outcomes, while the second phase utilised Q methodology to explore viewpoints on how to best introduce control-room technologies.

The results from this study found that resistance to technology stems from six underlying areas, namely: organisational factors, project viability, design practices, technical attributes, implementation processes, and how operators came to make sense of the new system. A major point of agreement amongst managers and designers of safety-critical systems was the importance of user input into the design of new technology. However, interviews with controllers found that opportunity to provide input was rarely experienced.

The Q-study disclosed four distinct viewpoints on how to best introduce new control-room technology. While different reasons were provided, three of the four viewpoints (Pragmatists, Democrats and Strategists) supported end-user input during the design process. A major reason for end-user input given was that end users have unique insight into what they do that no other stakeholder can provide. However, the fourth viewpoint (Traditionalist), which represented less than one-fifth of all participants, was adamantly opposed to user involvement during the design process. Furthermore, other Traditionalist

values were noted to potentially undermine the controller's ability or desire to adopt new technologies. The results indicate that a Traditionalist viewpoint has significant influence over other more popular perspectives. This suggests that the Traditionalist viewpoint dominates acquisition decision-making in participant organisations. Hence a power struggle within design teams of safety-critical systems may exist that has not yet been identified. Results of which may impact the future success of new control-room technologies.

These findings show that the power balance during the decision-making phases of acquisition and design can influence end-user technology adoption outcomes. Furthermore, if the power balance is not recognised or addressed, new control-room technologies may continue to be introduced in ways that are incongruent with effective technology adoption processes. From these findings, safety-critical system stakeholders may be better able to explain and predict events surrounding the introduction of new control-room technology.

Acknowledgements

Firstly, I wish to acknowledge my supervisory team: A/Professor Yvonne Toft, Dr Ryan L Kift and A/Professor Geoff Dell for your support and dedication throughout the research, and for the complementary way in which each of you contributed in the advice provided. Thank you, Yvonne for your inspirational direction, Ryan for keeping me focused and helping me stay on track, and Geoff for helping the team bring the project to a conclusion.

Thank you to CQUniversity for funding this project through the Commonwealth Government's Research Training Scheme (RTS) and Australian Postgraduate Award (APA). I also acknowledge the support provided by Professor Andy Bridges from the School of Human Health and Social Sciences. Furthermore, I thank the staff at the Centre for Railway Engineering for providing further resources for conducting the research and for disseminating its results. Special thanks go to Professor Colin Cole for enabling a couple of rare opportunities to meet and discuss my research with some prominent personnel in my field of study. Sincere thanks also goes to Tim Mc Sweeny for your meticulous proofreading efforts, to Ingrid Kennedy for your brilliant formatting work and to Dr Ron Day, Dr Gerard Ilott, and Dr Michele Wolfe for your encouragement and support.

I wish to express great appreciation to the prominent researchers who willingly agreed to meet and discuss my research, particularly, Professor John Wilson, the 'father of rail human factors' who passed away in 2013.

Many thanks to the supporting companies and all the participants in this research, particularly the controllers who freely shared their experiences and gave up their time to participate and to the many survey participants who offered their genuine opinions.

Finally, this thesis would not have been possible if it were not for my family and friends who helped me have a life outside my PhD and work. Particular thanks, goes to my partner Chris for helping me take time away from the computer and for freeing up time by taking over the domestic duties at home.

Declaration of Authorship and Originality

I, the undersigned author, declare that all of the research and discussion presented in this thesis is original work performed by the author. No content of this thesis has been submitted or considered either in whole or in part, at any tertiary institute or university for a degree or any other category of award. I also declare that any material presented in this thesis performed by another person or institute has been referenced and listed in the reference section.

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[Elise Crawford]

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Glossary

Term	For the purposes of this thesis the following definitions apply
AAS	Advanced Automation System
ANOVA	Analysis of variance
ATC	Air Traffic Control
Control system	An arrangement of different physical elements connected in such a manner so as to regulate, direct or command itself or some other system (Bakshi & Bakshi 2010, p. 1-2).
Controller	The controller is the person who interfaces with the control system and thus the end user.
Control-Room Technology Stakeholders	Please who have a stake in control-room technologies, namely: • Designer: individuals responsible for the technical design of new technology/systems, such as: technology innovators, architects, software developers, industrial engineers, manufacturers and suppliers of the product • End users: individuals who directly use technology to complete work tasks, such as: controllers, operators and trainers of control systems • Evaluators – individuals who evaluate new technologies or systems, such as: research and development staff, human factors, safety and quality control professionals • Managers: high-end personnel whose decisions impact new technology/system outcomes, such as: organisational, financial or project managers
Designers	See control-room technology stakeholders
End user	See control-room technology stakeholders
Evaluators	See control-room technology stakeholders
FAA	Federal Aviation Administration
Gestalt	German for form and shape and refers to holism, whereby natural systems should be viewed as a whole rather than a collection of parts.
Ghosting	The parallel operation of the old and new systems (also, to mimic)
Human-automation teamwork	Humans and machines (hardware and software) that work together support and compensate for each other where necessary to achieve a common task or goal.

Human factors (Ergonomics)	The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance (International Ergonomic Association 2016, p. 1).
HFAT	Human Factors Analytic Tools
HFI	Human factors integration: the process of integrating human factors concerns with other system elements.
Human system	The human element of a system which may comprise of one or more individuals.
HSI	Human systems integration is another term for human factors integration but often refers to nine domain areas namely: personnel, manpower, training, occupational health, safety, human factors engineering, environmental concerns, habitability and survivability.
IT	Information technology
Manager	See control-room technology stakeholders
MIS	Management Information Systems 1. A discipline that aims to improve the success of management information systems. 2. An integrated system that manages information used by managers to inform business practice.
New technology	Technology that is new to the organisation or user.
Openness to change	Change acceptance and positive view of changes (Wanberg & Banas 2000, p. 132)
Operators of control rooms	End users of control-room technologies. For the purposes of this thesis these individuals are collectively called 'controllers'.
Organisational conditions	The institutional forces that affect resourcing, performance and operations.
PCA	Principle Component Analysis
Perturbance	A cause of disturbance or upset (Collins English Dictionary 2015)
Praxical Knowledge	A specific type of tacit knowledge that arises out of practice, a form of learning through doing, the 'art of doing' (Bolt 2007, 2011, 2014, p. 1).
Project	A temporary endeavour undertaken to create a unique product, service or result and thus has a definite beginning and end (Project Management Institute 2013, p. 3).
Project Governance	The alignment of project objectives with the strategy of the larger organisation by the project sponsor and project team. A project's governance is defined by and is required to fit within the larger context of the program or organisation sponsoring it, but is separate from organisational governance (Project Management Institute 2013, p. 553).
Project	The person assigned by the performing organisation to lead the team that is responsible for achieving the project objectives (Project

manager	Management Institute 2013, p. 555).
Safety-critical systems	A system in which any failure or design error has the potential to lead to loss of life (Daintith 2004, p. 1).
SDLC	Systems Development Life Cycle
Sensemaking	A reciprocal spiral of evolving understanding that advances gradually over time by the interactions of enactment (taking action), creation (discovery of new knowledge), and interpretation (through reflection).
Sociotechnical system	A system containing human and technical elements that interact together for a common goal.
SPSS	Statistical Package for the Social Sciences
Stakeholder	An individual, group, or organisation, who may affect, be affected by, or perceived itself to be affected by a decision, activity, or outcome of a project (Project Management Institute 2013, p. 563).
Successful technology adoption	A technology transfer in which the adoptee (end user) becomes capable of performing tasks attached to the technology in a highly effective manner that can lead to expert use without undermining safety.
System	A set of interacting or interdependent components forming an integrated whole. Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning (Zergeroğlu 2015, p. 5).
System competence	Effective coordination, cooperation and collaboration amongst systems sub-systems for optimal function and safety.
System failure	System failure can occur in various ways and to varying levels. 1. A continuum underuse, from minimal to being abandoned. 2. A continuum of damage consequence to humans, objects or the environment.
Tacit knowledge	Knowledge that is in the form of ideas and insights that cannot be easily codified (made explicit).
TAM	Technology Acceptance Model
Technocentric	A term modelled on the egocentric childhood stage as identified by Piaget. 'A tendency to give a similar centrality to a technical object (Papert 1987, p. 23).
Technology	A tool, machine or system that can be used to do work (Griffith 1999).
Technology adoption	A personal process whereby an individual (adoptee) comes to know and use a technology that is new to them. The process extends from initial awareness through to expert use and monitoring of that adoption state.
Technology transfer	The movement of new technology from its creator or researcher to a user.
Unlearning	Throwing away concepts learnt in the past to give space for possible new learning (Pighin & Marzona 2011, p. 59)
Usability	The effective and efficient use of an object that is compatible with

	human needs, attributes, processes and wellbeing.
User input	End-user input relates to knowledge sharing through consultation and the provision of feedback through various forms of involvement and participation.
User involvement	Is synonymous with user participation
User participation	A set of behaviours or activities performed by users in the system development process (Barki & Hartwick 1989, p. 53)

Publications and Presentations Related but Ancillary to the Thesis

The following works by the candidate arose from the thesis work but do not form part of the examination content. However, they have been shared with industry and the scientific community on both local and international levels.

Journal Articles (peer reviewed)

Crawford, EGC, Toft, Y & Kift, RL 2013, 'New control room technologies: human factors analytical tools for railway safety', *Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit*, vol. 227, no. 5, pp. 529-538.

Conference Papers (peer reviewed)

Crawford, EGC, Toft, Y, Kift, RL & Crawford, CJL 2010, 'Entering the conceptual age: implications for control room operators and safety', in J Wood (ed.), *International Control-Room Design Conference 2010*, Institute of Ergonomics and Human Factors, CCD Design and Ergonomics Ltd, London, pp. 238-245.

Crawford, EGC, Toft, Y, & Kift, RL 2010, 'New technology adoption: risky business for the railways', in R Burgess-Limerick (ed.) *Safer and more productive workplaces: Proceedings of the 46th Annual Conference of the Human Factors and Ergonomics Society of Australia*, HFESA Inc, Sydney, pp. 105-114.

Crawford, EGC, Toft, Y & Kift, RL 2013, 'Grassroots and tree tops: finding the balance in the technological jungle', in *The Right Balance: Proceedings of the 49th Annual Conference of the Human Factors and Ergonomics Society of Australia,* HFESA Inc, Sydney, pp. 1-14.

Crawford, EGC, Toft, Y & Kift, RL 2014, 'Attending to technology adoption in railway control rooms to increase functional resilience', in D Harris (ed.) *Engineering Psychology and Cognitive Ergonomics 2014*, *Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence*), vol. 8532, Springer, Heidelberg, pp. 447-457.

Conference Presentation Papers (not peer reviewed)

Crawford, EGC 2015, 'Adoption-focused design for improved system competence and safety', presented at the *SIA Visions Conference 2015*, 19-21 October 2015, Gladstone QLD

Paper/Poster Presentations

Crawford, EGC, Toft, Y, & Kift, RL 2010, 'New technology adoption: risky business for the railways', in R Burgess-Limerick (ed.) *Safer and more productive workplaces: Proceedings of the 46th Annual Conference of the Human Factors and Ergonomics Society of Australia*, HFESA Inc, Sydney.

Crawford, EGC, Toft, Y, & Kift, RL 2011, 'Q Methodology – a good sort for global corporations', presented at the *27th Annual Conference of the International Society for the Scientific Study of Subjectivity*, 7-9 September 2011, Birmingham UK

Crawford, EGC, Toft, Y & Kift, RL 2013, 'Maintaining control within a socio-technical system: can it be done?', in *10th World Congress on Railway Research*, SPARK, RSSB, Sydney

Conference Presentations

Crawford, EGC, Toft, Y, Kift, RL & Crawford, C 2010 'Entering the conceptual age: implications for control room operators and safety', presented at the *International Control-Room Design Conference*, 25-26 October 2010, Paris FR

Crawford, EGC, Toft, Y, & Kift, RL 2011 'Q Methodology – a good sort for global corporations', presented at the *27th Annual Conference of the International Society for the Scientific Study of Subjectivity*, 7-9 September 2011, Birmingham UK

Crawford, EGC, Toft, Y, & Kift, RL 2011 'Improving safety through robust and functional socio-technical systems, a human factors concern', presented at the 3rd (Institute for Resource Industries and Sustainability (IRIS) Postgraduate Students Conference, 2 December 2011, Rockhampton, AU

Crawford, EGC, Toft, Y, & Kift, RL 2013 'Technology adoption when safety is critical', presented at the *Safety in Action Conference*, 18-19 June 2013, Brisbane, AU

Crawford, EGC, Toft, Y, & Kift, RL 2013 'Designing resilience into railway control rooms', presented at the *Inaugural Control Room Design and Operations Conference*, 11-12 March 2013, Sydney, AU

Crawford, EGC, Toft, Y, & Kift, RL 2013 'Grassroots and tree tops: finding the balance in the technological jungle', presented at the *49th Annual Human Factors and Ergonomics Society of Australia Conference*, 2-4 December 2013, Perth, AU

Crawford, EGC, Toft, Y, & Kift, RL 2014 'Attending to technology adoption in railway control rooms to increase functional resilience', presented at the *11th International Conference on Engineering Psychology and Cognitive Ergonomics, at HCI International* 22-27 June 2014, Crete, GR

Crawford, EGC 2015, 'Adoption-focused design for improved system competence and safety', presented at the *SIA Visions Conference 2015*, 19-21 October 2015, Gladstone QLD

Chapter 1. Introduction

Technological advancement has significantly influenced productivity gains and safety since the industrial revolution. However, the introduction of new technology into safety-critical environments has been historically problematic. Past disasters, particularly during the late 1970s and early 1980s are a testimony to the level of damage that can occur when a safety-critical system fails. The aircraft disaster at Tenerife in 1977 resulted in 583 deaths (Fearn 2012), and the partial nuclear meltdown at Three Mile Island of 1979 released radioactive particles into the atmosphere that took 20 years to clean-up at a cost of USD $1 billion (United States Nuclear Regulatory Commission 2013). Significantly, in 1986 the nuclear explosion at Chernobyl became a turning point in history. For the first time, effects of a failed safety-critical system impacted countries beyond immediate borders and at a magnitude that had not been foreseen, leaving affected countries unprepared. Aside from the horrific impact on human life, the land is still contaminated in parts of Russia, Belarus, and Ukraine (Nuclear Energy Agency 2002). In light of these events and others, it became evident that advancement in technology not only contributed to occupational and societal life in a significant way, it also contributed to some of the worst accidents in history.

Accidents rarely occur from a single event. Rather, they occur from the accumulated effect from a number of errors or incorrect assumptions, often perceived as trivial (International Atomic Energy Agency 2014). Many nuclear accidents have been traced back to human error induced by poorly designed control rooms (Nuclear Energy Agency 1988). However, knowing the extent to which poorly addressed human factors contributed to accidents proved difficult due to the variance in classification systems and the way reporting is done. A recent study that examined 76 international accident databases, from 2001 to 2012, found that human factors accounted for 31% of all aviation accidents and 87.5% of all rail accidents. Human factors issues were reported in terms of operational human error, errors within control rooms, maintenance errors, and design errors (Day 2013). A recent study on accidents in the manufacturing industry found 70 different human factors associated with hand injuries alone (Soares et al. 2012). While the exact magnitude of the problem is difficult to determine, accident investigators recognise that poorly addressed human factors during design, operations, and maintenance was a leading contributor to accidents (Health

and Safety Executive 2001; McCreary et al. 1998; Weick 1993). Thus, consideration of human factors during the design of new technology reduces the likelihood of error, resulting in safer, enhanced work performance and greater user satisfaction (Wickens et al. 2004; Wise, Hopkin & Garland 2009).

Human factors are a broad range of human performance issues that arise from interactions with other system elements, while ergonomics (or human factors) is a design science that aims to optimise overall system performance. Human factors has been defined as:

> The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance (International Ergonomic Association 2016, p. 1).

In 2009, aviation scholars predicted that human factors engineers would face greater challenges in the future as computer screen displays and automation advance (Koonce & Debons 2009). An increased awareness of modern concerns has led industries with safety-critical systems (e.g. transportation systems and processing plants) to a practice of integrating human factors into every aspect of work. In some cases, human factors integration (HFI) has been mandated by safety regulators (Balfe et al. 2012; Civil Aviation Safety Authority 2009; Office of the National Rail Safety Regulator 2014). New challenges to HFI continue to arise as control systems become increasingly integrated with new computer-based information-driven systems.

Control technologies of safety-critical systems have their roots in industrial applications that predate the advent of digital technology and software. Early safety-critical systems were composed of mechanical hardware and were primarily powered electromechanically. Physical measurements such as temperature, volume and pressure about the system's functioning were transmitted via an analogue signal to be displayed in a dedicated control room. Hence, control-room technologies provided the human interface for the system to be controlled.

A classic example of an early control room that dates back to the 1870's are railway signal boxes (Graham 2015). Plate 1:1 shows their mechanical lever frame system.

Plate 1:1 Arbroath Box Lever frame System

Source: Graham (2015)

Signal boxes are little buildings located near a junction or station where railway tracks intersect. To ensure trains pass safely, an operator (signaller) sets stop or go signals and manipulates the levers to activate interlocking mechanisms on the track. Network Rail have 800 operational signal boxes across the UK (Network Rail 2015). However, signal boxes are gradually being replaced with more modern technology. Over the next five years, Network Rail plans to phase out all 800 signal boxes to establish 12 highly automated national control centres at a budget of £38billion (Network Rail 2015). Subsequently, the integration with computer-based information-driven technologies will significantly change the nature of railway control in Britain. Changes like this are similarly occurring across other safety-critical industries. Plate 1:2 shows an Australian example of the more modern signalling interface. The plate illustrates the gradual move toward digital and computerised technology.

Plate 1:2 Partially Computerised Signalling System in Australia

Source: Author (2011)

One important feature that improved the efficiency and effectiveness of computerised technology was the advent of the user interface (Harsh 2005). The windowing environment, as displayed in Plate 1:2 made it more accessible to manipulate and extract information. This enhanced decision making, planning, and organisation. The interface also provided greater control over business practices (Jain 2013). It is no wonder that operators of safety-critical systems also want to adopt these more sophisticated technologies. Plate 1:3 shows the new type of Automated Train Management System currently being rolled out across many locations in Australia. However, information-driven technologies (IT) have their own history of failure. Aside from a need for increased know how to avoid operational errors, unstable software presented significant problems particularly for early adopters (Harsh 2005). Researchers of management information systems (MIS) have found a positive correlation between system complexity and requirements for enhanced levels of knowledge and skill (Eastwood, Chapman & Paine 2012). Thus, to reduce the gap between the user and design many organisations implement robust training regimes.

Plate 1:3 Automated Train Management System

Source: Australian Rail Track Corporation & Lockheed Martin (2013)

In contrast, training has not always been found to be the best solution to resolve human factors related failures. For instance, during crisis decision making trained procedures have been found to break down during emergency situations (McCreary et al. 1998). To resolve a crisis quickly, decisions need to be made with incomplete information. This leads to a reliance on intuition that is tacit in nature (Ingham 2008). Similarly, IT developers acknowledge that to design in support for tacit decision making is highly challenging. This is because IT is developed using an explicit knowledge model (Eastwood, Chapman & Paine 2012; Harsh 2005). Misalignment of knowledge types can pose significant problems to operators in general, let alone controllers of safety-critical systems.

The current situation emerging in modern control rooms due to increased computer-based technology is a rising level of integration between hardware and software elements. The human factors research community are finding that this type of integration is creating new and unanticipated complexities (Balfe et al. 2012; Pew & Mavor 2007). Therefore, the introduction of new computer-based technologies into control rooms has heightened safety concerns within safety-critical industries.

Concerns like this can put controllers in a difficult position when expected to adopt and use technologies they may know little about, or have not yet come to trust. The Federal Aviation Administration (FAA) has had to endure technology adoption concerns for many years. In

1994, the FAA had to terminate the Advanced Automation System (AAS) project because air traffic controllers refused to adopt the new technology. Investigators deemed the AAS project as unreasonably complex and too difficult to be operated by the air traffic controllers (Pew & Mavor 2007). Abandonment of the AAS project resulted in a USD $1.5 billion loss (Cone 2002). Still trying to revolutionise the now 35-year-old system, the FAA continue with their plan to complete implementation of their new air traffic management system, called NextGen, sometime before 2020. However, while the system is being rolled out across the country the FAA continues to experience safety issues. The initial installation in 2007 was described by controllers as 'frighteningly buggy' (Breselor 2015, p. 3). Furthermore, defects in the newly introduced NextGen software were reported to cause aviation havoc throughout 2015 (Yanofsky 2015). As such, successful deployment of NextGen is yet to be realised.

Disruption to control tasks in control rooms can lead to disruption in the field. Unlike other work systems that are not safety-critical, the achievement of effective technology adoption that leads smoothly to expert use is very important to stakeholders of safety-critical systems. However, the emerging complexities that arise from progressive system integration have raised concerns for accident prevention in the future. These events give rise to additional concerns regarding the emergence of new human factors issues which have implications to the already a challenged gap between safety-critical design and safe implementation by users. Therefore to reduce the gaps in knowledge identified, this study aims to gain greater insight into the factors that influence the successful introduction of new control room technologies so that technological advancements might be optimised in the future. To identify what is known about safety-critical design and safe implementation practices, a critical review of the literature was conducted.

Chapter 2. Literature Review

2.1 Introduction

The progressive integration of computer-based technologies into safety-critical systems is adding a third dimension to modern control and concerns for safety are raised. At this time, it is unclear how this trend will influence human factors and thus future accident prevention strategies. Knowledge from the management information systems (MIS) literature might contribute to a greater understanding of the potential risks that new information-driven technology may introduce, however, little is known about its transferability to a control-room context. To shed light on these concerns, a review of scientific literature has been undertaken. However, before embarking on this critical review, a brief background on control systems is provided to set the context for this research and to highlight some of the unique characteristics of safety-critical control systems.

2.2 Background

2.2.1 Some definitions

Control systems help to achieve system efficiency, effectiveness and safety. Knowledge of what a system is can help to shed light on what a control system does. A system has been defined as:

> A set of interacting or interdependent components forming an integrated whole. Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning (Zergeroğlu 2015, p. 5).

The most common definition for a control system is:

> An arrangement of different physical elements connected in such a manner so as to regulate, direct or command itself or some other system (Bakshi & Bakshi 2010, p. 1-2).

The controller of a control system is 'the element of the system itself or external to the system which controls the plan or the process' (Bakshi & Bakshi 2010, p. 1-2). For the purposes of this thesis, the controller is the person who interfaces with the control system and thus the end user. Control systems are often described as safety-critical. A safety-critical

system has been defined as ‘a system in which any failure or design error has the potential to lead to loss of life’ (Daintith 2004, p. 1). Therefore, in light of these definitions, a safety-critical control system can be defined as:

> An arrangement of system elements connected in such a manner so as to regulate, direct or command itself or some other system and which any failure or design error has the potential to endanger lives.

Examples of safety-critical systems include various medical devices, people deployment in the military, transportation, and process control. Failures from safety-critical systems can be localised while others can have far-reaching effects. The recent train derailment in 2013, in Lac- Mégantic, Quebec illustrates the magnitude of the disaster that a safety-critical system failure can create. Upon derailment, the 72 tanker cars spilt 7.7 million litres of petroleum crude oil which subsequently exploded. The explosion not only damaged tanker cars and locomotives, it killed 47 people, destroyed 40 buildings and damaged 53 vehicles. It also polluted the town’s water supply (Transportation Safety Board of Canada [TSB] 2014). The damage goes further. One year later, the train company filed for bankruptcy, due to the costs associated with accident liability (Fishell 2014; Horn 2015).

In addition to being safety-critical, failure of information systems can also have other devastating effects. For instance, the recent Queensland Health’s failed payroll system is a prime example of large-scale economic losses from an information system failure. Failure of the project led to a $1.2 billion dollar loss (Horn 2015). In 2010 when the system went live, it was reported that 85,000 staff were affected due to inaccurate pay with some staff not paid at all (LeMay 2012). Losses also impacted external stakeholders. Rather than borne by shareholders as with commercial system failure, costs were borne by Queensland taxpayers (Remeikis 2015). In both these cases, system failure was considered a disaster and thus protection against this type of failure from happening again in the future is highly important. However, the significant distinction between the two systems is that unlike information systems that control data, safety-critical systems have the added potential to endanger lives. The risk to human life, as a possible failure consequence, places greater emphasis on finding effective ways to avoid system failure into the future.

As noted earlier (Chapter 1) information systems are increasingly integrated with more traditional safety-critical systems. As such, information systems are extending the definition

of what constitutes a safety-critical system. Thus, an emerging concern is the instability of software. A number of years ago, test results were found to be well below many industry standards, particularly the safety goal to achieve 10^{-9} accidents per hour held by the aviation industry (Bowen & Stavridou 1993). Since this time, there has been a rising number of studies to show that software testing and validation is a concern for the integrity of safety-critical systems (Bowen 2000; Johnson 2011; Knight 2002; Özçelik & Altilar 2015; Smith & Koothoor 2016; Youn & Yi 2014). One problem identified with software is that the effectiveness of reliability approaches is difficult to measure (Bowen 2000). Another problem offered is that software design standards are difficult to follow (Youn & Yi 2014). Furthermore, while software does not show signs of wear like hardware might, software errors have been described as far more unpredictable and random than hardware errors (Bowen 2000). This problem is further compounded in sociotechnical cases, whereby both people and technology interact together to achieve common goals (Baxter & Sommerville 2011).

If a system failure is measured against success criteria, then the success criteria of a safety-critical system can be described as one that functions efficiently, effectively and guards against unsafe events. This perspective of failure and success has been adopted for this study and reflects a very different meaning to that of project managers who aspire to achieve a project completed on time, on budget and with specified features and functionality (Project Smart 2014; The Standish Group 1995). Therefore, the need to know how to achieve system efficiency, effectiveness and to close any gaps that can lead to unsafe events is highly relevant to failure mitigation and thus to this study. Specifically, this study has focused on three safety-critical industries, namely: Aviation, Rail and Power. System characteristics of which are briefly discussed.

2.2.2 Industrial control systems

The control systems for each of the three industries can be described as sociotechnical in nature. Modern control systems are a suite of systems comprised of human and technical elements, including both hardware and software componentry. The control system functions within a broader work context that can influence the core goal of the control system. Influential factors include: physical, operational, technological, economic, political

and social (Figure 2:1). The technologies within the control room serve as the user interface to the technical elements of the system. The control room resides within a larger control centre that contains other associated rooms and services that support the common operational goal.

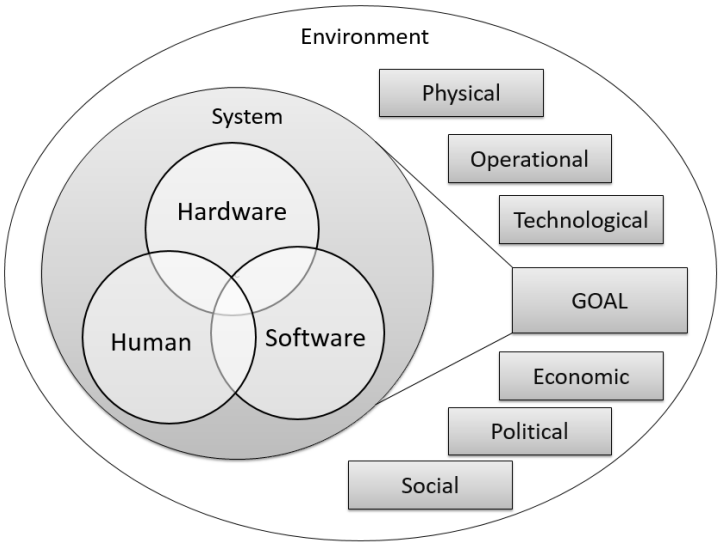

Figure 2:1 Elements within a control room

Adapted from: Human Performance Optimization Division (2009, p. 9)

2.2.3 The control room

Control rooms provide the user interface to the system's status. Their safety-critical nature demands high-level security and is thus regulated by law. Some control rooms are very busy noisy places, where personnel communicate with each other and on the telephone or radio to external stakeholders, as was the case for the metropolitan train control room in Melbourne (Plate 2:1) and the Ergon Energy power distribution plant in Rockhampton (Plate 2:2).

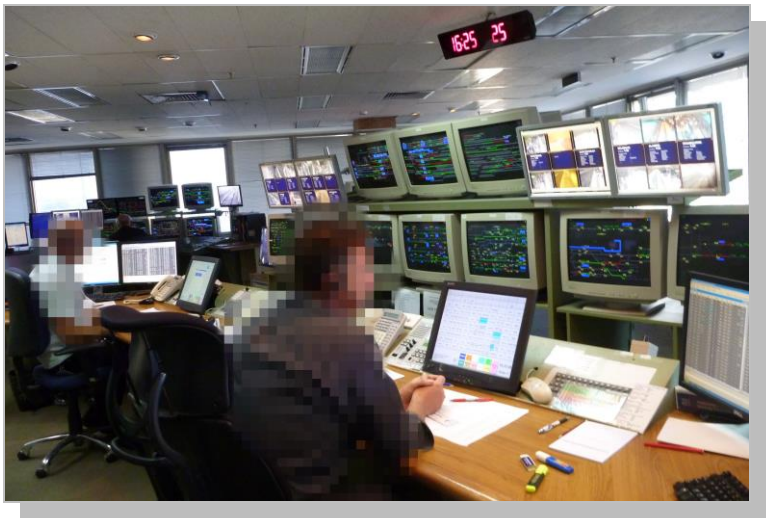

Plate 2:1 Metrol rail control room

Source: Author (2011)

Plate 2:2 Depiction of the control room at Ergon Energy

Source: Egli (2015)

Conversely, some control room environments seem very intimate, are very quiet and can have just a single controller and a manager. The Stanwell Power Station was initially designed as a solely technical system. However, too many issues with the plant necessitated a human overseer. Hence a control room on site was created.

The nature of the control rooms depends on the goal of the system, the technologies used to help the controller interface with the system, and geographic requirements. Every control room has organisational processes and procedures that help to guide smooth operation.

Effective communication is essential for any integrated system. Technology elements must communicate with each other and with the human operator. For instance, where software has been integrated with hardware, sensory hardware in the field must accurately and completely transmit data to software componentry. Software must accurately convert the data to information that is relayed in such a way to be understood and useful for the controller. Additionally, people need to communicate effectively with each other. Various types of radios, pagers and telecommunication technologies allow controllers to communicate with field staff (i.e. technicians, pilots, train controllers, maintenance works), internal personnel and external agencies. Hotlines that allow controllers to make contact with, or be contacted by relevant personnel immediately are also used.

2.2.4 The technological system

The technology used in control rooms reflects the type of industry, the nature of the control system and technological advancements at the time of implementation. For the participant organisations in this study, the technological componentry involves both hardware and software. Field technologies (sensory hardware) transmit analogue or digital data back to technologies inside the control rooms. Digital data is first passed to software programs that convert the data into usable information that is then available to the controller via computer screens. Additionally, various communication technologies are utilised to aid human to human communication, such as radios and other telecommunication systems. Communication systems allow controllers to contact with field staff, such as: technicians, pilots, train drivers, and maintenance workers' communication with internal personnel, and external agencies. Increasingly, software leads to greater automation of systems.

2.2.5 The human system

There are usually at least two human roles within a control room environment, controllers and operations managers. Larger centres can have one or more floor supervisors, depending on the number of controllers, and some centres have dedicated phone staff taking calls from customers.

The controllers are the primary end users of the control interface technologies. Amongst the human factors community, and for this thesis, the term 'end user' refers to the individual

who directly interfaces with the particular system or technology. This definition is in contrast to the computer science definition that would classify controllers as non-programming end users, one of six other definitions for end users (Rockart & Flannery 1983). In other words, unless qualified to do so, controllers of safety-critical control systems normally work through software provided by others. This point is made, because, definition distinction becomes increasingly important as organisations introduce computer-based technologies and begin to interact more closely with computer experts. General Managers oversee operations often away from the control room. Operations managers or floor supervisors oversee operations within the control room environment. Support personnel such as relief staff and technicians interact intermittently while a variety of controllers are responsible for the operational activities within the control room.

The operational component system functioning is monitored by shift supervisors and operations management. Their primary role is to ensure operations run smoothly and according to schedule. In the event of an emergency, all personnel in the control room may be involved. Controllers not directly involved may cover for those who are, while the operations manager is likely to lead proceedings with the assistance of the shift supervisor and safety personnel. The controller(s) responsible for the area in question will work closely with the contingency team and external stakeholders. Under normal conditions, train traffic can involve monitoring systems, looking for changes and trends, pre-empting problems, problem-solving, troubleshooting and contingency thinking when deviations to planned functions are identified. These activities require a number of cognitive skills which can be made more difficult when working in a complex environment.

An understanding of the characteristics of controllers can help to highlight human factors concerns with regards to strategies for recruitment, training and change management. Therefore, psychographic and demographic concerns are discussed briefly.

2.2.5.1 Psychographics of controllers

Organisations with safety-critical systems recruit new staff with great care to ensure candidates are selected who can produce the highest possible job performance while experiencing job satisfaction. The Consortia recruitment company in Australia look for 16 personality factors when assessing emotional intelligence and specifically recruit prudent

candidates who exhibit less risk taking behaviours. Additionally, recruits who are good lateral thinkers, act calmly under pressure, score above average on perfectionism, and have good (but not too high) self-esteem are highly regarded (Johnston 2013). Although differences exist between industries and individual tasks, overall, effective controllers have been described as mostly introverted, focused on the task, can work alone and in teams, are highly rule conscious and follow set procedures to protect the network and lives. They tend to be conservative or traditional and do not like change for the sake of change. They can come across as insensitive due to their tough-mindedness, and inclination to call a spade a spade (Johnston 2013).

2.2.5.2 Demographics of controllers

Gender: Safety-critical industries are male dominant. One Australian study on the railways reported that women represented 20% across all rail jobs and most are in administrative positions such as human resources, finance and data processing (Munro 2014). However, to partly offer equal opportunity, but also to take advantage of individual strengths, women are being encouraged into the industry (People 1st 2012). Similarly, in 2012-13 women represent 19.5% of all Airservice employees (Airservices Australia 2013). There are some advantages to having a diverse workforce. In general, women are less vulnerable to peer group pressure, are less competitive and do not need to demonstrate superior skills, as men do. However, there have been times reported where women have tried to prove themselves as equals with men and this has been found to impair their judgement (Aviation Theory Centre 2011). In contrast, other studies on individual differences in performance of recently employed air traffic controllers found no significant differences for gender (Karson & O'Dell 1997; Nye & Collins 1991). Furthermore, personality profiles for men and women were similar regarding an interest in air traffic control (Karson & O'Dell 1997; Nye & Collins 1991). When it comes to adopting new technology women tend to rely more on trusted peer opinion than men do (Rogers 2003).

Age: The ageing population is a developed world concern and reflected in workplaces today, including control room environments. Half of the employees at Airservices Australia (2012-2013) are over 45 years of age (Airservices Australia 2013). Similarly, a study conducted on Australian train controllers found that 42% were 46 years of age and above (Day 2013). A

younger cohort was found in the UK with the average age for signallers at Network Rail between 30 and 35 years (Ferreira et al. 2008). Similar results were also found in a US study on coal-fired power workers that reported the average age in the US to be 48 years (Krishnan 2007). Of potential concern, a recent study found that age influenced work performance amongst pilots (Lu, Wu & Fu 2014). Furthermore, with age, short term memory and retrieval of information become more difficult, eyesight deteriorates and reflexes become slower. However, others have found that some of the age-related physiological deteriorations can be offset by experience and maturity (Aviation Theory Centre 2011).

Experience: A human factors concern is the loss of experience when experienced personnel begin to retire. A study almost ten years ago predicted that the US coal production industry would lose half their experienced staff within a decade unless action was taken to overcome the losses in leadership and technical talent (Krishnan 2007). One strategy is to use alumni networks. To ensure knowledge and experience are not lost when employees retire, Airservices gain access through an alumni network (Airservices Australia 2013). Another concern with experience is that the modern workforce, in general, is more mobile, less committed to an organisation and diverse in qualifications and competencies. Today, a worker may only stay two to five years before moving on (Wilson & Norris 2005). Therefore, this trend indicates that new staff will have less time to develop skills and competencies putting their ability to grasp key and sometimes tacit skills at risk.

Teamwork: Safety-critical control is usually managed by a team of controllers who work intimately with a suite of technologies. At times they work alone, at other times they work as a team in all manner of combinations. However, in circumstances when something has gone wrong or is about to go wrong, all will play a role and work together for swift mitigation and recovery (Network Rail 2010). Controllers work closely with their technologies in a similar way to human teamwork (Lüdtke et al. 2012). However, computer-based technologies have not always assisted productive team involvement. Human factors researchers are currently looking for ways to improve human-automation collaboration by improving the teamwork capability of the automated partner (Balfe et al. 2012; Harbers & Neerincx 2014; Lüdtke et al. 2012). Improved system collaboration is likely to influence user adoption outcomes positively.

Various names are assigned to the roles where people directly interface with control systems to control the system. Therefore, in this thesis, the general term 'controller' is used to denote the end-user of control-room technologies. Furthermore, while many factors are similar across the various safety-critical industries, there are some unique differences worth noting to help set the context for this thesis.

2.2.6 Some unique differences

2.2.6.1 Air traffic control

Air traffic control is concerned with keeping aircraft separate while in the air. Managers of Air traffic controllers (ATCs) are concerned about flight productivity. The technology in towers helps air traffic controllers (ATCs) to know what the traffic is, where it is, and what is going to happen in advance. In Australia, there are also two radar centres who look after segments of the airspace. Unique to air traffic control are radar displays. In the towers, these complement situational awareness of aircraft by providing a relative position of all the aircraft. The Radar display is fed information captured by a number of radar heads. This information is transmitted by technology on the aircraft. However, most of the traffic is separated visually with the aid of binoculars (Plate 2:3). At the commencement of this project, the Rockhampton tower was equipped with the paper-based flight strip technology (Plate 2:4). Controllers would record the flight details by hand onto paper strips that would be manipulated about the desk to indicate, whether an aircraft was incoming, on the ground, or outbound.

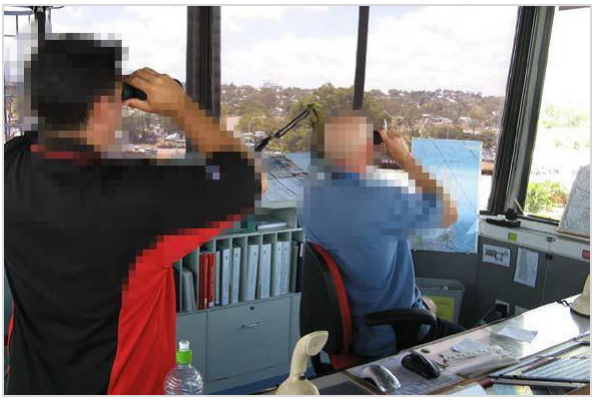

Plate 2:3 Rockhampton tower with flight strip technology

Source: Author (2011)

The new tower in Rockhampton was part of a larger national tower project that commenced in 2009. The Rockhampton tower was officially opened in 2013 (Airservices Australia 2014). All four new towers were fitted out with the New Integrated Tower Automation Suite, a purpose-built technology. Touch screens display the traffic conditions, details about the aircraft, and electronic flight data strips (Plate 2:4). Communication technologies are extremely important to the safe passage of aircraft. Outside peak traffic times, both the metropolitan and regional control towers are fairly quiet work environments.

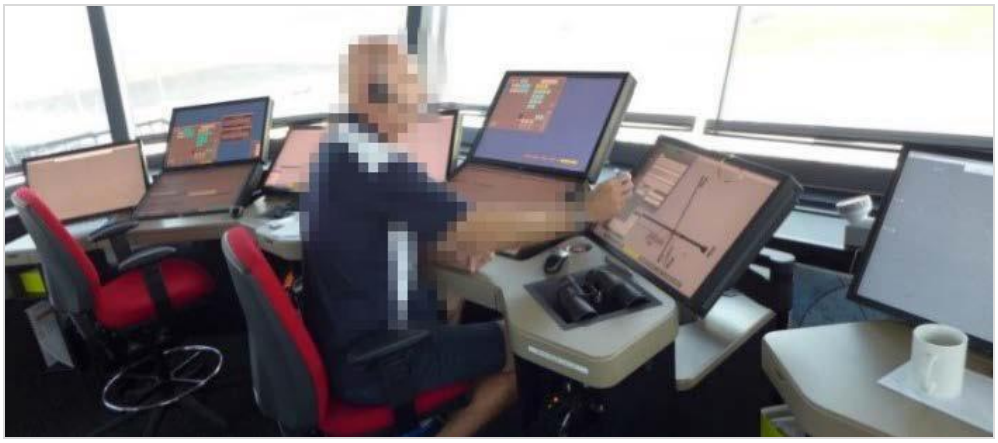

Plate 2:4 New Integrated Tower Automation Suite, Rockhampton

Source: Author (2011)

2.2.7 Train traffic control

Train traffic control is concerned with keeping trains separated efficiently. Similar to ATCs, train traffic control managers are concerned about safety but also and more immediately about trains running safely and running on time. The integrated systems were specifically developed to display the networks of electrical componentry, activity on the tracks, signalling information, and other associated information, such as scheduling, and crew resourcing (Plate 2: 5). Train controllers also rely heavily on their communication technologies to communicate with field staff, train drivers and station masters throughout the day. The Rockhampton Queensland Rail, a regional control room and the metropolitan Metro control room in Melbourne were both busy, noisy environments, particularly during peak traffic times. In Metrol, the terms ‘network controller’, ‘signaller, and ‘electrical officer’ denoted the three main roles within the control room. Regional train controllers take on the

signaller's responsibilities, and thus only 'network controller' and 'electrical officer' terms are used.

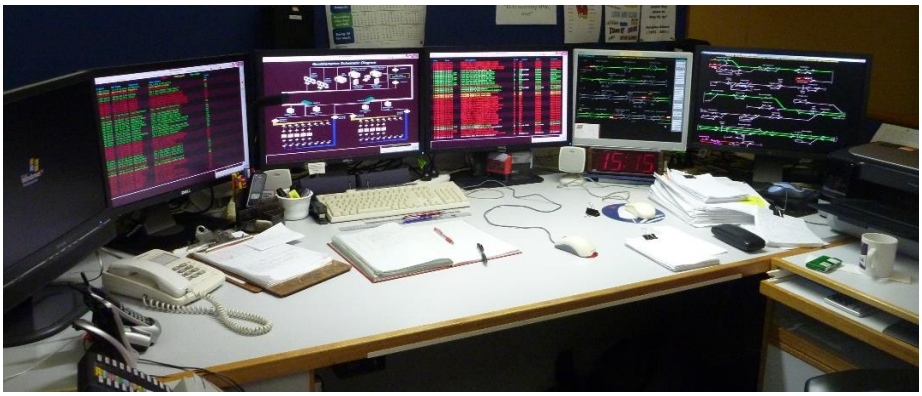

Plate 2:5 Train traffic control technology suite, Queensland Rail Rockhampton

Source: Author (2011)

2.2.7.1 Coal-fired power production control

Coal-fired power production is concerned with generating sufficient power for consumer demands. Managers of power controllers are concerned with power production for market trading. In contrast to transportation systems that control mobile plant, power plant controllers control activity within a fixed position. In the power production control room, the screens are not used to operate the plant, but rather to allow the controller (the term at Stanwell is plant technician) to monitor and predict the status of the plant. Also, unlike transportation, power plant controllers respond to alarms that indicate deviations from what might be considered normal. Alarms include audio, visual and tactile systems. A pocket pager alarm is also worn to supplement alerts when the controller may be outside in the plant. Should something need attention, field staff are called in to attend to the plant's needs. A picture could not be taken of the control room. However, Plate 2:3 provides an example of what the control room looked like.

2.2.7.2 Power distribution control

Power distribution controllers (the term at Ergon Energy is network operations officers) are concerned about the safe delivery of electricity to customers in their network. However, when a power outage occurs, customer dollars are lost and managers of controllers are very concerned about this. Where possible, controllers control the network from the computer-

based control system. In cases where the information from the field is not transmitted to this system, controllers rely heavily on their telecommunications systems. Thus controllers resolve many electrical outages on the phone by directing field staff to make the necessary adjustments, at the location of the problem is. Therefore, unlike Stanwell, power distribution is a noisy environment with controllers communicating to technicians in the field constantly, as depicted in Plate 2:2.

2.3 Technology Adoption in Control Rooms

Theoretically, when an organisation decides to introduce a new technology, there are at least two waves of technology adoption that occur and in many cases three. Firstly, decisions regarding control room technologies and their implementation often occur at head office by top personnel who have worked closely with their research and development teams. The individuals who adopt initially, usually have some idea of the type of technology they are looking for and thus have at least a concept idea. This group of individuals do not normally use the technology, but rather adopt the technology for others to use. Therefore, in this context, the term 'adoption' means to embrace an idea/technology and support its introduction.

The second phase of technology adoption occurs at the individual business unit level with managers of individual control centres. Sometimes local managers are given an opportunity to be involved in the project's development, but not always. Rather closer to design finalisation, unit managers typically start to get to know the purpose for the new technology and what this might mean to them and their workflow. In this context, the term 'technology adoption' means to get to know about a new technology and to help its implementation and deployment activities. Local managers may or may not accept the idea, but the decision to adopt or not is above his level of authority.

Thirdly, last but not least, the end users who are expected to use the new system will learn about its existence and thus begin the technology adoption process (Leech 2010). In this regard, the phrase 'technology adoption' means to come to know about a new technology and to become competent in its use. Figure 2:2 provides a representation of the three-tier technology adoption process as it might occur for a rail company with four business units.

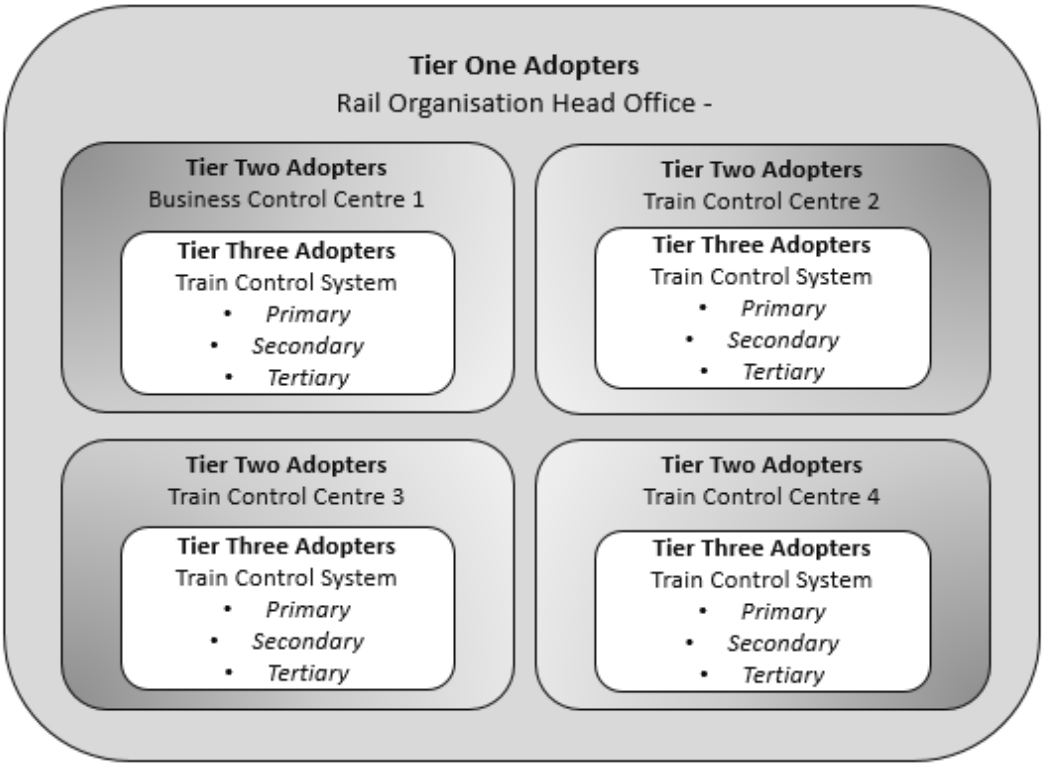

Figure 2:2 Three tier technology adoption of train control systems

Tier one adopters are senior personnel located at the organisation's head office, tier two adopters are the individual business unit managers and tier three adopters are those who will be using the new technology as part of their normal work process. The third tier of users can be further broken down to primary, secondary and tertiary users (Eason 1987). Primary users (also called end users) directly use the technology (e.g. train controllers, electrical controllers, signallers, dispatchers). Those who occasionally use the technology through an intermediary (linked technology) are secondary users (e.g. schedulers, planners, control room supervisors, control centre managers). Those affected by the use of the technology are the tertiary users (e.g. train drivers, emergency services, senior company decision makers). What is apparent in the three-tier technology adoption hierarchy is that those who will use the technology least, are often the first to embrace and adopt it.

2.4 Literature on New Technology

The literature reviewed on new technology was undertaken to determine the current knowledge associated factors that influence the safe introduction of new control-room technology. Therefore, the following topics were examined: theories on user resistance

toward new technology, theories on technology adoption and acceptance, the sensemaking perspective, and theories on design. Literature was drawn from the Social Sciences, Computer Sciences, MIS research community, Human Factors, and Design Sciences.

2.4.1 Theories on user resistance

Organisations stand to achieve greater productivity gains by adopting MIS that can collect, process, store and transmit information more efficiently and accurately rather than through manual systems (Garcia-Olaverri & Huerta 2012; Ranisavljević, Spasić & Mladenović-Ranisavljević 2012). Thus user resistance to these technologies is frequently perceived to be negative (Hirschheim & Newman 1988; Selander & Henfridsson 2012). This is very pronounced when the new information system (IS) is intended to benefit users. Nevertheless, in such cases, studies have shown that a surprising number of staff resist and avoid using new technology (Bhattacherjee & Kikmet 2007; Klaus & Blanton 2010). Scholars suggest that rather than focusing on resistance it can be more useful to understand the reason behind the resistance (Ford & Ford 2009; Markus 1983).

A review of the literature on user resistance found a relatively small number of studies (*N* = 52). All studies were found to associate with information technologies. Resistance to new control room technology may be less common, due to its predominance of hardware technology and possibly due to the mandatory nature in which controllers are expected to adopt new control-room technologies. However, while no studies were found on user resistance to safety-critical systems, the introduction of software and information driven technologies is seeing user resistance occurrences. One infamous example occurred in 1994 when the Federal Aviation Administration abandoned the new Advanced Automatic System, at a cost of $1.1 billion USD, due to software problems (Cone 2002).

Scholars acknowledge that user resistance to new IT and associated usage behaviour has received less attention compared to the interest in technology acceptance (Cenfetelli 2004; Kim & Kankanhalli 2009; Lapointe & Rivard 2005). One reason offered, is that user resistance is often viewed as the reverse side of acceptance (Laumer & Eckhardt 2012). Another reason offered, is that humans are naturally resistant to change (Bhattacherjee & Hikmet 2007; Luecke 2003). However, MIS scholars posit that one rule cannot account for all user resistance (Joshi 1991). This has led scholars to believe that studies on technology

acceptance provide little insight into the cause of user resistance (Cenfetelli 2004; Laumer & Eckhardt 2012). Some studies have found that the way managers react to user resistance to new technology can either increase or decrease it. For instance, Rivard and Lapointe (2012) offer that if no action is taken to resolve or acknowledge the resistance, user resistance will increase, while addressing or dissuading resistance in a credible way can help to reduce user resistance. Thus, there is a case for understanding the underlying issues that lead to user resistance.

Research into user resistance concentrated at a time in history when software and IT became commercially available and organisations made IT more readily available to take advantage of its benefits. Four theories were developed during this time, providing reasons for user resistance during the 1990s (Lapointe & Rivard 2005). However, Lapointe and Rivard (2005) only found 43 articles published before 2005. Laumer and Eckhardt (2012) found an additional four, while this review found another five articles (Ali et al. 2016; Klaus, & Blanton 2010; Laumer et al. 2016; Rivard & Lapointe 2012; Selander & Henfridsson 2012). Authors of the user resistance literature, have not come to a theoretical consensus as to what causes users' resistance toward new technology. Therefore, summaries of three main theories as proposed by Markus (1983) are briefly provided below.

People-determined theory – This theory posits that internal aspects of people are the reason behind user resistance toward new technology. Martinko, Henry and Zmud (1996) proposed that personalities that project negative expectations regarding technology adoption will lead users to resist. People-determined advocates believe that some people have a natural proclivity to view change in a negative way. Laumer et al. (2016) examined user resistance to new technology in mandatory settings and offered that the natural tendency to resist change is a significant enabler for predisposed resistance toward new technology. The people-determined theory of resistance posits that individuals who have a tendency to view new technology and associated change negatively, have a disposition towards resistance to change personality trait and thus supported past propositions based on status quo bias (Polites & Karahanna 2012). Furthermore, the tendency to resist change (personality trait) was found to be a stronger predictor (R^2=23.2%) of user resistance than age, gender or work experience (Laumer et al. 2016).

System-determined theory – This theory is a political variant that posits that attributes of the new technology are the cause of user resistance. Marakas and Hornik (1996) proposed that attributes of the system are perceived as a threat and thus potential users will resist. Much of the research conducted on achieving user acceptance has focused on attributes of the technology (i.e. perceived usefulness and perceived ease of use) as the cause of user resistance (Davis 1989; Rose & Fogarty 2006). Similarly, the human factors community recognise the importance to achieving designs that match their users as evidence by the many topics of interest, including human-computer interaction, user-centred design, usability, and human-automation interaction. Therefore, this theory posits that poorly designed technologies are the cause of user resistance and thus is system-determined.

Interaction-determined theory – This theory posits that user resistance arises from an interaction with system characteristics and its social context of use (Markus 1983). Therefore, it is not perceived to be good or bad, but indicative of a shift in power. Markus (1983) explains that those that resist will lose power if the new technology is introduced, while those who stand to gain, will accept. Thus, where there is a redistribution of power, the winners will accept and the losers will reject (Markus 1983).

In a safety-critical context, the design of human-automation systems is very important. Therefore, scholars recommend care where the power balance falls when designing the functional allocation between the two elements (Balfe et al. 2012). Studies have shown that controllers will reject technology at the point in which control becomes more prominent in automation (Bekier, Molesworth & Williamson 2012).

Equity-implementation theory – Joshi (1991) argues that no single rule can explain an individual's resistance to change since many readily adopt changes that go in their favour, such as pay raises or promotions. He, therefore, proposes that new technology that leads to perceived social inequality leads to resistance. Thus changes that are favourable are easily adopted and sometimes actively sought after. Joshi (1991) explains that people assess change at three levels to determine social equality within the organisation and amongst peers. The equity-implementation theory is based on equity theory. The first level evaluates the individual's loss or gain of equity status within the organisation, the second level evaluates the relative outcomes in relation to the organisation, and the third level evaluates

the relative outcomes in relation to other users. Joshi (1991) proposes that knowledge of how users assess change can help managers to develop strategies to overcome resistance when new technologies are implemented.

Multilevel model of resistance - Lapointe and Rivard (2005) posit that user resistance toward new technology is multileveled. The theory posits that user resistance is a response to perceived threats as a result of an initial interaction with the new technology. Therefore, this theory builds upon the interaction theory to explain behavioural responses according to their intensity. The four stages of resistance are: apathy, a condition of lack of interest; passive resistance, resisting with a refusal to accept responsibility; active resistance, voicing dissatisfaction and formation of coalitions; aggressive resistance, the and perception of threats which leads to rebellion.

2.4.2 Technology adoption theories

The introduction of new technology initiates a change within the organisation at both the individual and organisational level. As an aspect of this change, users are expected to adopt and use the new technology, particularly when adoption is mandatory, as is often the case in a control-room environment. However, mandatory technology adoption is not always achieved successfully. New technologies are vulnerable to failure and can incur significant costs. It is not unusual for large companies to invest over $100 million on their enterprise resource planning activities (Robey, Ross & Boudreau 2002; Seddon, Shanks & Willcocks 2003), only to experience a failure rate, sometimes above 50% (Adam & O'Doherty 2003).

Poor or failed technology adoption can have a negative influence on new technology success and organisational benefits. Adoption levels that risk new technology success include: being rejected before implementation (Software Magazine and King Content Co., 2004), delays during implementation (Centre for Railway Engineering 2010; Karsh 2004), stifled technology adoption due to difficult to learn technologies (DesRoches et al. 2008; Karsh 2004), and underutilised or not used as designed (Norman 1998). All of these failures often stem from designs with poor consideration of human factors (Green 2009; Hollnagel 2007; Stone 2008). Furthermore, technology adoption delays and usage deviations can introduce the potential for error whereby unintended actions may lead to unwanted consequences (Parasuraman & Riley 1997). Central to improving enterprise project success,

is to plan for failure and to find best-practice approaches (Stolovitsky 2012). Therefore, with the aim for improved end-user adoption success, this section examines the literature on four main theories associated with technology adoption.

2.4.2.1 Dissemination model (Diffusion of innovation)

Diffusion literature and the concept of technology transfer began with early European social scientists and in the United States during the 1920s (Backer 1991; Rogers 2003). The diffusion of innovation model was the first to formalise the study of technology transfer and has become one of the most popular models found in the literature. Headed by Everett Rogers who took a lead in the development of the *Diffusion of Innovations Theory* Rogers presents the dissemination of innovation as it typically occurs in a population and the decision-making process taken by individuals as they adopt the innovation (i.e. new idea, new technology).

Rogers (2003) described the 'diffusion of innovations' to mean the distribution of uncertainty-reducing information throughout the social system. Social scientists studied the natural process whereby an innovation diffused across a community and technology adoption patterns emerged across population groups that followed the normal Gaussian distribution curve. Furthermore, technology adoption patterns across the population tend to lie across a continuum, such as: from risk taker to risk averse, from change willing to change averse, from a willingness to adopt under great uncertainty to must be certain before adopting, from social participant to socially isolated, empathetic to dogmatic, information seeker to non-information seeker, from preferring empirical information to a preference of subjective opinion, from an ability to deal with abstraction to one that cannot, and having a high degree of technical knowledge to low, as illustrated in Figure 2:3.

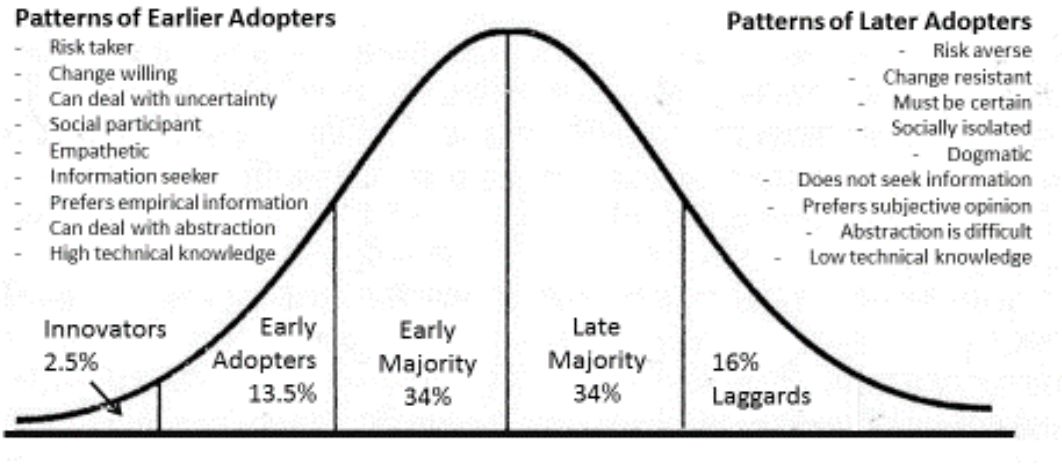

Figure 2:3 Innovation diffusion population patterns

Innovators have been described as almost obsessively venturesome, rash, daring and risk takers (Rogers 2003, p. 283). They are keen for new ideas and hence join new networks to do so. Innovators tend to have control over substantial financial resources and can, therefore, absorb the losses should an innovation be unprofitable. They are capable of understanding and applying complex technical knowledge and can manage high levels of uncertainty concerning an innovation. However, due to their perceived rashness, they may not be well respected by their local peers. On the other hand, the *Early Adopter* group is well respected by their peers because they have developed firsthand knowledge to reduce the level of uncertainty about the technology under evaluation. Furthermore, they can produce evidence of the successful and discerning use of new ideas. In this regard, they become a role model for others and opinion leader advisors.

The *Early Majority* group have been described as deliberate adopters. Before adopting something new they consult with Early Adopters to learn about their experience and to glean 'how to' knowledge. This group is seldom considered an opinion leader. However, due to their strong social connections they serve as a vital link in the technology adoption process for communicating the innovation. Members of the *Late Majority* have been described as sceptical. This group are more likely to adopt due to pressure from others. They are very cautious as they do not have the resources to take big risks. In general, the innovation must be proved successful for them to adopt. Members of the *Laggards* resist technology adoption, due to a general suspicion of new ideas and change agents. Their

point of reference is based on the past and prior experience. Members of the Laggard group have been described as traditional in their approach (Rogers 2003).

An understanding of the different adopter group patterns is important as Rogers offers that change agents should take a different approach when communicating the innovation across the groups. This has become known as *audience segmentation*. Furthermore, Rogers identified the existence of an innovation/needs paradox whereby he found that in some cases the individual who is perceived to gain most from an innovation is usually last to adopt. To illustrate this paradox, he uses the uptake of nationally promoted contraception in third world countries whereby the elite families adopt first and the poorest families generally do not adopt (Rogers 1973).

The diffusion of innovations has four elements, whereby the *(1) innovation* is *(2) communicated* through certain *channels,* over *(3) time* and among members of *a (4) social system*. The *innovation* is 'an idea, practice, or object that is perceived as new by an individual or another unit of adoption.' The perception of newness evokes a reaction from the potential adopter which can prompt the individual to undergo the technology adoption process and finally make the decision to adopt the innovation. Different rates of technology adoption have been attributed to the innovation attributes as observed by individuals (Rogers 2003, pp. 15-31). Rogers (2003, p. 15 – 16) identifies five innovation characteristics that help to increase its rate of technology adoption, namely:

1. *Relative advantage* – the degree in which a person perceives the innovation to be an improvement upon what it is superseding;
2. Perceived *compatibility* with existing personal values, needs and past experiences, as well as compatibility with those of members of the individual's social system. Rogers explains that the development of a new value system takes time and thus slows the technology adoption process;
3. *Complexity* – the perceived level of difficulty to come to use and understand the innovation;
4. *Trialability* – the level of experience an individual can have with the innovation as a result of trying it out for themselves, to reduce the uncertainty regarding its use.

5. *Observability* – the degree to which a person can observe the results of the innovation being used by others. Rogers explains that visibility of results stimulates discussion, as adopters seek peer evaluations of the innovation.

Similarly, technologies that expedite technology adoption have also been described as 'appropriate' in that, they are not excessively expensive, easy to maintain, appropriate for small applications, compatible with one's needs for use and creativity, and not difficult to learn (Pursell 1993).

Communication channels enable the technology adoption process to occur. Rogers (2003) explains that without the exchange of new information, diffusion of innovation cannot occur. From an organisational perspective, if a new technology is available but no-one is aware of its existence, it will never be adopted (Johnson, Gatz & Hicks 1997). While dissemination of information may be best accomplished by experts transferring specialised knowledge to willing recipients in the early stages (Rogers 2003), one form of communication is not enough to reach all potential adopters. For instance, while research and development teams (i.e. early adopters) may consult scientific studies, this is not the preferred method used by most individuals who rely on the subjective evaluations of those who are already using the innovation. Rogers (2003) suggests that this reliance on peers illustrates that the diffusion process can only continue if individuals model and imitate others within their personal networks, which also supports the notion of social learning theory.

Social learning theory offers that people not only learn from their own experiences, they also learn from the experiences of others and modelling the observer (Bandura 1977). Social modelling involves taking essential elements from an observed behaviour and adapting it or reinventing it to suit ones' own needs (Bandura 1986). Hence, the technology adoption process is highly social and involves interpersonal communication channels.

The process of innovation diffusion and adoption occurs over *time* in three aspects, during the (1) innovation-decision process whereby the individual goes from first learning about the innovation to making the decision to adopt or reject it, (2) the innovativeness of the individual regarding when they adopt according to the bell curve phenomena, and (3) the

rate of adoption of the innovation within a social system. Timing can be extremely important for the success of an innovation. Technologies can be made available too early or too late to be beneficial to potential users and thus increase the risk of failed adoption. Therefore, delivering technology at the time when users need or want it can help to overcome barriers to its adoption (Johnson, Gatz & Hicks 1997).

A significant threat to continued diffusion has been identified and labelled the 'chasm'. The chasm represents a stalling of technology adoption at the 16% uptake point, the uptake point between early adopters and the early majority where customers seek solutions and convenience (Moore 2002). To accelerate across this chasm, marketing strategist, Chris Maloney (2010) recommends that marketing tactics need to change from 'scarcity' which attracts visionaries to 'social proof, to attract and accelerate the diffusion process. Some ways to disseminate social proof could include blogs, peer-generated videos, and podcasts. During the process of seeking social proof, individuals gain an opportunity to learn from others. This reduces the time required to adopt new technology.

The innovation-decision process has been described as a five-step process that usually occurs as a time-ordered sequence (Rogers 2003, p. 169):

1. *Knowledge* – the period in which the potential adopter first come to learn about the innovation and has some understanding of its purpose and function.
2. *Persuasion* – the period that involves the formation of an attitude (favourable or not) toward the innovation.
3. *Decision* – the period in which the potential adopter undertakes certain activities, including peer consultation, that assist movement towards a choice to adopt or to reject the innovation.
4. *Implementation* – the period in which the adopter begins to use the innovation.
5. *Confirmation* – the period in which the user re-evaluates the decision to adopt based on actual use.

Figure 2:4 outlines the process and shows how communication channels ensure the continuance of the process. Rogers (2003) explains that the innovation-decision process involves information seeking and processing activities for the purpose of understanding the

innovation and reducing the uncertainty associated with it. Therefore, the technology adoption process appears to involve sensemaking which will be discussed later in this section.

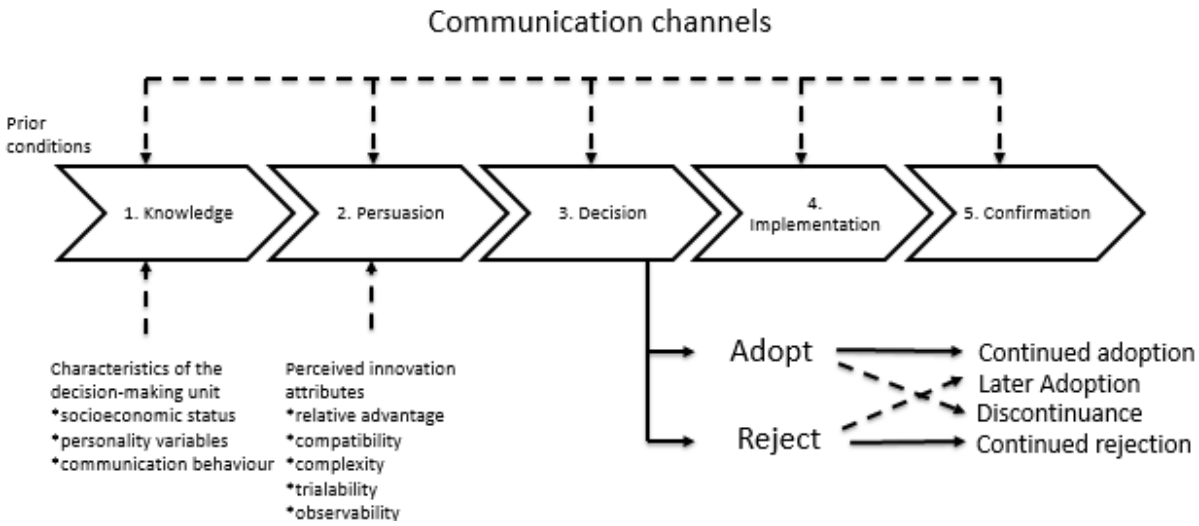

Figure 2:4 Rogers Innovation Decision Process

Significantly, social systems play a significant role in determining the rate and prevalence of innovation diffusion and adoption. A social system has been defined as 'a set of interrelated units that are engaged in joint problem-solving to accomplish a common goal' (Rogers 2003, p. 23). Diffusion takes place within a social context that sets the diffusion boundary and can be influenced by how the social system is structured. His list includes the social norms of diffusion, the roles of change agents and opinion leaders, types of decisions made and the consequences of adopting or rejecting the innovation. Change agents can be key players toward influencing attitudes toward technology adoption and therefore need to be sensitive to the context of use. Pacey (1986) states that change agents have a responsibility to make it their business to support the adoption of new technology.

2.4.2.2 Three-phase model

The technology transfer model proposed by Ruttan and Hayami (1973) illustrates how tacit knowledge is inherently linked to technology transfer. The model identifies three distinct phases of technology transfer: material, design and capacity transfer. The first phase, *material transfer* is characterised by a simple transfer of the new product and its associated techniques. At this stage adaptation of the product to the new environment is not a

concern. The second phase involves the transference of the design specifications. The *design transfer* phase is performed by providing the user with the blueprints, documentation and tooling specifications so that the user can begin to use the new product in their environment. *The capacity transfer* is much more comprehensive and involves the transfer of scientific knowledge that enables the user to expand upon and build new technology on their own. This is the case with licensing agreements and franchise practices. Thus tacit knowledge extends from basic usage in the material transfer phase, to the ability to recreate the product in the design transfer phase through to expansion of the original idea at the capacity transfer phase. As each phase extends application of the original technology, increased tacit knowledge is required, as illustrated in Figure 2:5

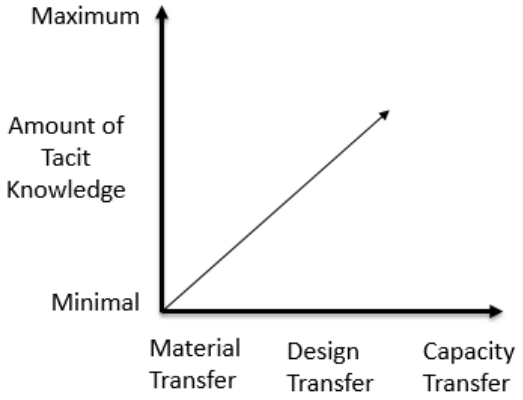

Figure 2:5 Amount of tacit knowledge per transfer type

Source: White (1998)

2.4.3 Technology acceptance theory

As the growing prevalence of computer-based technologies introduces greater automation and new interactions into control rooms, it is perceived potentially useful to this study to examine the research conducted by the Computer Science and MIS research communities. The 1970s and 1980s saw a rapid rise in the number of information technologies (IT) that were being developed and failing. Motivated to improve the success of IT (including MISs) much of the research focused on learning about the factors that lead to (i.e. antecedents) the decision to accept or reject new technology.

Technology acceptance is an extensive research area in its own right. Marangunić and Granić (2014) identified seven extensive literature reviews published between 1986 and

2013 on studies that used the Technology Acceptance Model (TAM). As of March 2016, a *Google Scholar* search produced 1,870,000 TAM citations. To review the entire TAM literature is beyond the scope of this study. However, since computer-based technologies are increasingly integrated with control-room technology, it was deemed potentially useful to identify some of the theoretical assumptions and key findings related to improving technology acceptance that might be transferred to a control-room context.

2.4.3.1 Background of TAM

During the 1970s information technologies had not yet become personal devices as they are today and therefore research focused on improving the individual use of enterprise investments. User satisfaction was believed to signify technology success (McKeen 1994). Bailey and Pearson (1983, p. 531) were the first to define and quantify user satisfaction as 'the sum of one's feelings or attitudes toward a variety of factors affecting that situation'. As a result, a number of instruments, mostly in the form of Likert-scale surveys, were developed to measure and analyse user satisfaction with computerised technology in an attempt to explain behaviour in usage (Bailey & Pearson 1983; Chan 2010; Doll 1988; Islam 2011; Lewis 1995; McKeen 1994). However, by the next decade, technological advancement led to increased system complexity, and the list of factors that contribute to computer use became extensive and was considered overly cumbersome. In 1983, Bailey and Pearson published their user satisfaction scale which contained 39 factors (Appendix A2.1). In the conclusion of this study, Bailey and Pearson (1983) recommended that measurement would be more useful if the number of factors was reduced and that this could be done by grouping them into subsets. This led MIS researchers to look for alternative ways to validly measure and predict system use.

2.4.3.2 Original TAM

During the mid-1980s, Fred Davis decided to examine the decision point to better understand *why* (i.e. the motivation) technology was accepted. In 1986, he developed and validated his Technology Acceptance Model (TAM). The conceptual framework for Davis's thesis was based on the Theory of Reasoned Action (TRA) (Fishbein & Ajzen 1975), whereby individuals make reasonable decisions based on external *stimuli* that motivate the *organism* to *respond* to a particular behaviour. In line with these motivational linkages between

external stimuli and an individual's subsequent behaviour, Davis modelled his Technology Acceptance Model (TAM). Thus the *stimulus* was represented by external variables, the technology features and capabilities, the *organism* was represented by the user's motivation, and the *response* was represented by actual system use, as displayed in Figure 2:6. Davis (1989) also established and validated two new measurement scales for predicting user acceptance. The two scales consisted of six items and were found to have high reliability according to Cronbach scores of .98 for perceived usefulness and .94 for perceived ease of use.

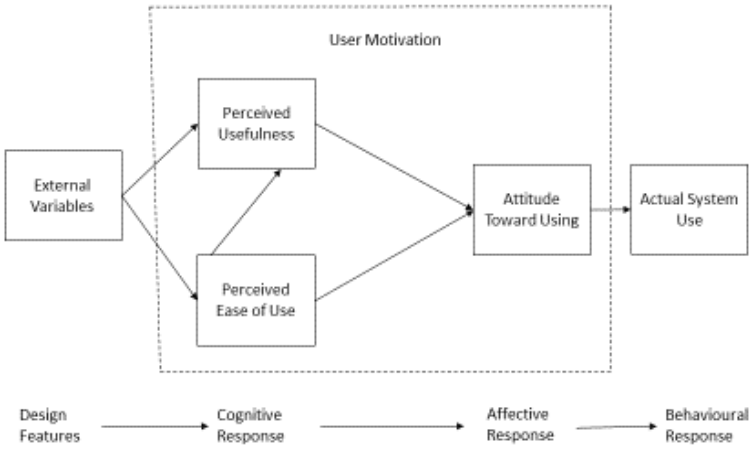

Figure 2:6 Davis's (1985, p. 24) Technology Acceptance Model

2.4.3.3 TAM in general

The general consensus across the TAM research community is that the *utility* (i.e. perceived usefulness) and *design* (i.e. perceived ease of use) of the product are the two primary determinants for acceptance (Davis 1989; 1993; Fenech 1998; Venkatesh & Davis 2000; Lee, Kozar, Larsen 2003). Perceived usefulness is defined as 'the degree to which a person believes that using a particular system would enhance his or her job performance' and perceived ease of use is defined as 'the degree to which a person believes that using a particular system would be free of effort' (Davis 1989). In 1993, Davis found that perceived usefulness (PU) could directly influence an individual's behavioural intention to use a particular technology four times that of perceived ease of use (PEOU). To understand the antecedents of PEOU, Venkatesh (2000) found that personal anchors (i.e. general beliefs) and adjustments (i.e. updated beliefs based on direct experience) influence PEOU which can be further moderated by additional experience with the new system.

Likert-scale questionnaires are typically used and analysed using factor analysis and regression techniques. TAM has been reported to consistently explain around 40 percent of the total variance in individuals' intention to and actual use of IT (Legris, Ingham & Collerette 2003; Venkatesh & Bala 2008).

Since TAMs first application, TAM has been evaluated, tested, redesigned and expanded over the past three decades. Only two of these models will be presented here, the Unified Theory of Acceptance and Use of Technology 2 (Venkatesh, Thong & Xu 2012) and the Technology Acceptance Model 3 (Venkatesh & Bala 2008).

2.4.3.4 United Theory of Acceptance and Use of Technology 2

Since the 1990s many models have focused on personal choice factors and use of personal devices. This focus recognises the changed market whereby software applications in all manner of personal devices have become commercially available and thus more readily obtained by the public. Thus in 2000, Venkatesh and Davis proposed to extend the TAM Model. This led to the development of the Unified Theory of Acceptance and Use of Technology (Venkatesh et al. 2003). This model represents an effort to bring together a common theory that explains an individual's acceptance behaviour in voluntary circumstances. This unified model has since been updated and in 2012, the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) was published (Venkatesh, Thong & Xu 2012). In UTAUT2 (Figure 2:7) age, gender and experience are shown to moderate the effects of the determinants (listed on the left) that influence behavioural intentions and thus likely technology use. A definition for each of the constructs used in these models can be found in Appendix A2.2.

The UTAUT2 was extended based on findings from other scholars that presented three new constructs with predictive power, namely: hedonic motivation (i.e. the degree of playfulness), price value (i.e. perceived trade-off between benefit and monetary cost) and habit (i.e. the extent to which an individual performs tasks automatically). Hedonic motivation was found to be a more powerful driver of behaviour change than performance expectancy in non-organisational settings and found to be stronger in younger men who are less experienced with the particular technology being studied. Price value was found

important to older women. This model has been found to explain 56 to 74 percent of behavioural intention and 40 percent of technology use (Venkatesh, Thong & Xu 2012).

The primary aim of TAM models is to predict intention of use that is expected to influence actual use. However, as the results reported above show, behavioural intentions are not always enacted. Thus while many promising findings have been found to influence behavioural intentions toward IT use, what influences actual use is still unknown.

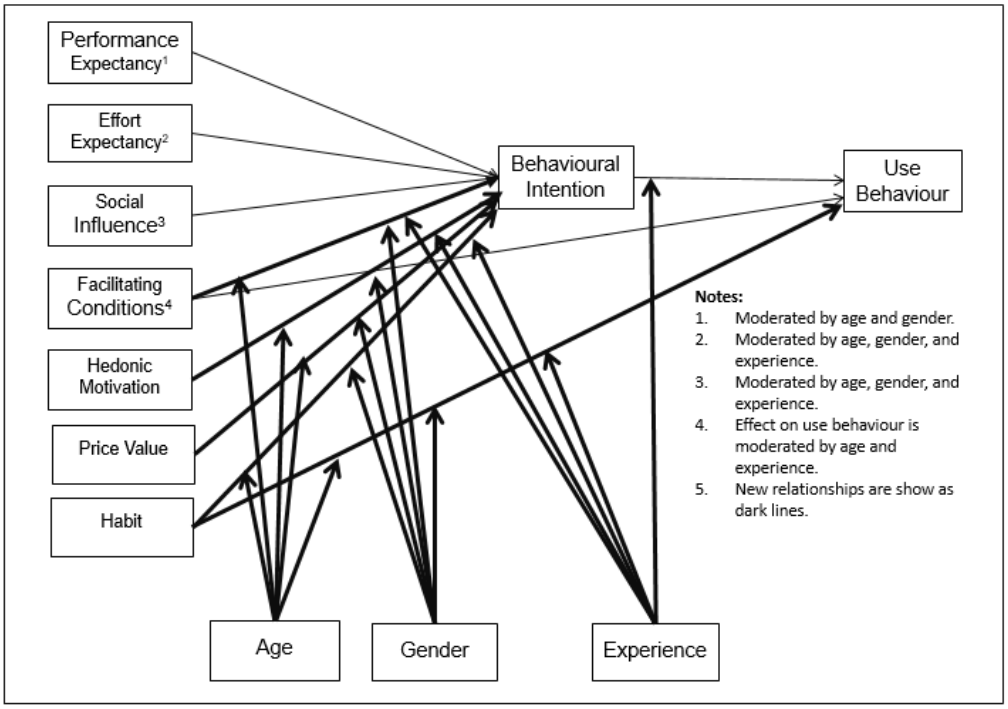

Figure 2:7 Unified Theory of Acceptance and Use of Technology 2

Source: Venkatesh, Thong and Xu (2012, p. 160)

2.4.3.5 Technology Acceptance Model 3 (TAM3)

Another model worth examining is the Technology Acceptance Model 3 (TAM3). This model presents an extension of the original TAM. TAM3 has been specifically developed for organisational settings to bring across some of the findings from models established for personal use to also apply to organisational settings. The model shows that experience and the feeling of voluntariness have moderating influences on behavioural intention and an indirect influence on perceived ease of use. The study undertaken to test TAM3 (Venkatech & Bala 2008) found that as experience increases, the negative perception of ease of use diminishes. Perceptions of ease of use, in turn have been found to influence perceptions of

the usefulness of the new technology, as shown in Figure 2:8. This model has been found to explain 31 to 36 percent of the total variance in technology use (Venkatesh & Bala 2008). As with other models, this model is used to predict behavioural intentions to use.

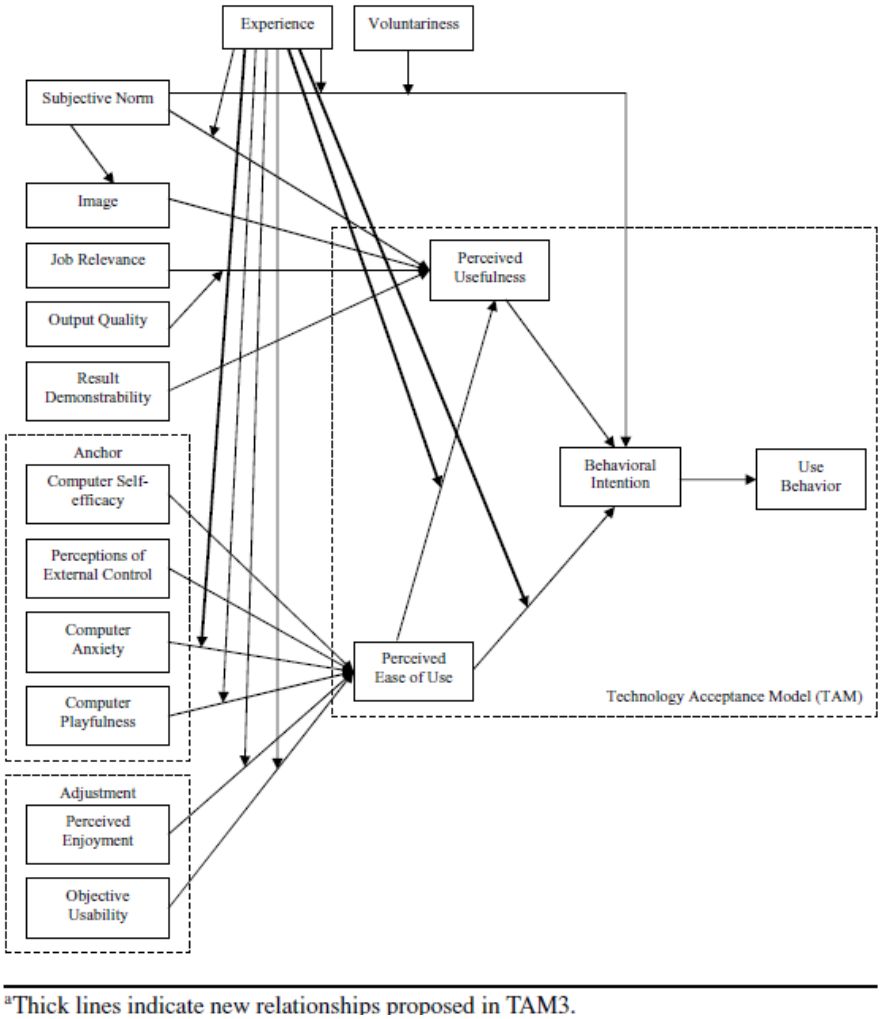

Figure 2:8 Technology Acceptance Model 3
Source: Venkatesh & Bala (2008, p. 280)

2.4.3.6 Other models

The development of the Technology Acceptance Model (TAM), has attracted a great deal of research interest from the MIS research community. Davis (1985, 1989) proposes that two main constructs (1) perceived usefulness (PU) and (2) perceived ease of use (PEOU) determine and predict an individual's intention to use a technology, as illustrated in Figure 2:6. Since this first iteration, TAM has been tested, extended, and redesigned to investigate the influence that preconditions (i.e. external variables) may have on the two determinants

that influence an individual's behavioural intention. Factor analysis and regression are commonly conducted to determine the percentage of variance in behavioural intention. In organisational settings, TAM scholars suggest that managers can use the results from TAM studies to predict likely acceptance by users and to diagnose the reasons for reluctance to accept so that corrective action might be taken to increase acceptance (Davis 1989; Venkatesh & Bala 2008). A brief overview of some of the more prominent TAM models can be found in Appendix A2.3.

2.4.3.7 Limitations of TAM

This emphasis for TAM models to focus on behavioural intention has been met with criticism. Scholars propose that self-reported use is problematic as it does not measure actual IT use (Legris, Ingham & Collerette 2003; Turner et al. 2010). Therefore, scholars suggest that TAM models do not focus on the real problem (Lee, Kozar & Larsen 2003).

Additionally, TAM models are founded on the Theory of Reasoned Behaviour (TRB) (Fishbein & Ajez 1975). The TRB assumes that behavioural intention will lead to actual behaviour. This assumption has been brought into question. While some scholars point out that there is some evidence to suggest that a unidirectional correlation does exist (Turner et al. 2010), other scholars refute it. Rather, scholars suggest that the assumption that behavioural intentions lead to actual behaviour potentially leaves other influential factors unexplored. Researchers have identified that organisational and social factors are rarely attended to in TAM models (Legris et al. 2003; Bagozzi 2007; Salovaara & Tamminen 2009).

All TAM models follow the same unidirectional causal process (Li 2010). This unidirectional TAM model is also contrary to learning theories, namely the Social Cognitive Theory, and Sensemaking. Unlike the unidirectional causal process proposed in the acceptance literature, both Social Learning Theory (Bandura 1977), later renamed Social Cognitive Theory (SCT) in 1986, and Sensemaking explain learning to be a cyclic process. Social Cognitive Theory posits that humans function, adapt and change and thus learn by way of a dynamic three-way reciprocal causal relationship involving behaviour, personal factors (affect and cognitive) and environmental conditions. These factors continually interact and influence one another in a bidirectional way. Similarly, the sensemaking process entails an interrelated process of three constructs, namely: creation, enactment and interpretation,

and thus the ability to make sense of something develops in an evolutionary cyclic way (Weick 1995). Thus, TAM models are met with criticism for ignoring the notion of cyclic learning.

The creators of TAM3 identified a limitation of TAM models for organisational settings. Venkatesh and Bala (2008) explained that while application of the knowledge gained from TAM studies can perceivably improve the favourability towards intended use of new IT, this knowledge cannot achieve the final step and achieve actual use. In light of this knowledge, Venkatesh and Bala (2008) offered that unless organisations make use of the IT adoption knowledge to develop effective interventions that can help employees to adopt new IT, such as training, technology adoption outcomes cannot be enhanced any further. Thus, while not explicitly labelled, Venkatesh and Bala identified a technology adoption gap in organisational settings that requires further research to close.

2.4.3.8 Closing the technology adoption gap

The authors of TAM3 identified a technology adoption gap between the technology and its use. Thus, in organisational settings, to close the technology adoption gap, the effort is required from both the technology end as well as from the user end to bring them towards each other. Thus, the development of more acceptable technologies has been found to be not enough to achieve optimal adoption outcomes. Rather, effective organisational interventions must also be developed to enhance the adoption process and thus to close the technology adoption gap. This notion is illustrated in Figure 2:9.

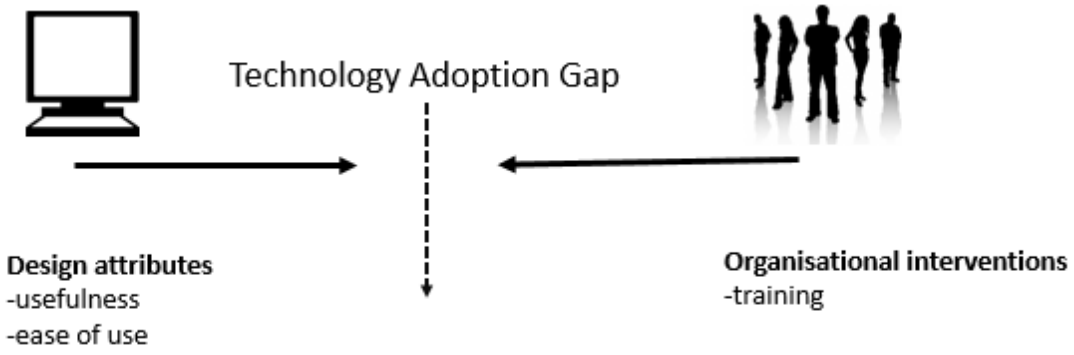

Figure 2:9 Technology Adoption Gap

While TAM models have their limitations, findings from TAM studies provide some insight into understanding the factors that may influence the pace and quality of end-user adoption, and thus may have some transferability to a control-room context.

2.4.3.9 Gaps in Knowledge

There are few studies that focus on why users resist new technology in organisational settings. Theories on user resistance show that user resistance is often viewed as bad by managers, and the way managers approach this resistance can influence resistance intensity. Rather, scholars offer that it can be more useful to view user resistance as feedback to an interaction conflict, but suggest more research is needed to support this focus.

Few social scientists study technology adoption of employees in organisations. The focus of most studies concentrates on a technology adoption gap that refers to technology uptake on a macro level, by organisations, industries, communities, regions or countries. As a result of the knowledge of technology adoption decision making, while quite extensive, is rarely applied to end-user adoption at a micro level. This work has primarily been conducted by the MIS research community.

The research conducted by the MIS research community is very extensive. However, TAM scholars recognise that TAM studies cannot, of and by themselves, resolve the technology adoption gap in organisations. Unlike the technology adoption gap referred to in the social science literature, TAM scholars have identified a gap between the technology as presented to users, and the action taken by the user to adopt the new technology. TAM scholars recognise that there is a need for organisations to develop effective interventions to help users come to adopt the new technology. Furthermore, TAM scholars believe that until organisational interventions are effective, the technology adoption gap will continue to exist. Past TAM studies have primarily focused on bringing the technology closer to the human by making the design attributes more useful and user-friendly. However, in organisational settings, TAM scholars have noted that the organisation also has a responsibility to help the user to achieve IT adoption. Training has been found to be the primary means for bringing the user closer to the technology. However, TAM scholars offer

that other organisational interventions are necessary if more effective and efficient technology adoption outcomes are to be achieved.

2.4.4 Sensemaking to enhance technology adoption

The connection between sensemaking and technology adoption is relatively new. Possibly the first to make this connection was Griffith (1999) who suggested that in organisations, the first sighting of technology features acts in providing cues from which the technology adoption process first begins and thus triggers to sensemaking commencement. Later, Seligman (2000) proposed that in mandatory circumstances, it may be more useful to know how individuals adopt. He offered that an exploration of how individuals come to make sense of new technologies may lead to a better understanding of the underlying processes that influence end-user adoption of new technology within organisations. From this understanding, more effective organisational interventions might be developed (Seligman 2006). Seligman proposed that the sensemaking perspective, according to Weick (1995), might be useful for this purpose. However, sensemaking as a theoretical construct is not fully developed and continues to mature. Therefore, knowledge on the relationship between sensemaking and technology adoption is sparse but warrants further exploration.

2.4.4.1 Theoretical origins

Conceptually, sensemaking related to organisation was originally developed by Karl Weick (1969, 1979) who focused on understanding the process whereby people became organised. Weick (1979) argued that *organisation* is an outcome of a process that evolves and the organising process is founded upon sensemaking. Sensemaking itself is a process that involves individuals who interact within a social setting, who take action and hence learn from lived experience about their identity and connection within this group and what to do next. The sense created during sensemaking takes the form of mental *cause maps*, mental frameworks that are retained in the individual's mind. As the group of individuals begin to take further action to organise themselves, behaviour within the group interlocks and any residue ambiguity is dealt with through negotiations until cause maps converge (Weick 1979). Organisation is achieved when the shared cause map emerges within the collective entity (i.e. group of people) (Weick & Bougon 1986). Thus the extent to which sensemaking is accomplished indicates the level of organisation reached.

As time has progressed, Weick's understanding of sensemaking has also evolved from early linkages to organising with a cognitivist perspective (Weick 1979), to one more closely aligned with social constructivist thinking that has been said to border on a quasi-phenomenological perspective (Sandberg & Tsoukas 2015). Under this new paradigm, sensemaking has come to be considered more than a cognitive process, but one that involves a constructive practice of taking action. In this regard, individuals discover their own inventions as they actively extract cues (i.e. significant stimuli) from enacted events that are understood to have created greater plausible meaning. These individually enacted events not only serve to update the individual's mental cause map, as Venkatesh (2000) also proposed, but also helps to update the mental cause map of those of others whom they interact. As a shared cause map emerges within and from the group, organisation is created and acted out (Weick 2001). Thus, as individuals begin to identify with a particular social context, they actively engage with other actors and through reflection, members notice and attend to cues from ongoing events that help them build plausible sense and thus guide further action taking (i.e. enactment). Gradually through enactment and continuously updated mental models of plausible sense, order is achieved.

From these theoretical origins we see where sensemaking parallels Social Cognitive Theory. Both SCT and sensemaking posit that individuals learn (make meaning) in a social environment, they cognitively learn (make sense through interpretation) from personal or experiences of others, which guides behaviours (enactments), which creates learning (sensemaking) and directs future action. Thus action (behaviour) is influenced by thoughts, beliefs and emotions. Rather than reactive agents, both theories suggest that individuals are proactive producers of the environments in which they interact (Bandura 1977, 1986).

In this regard the interpretation of sensemaking can be seen as a form of learning similar to SCT. Change triggers both learning and sensemaking and while learning is ongoing, the literature on sensemaking adds that sensemaking is very personal in nature and provides personal relevance. Scholars have suggested that sensemaking extends SCT in that enactment, rather than behaviour, highlighting the fundamental way humans exist, not just to learn but allowing for greater complexity that is more reflective of the modern world (Sandberg & Tsoukas 2011).

2.4.4.2 Application to technology adoption

In relation to the adoption of new technology, it is projected that the organisational aspect of sensemaking begins to develop when end users start to take action to make sense of a new technology. Interpretation of this action helps to form a more complete and organised picture about the new technology. If the decision is reached to continue to use the technology, sensemaking continues to the point of expert use and may lie dormant until cues that indicate changes to functionality trigger more active sensemaking once again. In regards to human factors integration (HFI) during design, it is anticipated that the interpretation of user testing (i.e. enactments of plausible meanings) may serve as feedback to designers about how well the design matches user needs. Thus the feedback also helps designers to update their own conceptual model of the design, and serve to better provide a more accurate picture of what the design should become. As more plausible meaning develops, feedback to designers can contribute to the refinement and redesign of the technology until the design becomes more aligned (organised) to the needs of the end user.

2.4.5 Assumptions

Weick uses social phenomenology to explain that we only have access to our world by way of lived experience. This supposes that 'actions are known only when they have been completed, which means that we (i.e. current knowledge state) are always a little behind. Our actions are always a little bit ahead of us' (Weick 1995, p. 26). In this way, sensemaking is realised by the individual retrospectively. A cognitivist explanation posits that major organisational change creates 'cognitive disorder' (Luscher & Lewis 2008, p. 221), which people need to 'make sense' of, in order to restore cognitive order. Where cognitive disorder exists, tension, frustration and anxiety are created and an emotional response is likely to accompany this tension. The inclusion of emotions is relatively new to sensemaking but has support from sensemaking advocates (Maitlis & Sonenshein 2010).

The concept of sensemaking has been described to have seven properties, namely (Weick 1995):

2.4.5.1 Property 1: Grounded in identity construction

As individuals learn about themselves through acting, reflecting and by interacting with others they develop an identity. An example of this concept is the unique identity of the human factors discipline which is recognised by the unique tools and methods ergonomists have developed and use in practice (Hendrick 2000). In this way, the human factors discipline has created its own identity.

2.4.5.2 Property 2: Sensemaking is retrospective in nature

Sensemaking can only occur once something has already happened. Therefore, sensemaking is retrospective because it is based on previous action, knowledge, or beliefs. Seligman (2000) offers that if technology adoption is a sensemaking behaviour then it is futile measuring an individual's likely acceptance, or behavioural intentions if they have not already had some experience with or learned from someone else's experiences of the new product. Therefore, individuals partly create the environment they interface with by action taken that in part influences other people of the same environment. Therefore, enactment provides information about what people notice, where structures are based on prediction, observation and explanation (Starbuck & Milliken 1988). That is, people enact based on predicted sensible environments (i.e. plausible meaning) obtained from dialogues and narratives.

2.4.5.3 Property 3: Sensemaking is a social activity

Sensemaking is individual (the sensemaker) and shared, and evolves through conversations with themselves and others. Sensemaking defines the identity of individuals and of a collective group. For instance, attempts to make sense are also contingent on what others in the group do think and say. Therefore, sensemaking occurs in social settings where discussions, interactions, and engagement occurs. In this regard, sensemaking aligns with social cognitive theory (Bandura 1989). For instance, information sourced (i.e. heard, saw, felt, etc.) from the group support learning that updates the individual's personal mental framework and moulds their identity. Therefore, an individual's technology adoption behaviour may be influenced by the social culture within the organisation. Where a negative consequence may be sensed, the individual may question whether they should adopt the new technology at the disapproval of others, and thus may align their behaviour with those

who are more influential to resolve internal conflict (Rice & Anderson 1994). Therefore, user resistance toward a new technology may be absolved in preference to maintaining status within a working relationship or work environment.

Seligman (2000, p. 365) identifies three ways that social impacts can influence an individual's technology adoption patterns: (1) when the sensemaker changes his or her technology adoption behaviour based on perceptions of what work colleagues may think, especially if there is a high preference to remain favourable with the group, (2) user resistance may occur due to perceived loss of status, autonomy or relationships with other work colleagues, and (3) where the sense makers technology adoption behaviour differs when working in isolation, rather than in close proximity with others. This suggests that the working context and social culture need to be considered when new technology is to be introduced.

2.4.5.4 Property 4: Sensemaking is an ongoing process

Sensemaking helps individuals to simultaneously mould and respond to the environments they interact in. As the individual enacts plausible meaning, he or she interpret the results from this action and makes greater sense of what is truth and thus new knowledge is created. This, in turn, guides further action and so on. Therefore, sensemaking is an ongoing evolutionary process. The same can be true for technology adoption. Opportunity to experience the technology increases understanding, levels of aptitude and thus skills develop. Over time, systems and the working environment change and what may have been perceived as useful under one context, may no longer be relevant in another or at another time (Seligman 2000). This suggests that it may be prudent to consider the systems lifecycle including its members, technologies, and the cultural environment when aiming to improve technology adoption outcomes.

2.4.5.5 Property 5: Sensemaking focuses on extracted cues

Cues are stimuli that have been encountered, perceived and attended to. They are familiar structures like seeds of information that help to develop a larger sense of what is happening and inform further action. Griffith (1999) suggests that technology features are cues and as such act as triggers to sensemaking, to help determine what explanation is acceptable and what information is relevant. An assumption cannot be made that those who experience an

event notice the same cues. Furthermore, Griffith (1999) offers that it cannot be guaranteed that two individuals, who notice the same cue, will integrate it in the same way into their mental frameworks.

2.4.5.6 Property 6: Plausibility drives sensemaking not accuracy

The accuracy of meaning is difficult to achieve in modern complexity where systems increasingly become more tightly networked and adaptive. Furthermore, the retrospective and continuous nature of reducing ambiguity through learning, cannot provide a totally accurate picture. This is because perceived sense is not confirmed until enacted and responded to by group members. Scholars have noted that plausible reasoning continues even though an individual has an incomplete and sometimes inaccurate understanding (Isenberg 1986). Therefore, sensemaking cannot be driven by accuracy, but rather plausibility, of what might seem reasonable according to the individual's needs and preferences. Sensemaking continues even when enactments based on misperceptions, reveal that the plausible truth was not accurate. Thus plausibility helps the sensemaker to develop a narrative to be acted out, in order to know what is truth and what is not (Weick 1995 pp. 55-61). Furthermore, personal preferences also influence what might be considered plausible. For instance, people have been found to rely not only on sensory experience to dictate plausibility, but also personal preferences toward what might be interesting, attractive, desirable, or goal-relevant (Fiske 1992).

Therefore, it is likely that preferential plausibility can influence attitudes and perceptions related to the adoption of new technology. For instance, with incomplete and even inaccurate understanding, individuals may not have formed a belief as to what *would* occur. However, a belief as to what *could* occur could be formed, and thus influence attitude toward technology adoption. The notion that preferential plausibility may take precedence over sensory stimuli is new and an identified area for further investigation (Seligman 2000).

2.4.5.7 Property 7: Sensemaking is enactive of sensible environments

By acting out plausible meanings as indicated above, individuals participate in the evolution of their own environments. With each enactment, the individual gains a greater understanding and the environment gradually makes greater sense. In this sense, the user of a new technology can manage any incompatibilities, by further acting out behaviours that

increase compatibility. This process of managing incompatibilities is evident when individuals start to work around a poorly designed system to be able to complete tasks. This compensation for incompatibilities has also been used to illustrate how man is at times his own worst enemy (Wilson & Sharples 2015).

Weick's concept model of sensemaking is thus influenced by stimuli, attention, exploration, attribution, global and comprehension, and create a frame of self, similar but different to a personal mental schema or viewpoint.

2.4.6 Operational definitions of sensemaking

For the purposes of this study, sensemaking is defined as a reciprocal spiral of evolving understanding that advances gradually over time by the interactions of enactment (taking action), creation (discovery of new knowledge), and interpretation (through reflection).

This definition is consistent with others and follows the perspective founded on the work of Karl Weick (1995). Other descriptions of sensemaking include: 'the making of sense' (Weick 1995, p. 4), a means for structuring the unknown (Waterman 1990), placing stimuli into a mental framework that directs interpretations as a means for understanding and comprehending something new (Starbuck & Milliken 1988). Sensemaking has been described as 'the cyclical process of taking action, extracting information from stimuli resulting from that action, and incorporating information and stimuli from that action into the mental frameworks that guide further action' (Seligman, 2000, p. 361). Gadamer (1975) describes sensemaking as involving 'whole/part' relationships in terms of a hermeneutic 'circle of understanding'.

From these descriptions, we see that sensemaking is a cyclic process that develops and evolves over time. Weick (2009, p. 195) explains that habitual behaviour is based on a history of identity shaping behaviours in response to two fundamental questions asked unconsciously and simultaneously: 'What's the story? Now what?', neither of which can make sense until reflected upon.

2.4.7 Constituents that define sensemaking

The constituents that define sensemaking in organisations can be summarised in the following way: Sensemaking is confined to *specific episodes* when internal processes are disrupted and last until restored satisfactorily. These episodes are triggered by *ambiguous events* that can be either planned or unplanned. Once triggered, sensemaking occurs through *specific processes* involved in creation, interpretation and enactment. These processes generate *specific outcomes* that provide a specific sense that guides further action. These processes are influenced by several situational factors, such as context, cognitive frames, language, identity, politics, emotion and technology (Sandberg & Tsoukas 2015, p. S26).

2.4.8 What sensemaking is not

A common tension amongst organisational researchers is the interchangeable use of the terms interpretation and sensemaking (Sandberg & Tsoukas 2015). Weick (1995, p. 16) explicitly states that sensemaking is not interpretation but rather a higher level abstraction that includes interpretive activities. Weick offers that the literal meaning of sensemaking is more accurate, i.e. 'making something sensible' than when it is expressed metaphorically, such as: 'how individuals make sense of their situations' which may only account for interpretive activities. To give greater clarity to this point Weick (1995, p. 8) explains that sensemaking consists of three distinct and interrelated processes: creation, interpretation and enactment.

2.4.9 The sensemaking process

The theory of sensemaking has helped researchers understand phenomena in organisational settings (Colville, Brown & Pye 2012; Maitlis & Christianson 2014). The process of sensemaking begins the moment an ongoing organisational activity is interrupted until it is suitably restored. The process of sensemaking has been described as: 'actors first create what they subsequently focus on for interpretation and act on those interpretations; the cycle is ongoing' (Sandberg & Tsoukas 2015, p. S14), and likened to a circle of understanding (Gadamer 1975). Therefore, the process of organising, involves individuals who interact within a situation (i.e. their environment), who take action based on a prediction of success to reduce uncertainty, and who take further action (enact) based on the new information

provided by the previous experience, the results of which become their new environment. The sensemaking process has three interrelated processes: creation, enactment and interpretation.

Creation occurs when individuals construct, extract, notice and bracket cues from experiences from the interrupted situation. At first, individuals create an initial sense of the disruption which starts the interpretation process. During the creation process identities are constructed as well as parts of the environment and thus humans are not subject to their environments, but actively contribute to their formation and hence their sense of agency (Weick 1995).

Interpretation entails fleshing out the early sense generated during creation and forming it into a greater organised sense that generates a more complete narrative of the situation. The extracted information is reflected upon to reduce ambiguity. Through interpretation, individuals discover their own inventions by extracting new information from actions taken. Reaction to these outcomes creates a plausible interpretation of events that make sense. Furthermore, interpretations are revised based on further action and its consequences, subsequent interpretations, as the cycle continues (Weick 1995).

Thus, the constituents involved in the sensemaking process show that interpretation involves more than cognition. As the seven properties of sensemaking have highlighted, the interpretative aspect of sensemaking involves taking action to create stimuli for cognitive processing. Cognition is the mechanism by which individuals come to create a mental framework about the situation or item they are making sense of. In this regard, they are a type of mental framework created for sensemaking and thus provide a mechanism for filtering and storing new information. Therefore mental frameworks have a reciprocal relationship with sensemaking, each influencing the other toward furthering a more complete reality by reducing uncertainty. Like all mental frameworks or mental models, they have undergone the scrutiny of personal cognitive schemas (i.e. organised patterns of thought or behaviour on a particular concept) to aid prediction and reasoning.

These mental models have been described as ‘personal, internal representations of external reality that people use to interact with the world around them’ (Jones et al. 2011, p. 1).

While mental models are unique to the individual based on their own life experiences, perceptions and understanding they have also been shaped by the perceptions, values and goals of others they interact and engage with. Interpretation, therefore, involves enacting plausible sense according to the existing mental framework. The new experiences are then evaluated retrospectively to determine whether the information contributed to improved sensemaking or greater ambiguity.

Enactment begins the process of sensemaking and has been described as when: 'actors first create what they subsequently focus on for interpretation and act on those interpretations' (Sandberg & Tsoukas 2015, p. S14). The enactment process involves acting on plausible meanings to achieve a more complete sense of the disrupted state for the purpose of coming to know to what degree their action will restore the disruption. Thus, the early action taken becomes part of the individual's living environment in which they now engage and take further action in (i.e. enactment). Again, this action may lead to further increments of the three processes, until the disrupted state is satisfactorily restored (Weick 1995). Therefore, sensemaking is a process for organising sense. Figure 2:10 shows the three interrelated elements considered essential for sensemaking to occur. The spiral represents sense being made over time.

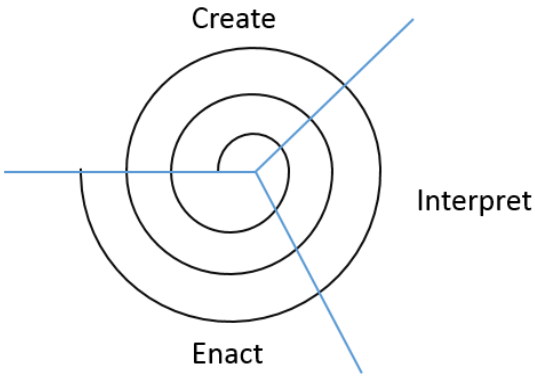

Figure 2:10 The sensemaking process

2.4.10 Sensemaking studies

A recent literature review, found that most of the studies that have taken a sensemaking perspective have focused at an organisational level during times of great disruption or major

change to understand how organising occurs (Sandberg & Tsoukas 2015). Of the 37 different organisational areas, half of these areas had only one published study, illustrating the extent of under-researched areas in this field (Sandberg & Tsoukas 2015). The dominant focus on organisations stems from the links Weick (1979) made between sensemaking and organising towards job performance (Narayanan, Zane & Kemmerer 2011; Taylor & van Every 2000). Others have examined sensemaking at an individual level. Dokko, Wilk and Rothbard (2009) focused on prior experience that individuals brought to the new work environments; while Morandin and Bergami (2014) examined specific meanings associated with the decision to participate in the organisation and how this related to job performance.

2.4.11 Sensemaking and technology adoption

Very few studies have focused on sensemaking and technology, and even fewer have focused on sensemaking and technology adoption. Early on, researchers recognised that the use of computers at work meant different things to different people (Turkle 1984). Computer science researchers have examined individual meaning in a subjective way (i.e. through symbolism) revealing the individual hopes, anxieties, dreams and inadequacies toward new computerised systems (Simon 1965). Furthermore, these representations of meaning have been found to influence how users interact with their technology (Feldman & March 1981). Prasad (1993) examined the process of computerisation taking a symbolic interactionist perspective from pre-introduction through to the technology adoption process and focused on: meanings, local interpretations, and enactment. Although not identified as sensemaking, the three elements match those of the sensemaking process as identified by Weick's (1995) and illustrated in Figure 2:10

Prasad (1993) found that symbolised meaning varied amongst individuals in the group and that these meanings changed during the technology adoption process. For instance, initial responses could be expressed in three ways: *pragmatic* – characterised by professionalism and thought to be inevitable, *pessimistic* – characterised as negative and disruptive, and *romantic* – characterised by optimism and idealistic expectations. As implementation progressed, symbolised meanings began to change and new terms emerged, such as alienation, as users experienced and learnt more about the new system. Prasad's (1993) study highlights that sensemaking began with initial perceptions of the technology, as

evidenced by symbolic representations of technology they anticipated. As computerisation progressed toward implementation and training, these symbolic representations changed to reflect current perceptions. These findings on sensemaking show that technology adoption begins well before an individual is introduced to the technology.

Some studies have used sensemaking to explain how technology adoption occurs. One study explained that sensemaking is triggered when technologies are introduced into organisations (Griffith 1999). Seligman (2000) aligned sensemaking activities with each stage of the innovation-decision process as developed by Rogers (2003) and offered that the stages of the innovation-decision process model could progress in alternative ways. Based on this research, Figure 2:11 shows how technology adoption evolves with advancements in sensemaking.

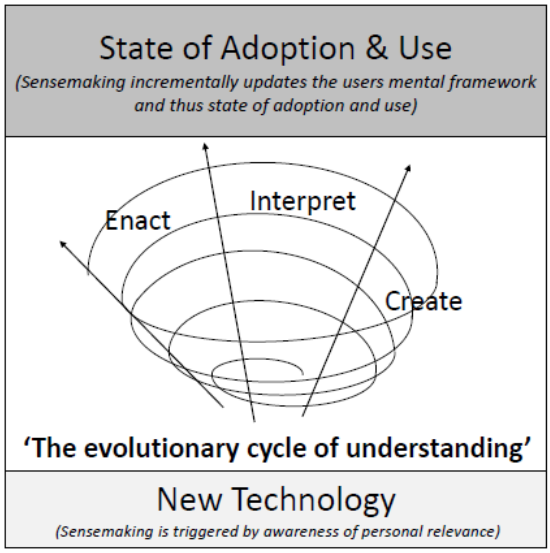

Figure 2:11 The evolving sensemaking spiral for technology adoption

The discussion above indicates that sensemaking, as used by organisational researchers may help them to discover the underlying processes during the technology adoption process. This knowledge may be able to contribute to the facilitation of conditions and interventions that help to facilitate sensemaking and thus improve technology adoption in mandatory circumstances.

2.4.12 Sensemaking and design

Aside from being used to aid the understanding of how users come to be organised, or come to adopt new technology, sensemaking amongst the human factors community is being used to improve human-computer interactions strategically.

Dervin (1983) was possibly the first to link sensemaking to data retrieval when the interpretation of observed data was noticeably difficult for the operator. Ten years later, sensemaking was operationalised to improve information retrieval, based on operator sensemaking during the design process (Russel et al. 1993). Russel and colleagues (1993) reported that people utilised three main processes when working out how to use a printer. These processes were similar to those offered by Weick (1995). The process was called 'the learning loop complex' (Russel et al. 1993, p. 272). This has led computer analysts to cluster data more closely to the mental representations of users, to improve information retrieval. For instance, Dervin (2003) uses sensemaking as a methodology for improved human-computer interaction.

Sensemaking is also being used to increase decision-maker mindfulness (a critical success factor) during enterprise resource planning. For instance, Sammon (2008) leverages sensemaking in his devil's advocate workshops to help decision makers become more mindful of the needs of stakeholders and thus the level of resources needed to ensure the success of purpose-built enterprise projects. Sensemaking is also being used in complex decision-making situations, particularly where a diverse set of stakeholders are involved, where sensemaking is used to help construct a shared understanding of a problem (Paradice & Davis 2008). In support of business sustainability, sensemaking is used in decision support activities to help management become more sensitive to environmental changes, in an effort to prompt more timely and better decision-making (Paradice 2008). Finally, sensemaking has been used to examine mental representations of air traffic controllers (Malakis & Kontogiannis 2013).

2.4.13 Criticisms of sensemaking

While sensemaking as a strategic intervention seems to be growing in popularity and has been used across many different disciplines, researchers who use and develop sensemaking have been criticised for mimicking or reinventing the wheel (Klein, Moon & Hoffman 2006).

Sensemaking is a complex phenomenon that is in its early stages of development as a theory. Nevertheless, it has attracted some criticism, implying that sensemaking is just packaging other theories under a different name. Klein, Moon and Hoffman (2006) suggest that some of this criticism may stem from oversimplified definitions like 'how people make sense out of their experience in the world' (Duffy 1995), or 'the making of sense' (Weick 1995). Five theories from psychology that were identified to have similarities with sensemaking include creativity, curiosity, comprehension, situational awareness, and mental modelling (Klein, Moon & Hoffman 2006). Claims of replication of each are refuted below:

Creativity has been described as the ability to generate useful outcomes in a novel way (Sternberg 1998) and as productive thinking, through the generation of novel solutions to problems (Wertheimer 1959). Weick (1995) explains that creativity occurs when individuals interpret and thus discover and create their own inventions. While the creation of new knowledge is a component of sensemaking, sensemaking goes further to encompass enactment of these creations to test their application to the scrutinised event. In this regard, sensemaking encompasses more than creativity alone.

Curiosity is often thought to denote the motivational aspect of exploratory behaviour (Mark 1998). However, curiosity, as a concept, is not fully understood. For instance, while originally developed upon insights from Gestalt psychology and behavioural decision theory, new insight from drive theories is suggesting that curiosity is aversive and stimulated by both internal and external factors (Loewenstein 1994). While individuals are motivated to make sense of an event, this motivation is only a small part of the process involved during sensemaking.

Comprehension is most commonly thought to be the understanding and interpretation of certain stimuli that primarily consists of words, phrases, or groups of words, and thus often

referred to as ‘reading comprehension’. The process of comprehension has been described as simultaneously extracting and constructing meaning through interaction and involvement with written language’ (Snow 2002, p. 11). As such, comprehension is commonly linked with literacy. While the process involves extraction and construction to develop understanding, theories on comprehension do not extend to more complex situations, nor do they consider the creation of plausible meanings and the testing of this plausibility. Therefore, the process of sensemaking is more complex than current theories on comprehension.

Mental modelling has been described as the process of thought in which explanatory, descriptive or predictive mental representations are created (Johnson-Laird 1999). These mental models are a personal representation and thus have also been described as ‘personal, internal representations of external reality that people use to interact with the world around them’ (Jones et al. 2011, p. 1). Johnson-Laird (1999) further explains that mental models are constructed to minimise the load on working memory and are based on a fundamental assumption, the principle of truth. Thus, the possible meaning is constructed as a mental representation of what is true. All mental models are thus subjected to the scrutiny of existing cognitive schemas (i.e. organised patterns of thought on particular concepts). For this reason, mental models also reflect personal beliefs, values and assumptions that can explain why people do the things they do (Bosch, Maani & Smith 2007). In this regard, mental modelling plays an important role in sensemaking, because the interpretation of enacted results requires a mental mechanism to filter and store information for which a mental framework can be created. However, mental modelling of and by itself is only one part of the sensemaking process.

Situational awareness is characterised by a state of knowledge about a situation (Endsley 1995). For instance, it has been described as ‘a dynamic mental model of the situation, in which explicit and implicit levels of knowledge can be distinguished’ (Lo, Sehic & Meijer 2014, p. 5). However, situational awareness does not provide any insight into how the mental image changes when the events being perceived change (Malakis & Kontogiannis 2013). The difference between sensemaking and situational awareness is that sensemaking is the process by which individuals come to know the situation, rather than knowledge of the situation. Therefore, sensemaking helps to create situational awareness but is not this knowledge.

While each of these theories may represent part of what sensemaking is, on their own, they do not capture the full meaning of what sensemaking entails, and thus sensemaking has merit as a unique theoretical construct.

2.4.14 Affect and cognitive bias on sensemaking

Affect is the automatic outward expression of emotion. Distinct emotions have been found to influence cognition and by extension sensemaking and adoption behaviour. Emotions are frequently portrayed as problematic. This is because they impose a subjective perspective on reality (Hofmann, Ellard & Siegle 2012). Faulty or exaggerated perceptions of reality that lead to irrational judgment (Oatley 2005) have the potential to inappropriately guide social behaviour and decision making (Keltner & Horberg 2015).

To understand emotions and how they influence behaviour is not well understood. Emotions have been described as a 'fuzzy set' with indistinct boundaries that are infused in beliefs, values and social norms (Averill 1998, p. 850; Parkinson 1995). Nevertheless, they have been found to influence attention and memory (Hofmann, Ellard & Siegle 2012; Ortiz de Guinea, Titah & Léger 2014; Rodger 2014), judgments and decision making (Oatley 2005; Ortiz de Guinea, Titah & Léger 2014), and expectations (Ginzberg 1981). Emotional experiences manifest automatically due to neurobiological (Hofmann, Ellard & Siegle 2012) and neuropsychological responses (Ortiz de Guinea, Titah & Léger 2014). For instance, cognition faults can creep in subconsciously from attention biases that result from heightened sensory cues from thalamo-amygdala projections (Hofmann, Ellard & Siegle 2012). As a result, individuals can be unaware of the emotional influence on cognition and potent bias.

However, it must be noted that while most studies have focused on the negative effects of negative emotional responses (such as fear and anxiety) on technology adoption, positive emotions can contribute to positive cognition. Rodgers (2014) examines the positive effect of inspiration and found it to influence memory and situational motivation positively. Therefore cognition and decision making can become biased when influenced by irrational emotions and thus become a human factors concern working against accurate sensemaking that influences technology adoption motivation.

2.4.15 Gaps in knowledge

Scholars have nominated the sensemaking perspective as a plausible means for greater understanding of how end users come to adopt new technology. This review has found that research in the area is promising but is spread and theories continue to evolve. Nevertheless, the sensemaking perspectives offer an alternative way to address the technology adoption gap identified earlier.

2.5 Sensemaking-Adoption Factors

There are a number of factors from the MIS literature that may help to explore the sensemaking perspective. Twenty-three factors have been chosen and discussed in further detail within the areas of personal attributes, facilitative conditions, environmental factors, organisational matter and user input.

2.5.1 Personal attributes

Various personal attributes have been identified to influence an individual's ability to adopt new technology. They are presented here.

2.5.1.1 Age

A growing human factors concern is the first world trend towards an ageing population which is also reflected in train control rooms and may have implications for controllers when new technology is introduced. Age has been found to moderate the intensity of influence that determinants of behavioural intentions have toward technology use (Venkatesh et al. 2003; Venkatesh, Thong & Xu 2012).

As mentioned earlier, in non-organisational settings, the behaviours toward adoption of younger men with less exposure to the technology are driven more by hedonic motivation (i.e. fun factor), than by performance expectancy. In regards to usefulness, older women were found to be influenced by price value (Venkatesh, Thong & Xu 2012).

Management Information Systems researchers have also found a link between age and attitude, as well as self-efficacy. For instance, older people are more likely to indicate that technology is not easy to use (Mikkelsen et al. 2002; Morris, Venkatesh & Ackerman 2005;

Seyal & Pijers 2004). Additionally, social scientists have found that older adults tend to be later adopters (Rogers 2003).

However, overall, the literature on this topic is mixed. For instance, one of the reasons put forward to explain why older individuals are slower adopters is because they are more cautious due to perceptions of risk (Rolison, Hanoch & Woods 2012). This is supported by other studies that found older individuals prefer certain gain over uncertainty (Mather et al. 2012). On the other hand, other studies have found no difference between age and risk behaviour (Mata et al. 2011). Computer anxiety has been reported as higher amongst older people (Mikkelsen et al. 2002), whereas others report no differences (Maurer 1994; Rosen & Weil 1995). Rogers (2003) puts forward that decisions to adopt by older people are linked to their socio-economic status, where an investment needs to be fruitful where finances are concerned.

However, while socio-economic status is not likely to be a concern in organisational settings, slower learning rates and unlearning may be. Early studies produced mixed results with some finding that short-term memory reduces with age (Bromley 1958) and in other cases, results were inconclusive (Jerome 1959). In regards to learning new technology, younger people are faster at learning a new technology than older individuals. A comparative study examined learning rate differences between age groups and found that those aged between 60 and 80 years, were found to be much slower, less accurate and would more easily forget than younger people aged 18 to 25 years (Jamieson & Rogers 2000).

Researchers offer that where older operators are required to learn new technology, age-specific training protocols may be necessary (Jamieson & Rogers 2000). In this regard, random learning schedules produced better performance outcomes for knowledge transfer (i.e. to other tasks) for all ages than block learning schedules which better supports knowledge acquisition (Jamieson & Rogers 2000). These findings indicate that allowance for random practice and training schedules can benefit all staff members regardless of age. Furthermore, due to an ageing workforce, from a sensemaking perspective, age may be a human factors concern.

2.5.1.2 Gender

The vast majority of research suggests that gender has a moderating effect on technology adoption (Huang, Lu & Wong 2003), particularly for women during the early stages of experience with a new technology (Padilla-Melendex, Aguila-Obra & Garrido-Morena 2013). The moderating effect has been found to be more pronounced in mandatory circumstances (Venkatesh et al. 2003), especially for older women (Morris, Venkatesh & Ackerman 2005; Venkatesh, Thong & Xu 2012). Furthermore, women have been found to have greater computer anxiety (Mikkelsen et al. 2001) and lower computer self-efficacy (Chou 2001; Shashaani & Khalili 2001).

Social scientists have found that women approach technology adoption differently to men. For instance, in the early stages of experience, women rely more heavily on information from their social networks than men do (Miller 1976; Rogers 2003). This need to consult with the social network is more pronounced in mandatory circumstances (Venkatesh et al. 2003). However, while social factors may be influential during the early experience, other scholars have found that social influence declines with more experiences with the new technology (Venkatesh & Morris 2000).

Furthermore, while gender effects are more pronounced in the early stages of experience, they generally diminish as experience with the technology increases (Hartwick & Barki 1994). With more digital natives entering the workforce, gender differences amongst workers, in general, may diminish, as no gender differences were found amongst younger workers (Shashaani & Khalili 2001). A study on teacher use of information communication technology found no gender differences across all age groups (Sang et al. 2010). Therefore, although the literature has found gender to be an influential factor in technology adoption, findings are somewhat mixed. To combat potential negative gender-related effects, older women in mandatory circumstances may simply require an opportunity for social networking and sufficient experience with the new technology.

2.5.1.3 Openness to change

Technology adoption has been found to be linked to a unique mix of psychographic and demographic qualities of individuals (Moore 2002; Rogers 2003). Personality has been found to correlate with behaviour (Cairns & Cairns 1994). Of interest to this study is *openness,* one

of the five core personality types (i.e. big five), identified by Donald Fiske (1949), and later expanded by Norman (1963), Goldberg (1981) and McCrae and Costa (1987). Individuals who are open to change have been found to be more able to cope with change and thus adopt more readily to new technology (Ghobakhloo et al. 2012; Wanberg & Banas 2000).

However, behaviour is not predetermined by personality alone. Social cognition theory posits that adaptation to change results from a reciprocal relationship between personal factors (including personality, emotions and cognition), environmental events, and outcomes from experiences of their own and others (Bandura 1986). Furthermore, individuals can control their feelings and thoughts, and thus actions (Bandura 1995). Additionally, researchers have found that personality traits can change over time (Roberts, Wood & Caspi 2008), and are influenced by interactions with situational circumstances (Cherry 2015), such as the work environments (Roberts, Caspi & Moffitt 2003). Therefore, the literature suggests that an individual's level of openness to change can be encouraged by increasing learning opportunities in a social environment and by changing situational factors that inhibit these opportunities.

Finally, Wanberg and Banas (2000) found that by providing information about the changes and by having individuals participate in change decisions, openness to change increased. Therefore, early information provision about the change may help individuals make sense of what the change will mean to them personally. Also, involvement in decision-making regarding the change encourages greater openness towards change which can lead to more complete knowledge and better judgment about the new technology and its impact upon technology adoption.

2.5.1.4 Employee attitude

Prior to any direct experience, individuals form attitudes toward new technologies (van Ittersum et al. 2012). Attitude has been defined as 'a settled way of thinking or feeling about something' (Oxford Dictionaries 2015). The definition implies that attitude is a mental state, and thus is a useful term to use to refer to a user's mental disposition prior to the user experience. Due to underpinning theory (i.e. the theory of reasoned action), the vast majority of MIS literature on technology acceptance has focused on finding the prediction determinants and their antecedents that influence user motivation which is assumed to lead

logically to usage behaviour. As illustrated in Davis's (1986; 1989) technology acceptance model, Figure 2:6, user motivation is expressed as a combination of cognitive evaluations of utility and design, and affective response to these evaluations that adds to the user's attitude toward the new technology. Thus, many studies reported that a positive attitude was paramount for adoption success.

However, attention to attitude as the final step toward action may be faulty logic. To accept something without taking action to confirm or dispel uncertainty is contrary to theories on technology adoption, social cognition, and sensemaking. Both sensemaking (Weick 1995) and social cognition theory (Bandura 1989) posit that acts of behaviour help individuals come to learn about their environment. Furthermore, technology adoption theory posits that individuals follow a decision-making process that involves trialling the product before the decision to adopt or reject is made (Rogers 2003). Therefore, while a positive attitude toward adopting a new technology may be logically ideal, it may not be enough. Rather, a focus on helping users make sense of the technology is possibly more fruitful. Few studies have focused on sensemaking and technology adoption, therefore making this an area that can benefit from further research.

2.5.1.5 Employee computer abilities

As modern control rooms introduce more computer-based technologies, controllers are increasingly required to have computer abilities. Actual ability and one's belief that a new task or goal can be performed well (i.e. self-efficacy) are strongly linked. Self-efficacy is the term used to describe the extent to which an individual believes that they can complete tasks and to reach certain goals (Ormrod 2013). Self-efficacy is of interest to technology adoption researchers, because of its influence on how goals, tasks and challenges are approached. For instance, those with higher self-efficacy believe they will perform well. Therefore, they generally do not avoid challenging tasks, but rather approach them as something to master (Bandura 1988).

An individual's self-efficacy is also reflected in computer self-efficacy (Compeau & Higgins 1995), where general computer self-efficacy was found to be a strong predictor of subsequent task-specific computer self-efficacy beliefs (Agarwal, Sambamurthy & Stair 2000). Self-efficacy can, therefore, help or hinder technology adoption efforts, as

technology competence has been found to impact adoption success of new technologies (Calderia & Ward 2003; Ghobakhloo et al. 2012; Thong 2001). Personal experience with the new technology has been found to help individuals learn more effectively and thus likely to increase the individual's self-efficacy (van Ittersum et al. 2012).

Training has also been found to positively influence technology adoption (Premkumar & Roberts 1999). Recent research acknowledges the generation gap between younger and older individuals and recommends confidence-building tasks to increase self-efficacy particularly for older workers (Lin & Wu 2004; Small & Vorgan 2008; Venkatesh et al. 2003). More specifically, Agarwal, Sambamurthy and Stair (2000) recommend training staff on a number of software packages, not just the specific one being implemented and in such a way to build the individual's computer abilities sequentially, so that prior learnings help to scaffold the next. Therefore, feelings of computer incompetence have the potential to undermine technology adoption efforts, since individuals with low computer self-efficacy may choose to avoid the new technology rather than to tackle it as an achievable goal.

2.5.1.6 Fears and uncertainty

Fears, uncertainty and doubt have been found to influence an individual's decision to adopt new technology negatively. User resistance towards new technology has been found to begin with fear (Lapointe & Rivard 2005) that is induced by judgments of low certainty and a minimal control (Lerner, Gonzalez, Small & Fischhoff 2003). Furthermore, design scholars have noted that engineering design has a way of dehumanising people and thus it was recommended that it include an emotional dimension in design (Jordan 1997).

Fear has been described as a basic emotional response to threat which is useful for quick mobilisation and adaptive behaviour and thus a survival mechanism (Ekman 1992; Hofmann, Ellard & Siegle 2012). It can be difficult to control fear because emotions are automatic responses that occur without conscious thought. Fear causes the nervous system to switch to a particular form of processing and activates regions of the brain such as the amygdala, hippocampus, and periaqueductal gray (Mathews, Yiend & Lawrence 2004). Studies have found that when these processes are chronically activated, they drain cognitive resources, increase the feeling of uncertainty and danger, undercut confidence, and inhibit those affected from concentrating on other matters (Keltner & Horberg 2015). Furthermore,

emotions also direct perception towards matters that are congruent with that emotional state (Niedenthal 2008) and thus amplify negative expectations of life outcomes (Lerner, Gonzalez, Small & Fischoff 2003). The biopsychological response to threat (i.e. fear) is therefore a natural response that needs to be attended to.

Uncertainty and doubt are related to fear as fear is a response to incomplete certainty. Therefore, it stands to reason that uncertainty and doubt are also factors that can induce user resistance (Hirschheim & Newman 1988; Jiang, Muhanna & Klein 2000). Fears can develop into passive cynicism and other more overt forms (Selander & Henfridsson 2012). Therefore, researchers recommend that fears and industrial uncertainty should be resolved as quickly as possible (Dekker 2014; Project Management Institute 2013). Furthermore, certainty of a bad outcome has been found to be better received than uncertain outcomes (Lazarus 1966).

2.5.1.7 Employee fear of reduced control of activity

As mentioned earlier, fear can be induced by a feeling of low control (Han, Lerner & Keltner 2007; Lerner & Keltner 2001). While, automation can help management achieve centralised control and greater ability to monitor work inputs, the impact on workers can lead to feelings of lost job autonomy (Sheridan & Parasuraman 1999). Control lost to automation is also a concern to controllers (Sheridan 1980). Bekier, Molesworth and Williamson (2012) found that the tipping-point for air traffic controllers to accept or reject new technology was when automation shifts the role of decision-making away from the operator. Furthermore, users have expressed a need to have final authority over the automation in order to maintain safety (Inagaki 2008).

Trust in automation can alleviate fears of lost control but only if the technology performs as expected (Parasuraman & Miller 2004). The perception of deskilling can also result in fear of lost control over automation (Alvarez 2008). For instance, as automation takes on a greater role within the control systems and controllers become supervisors of automation, prior skills can fade due to lack of practice, making it difficult for controllers to take over control manually when circumstances dictate (Sheridan & Parasuraman 1999). Of note, is that feelings of incompetence have been found to lead to emotion-focused rather than task-

focused coping mechanisms (Matthews 2001; Menachemi et al. 2007). Therefore, fears can lead to unwanted behaviour, associated with feelings of lost control.

2.5.1.8 Employee fear of reduced job satisfaction

Prior to the introduction of Davis's (1986, 1989) technology acceptance model, user satisfaction, as a sign of success dominated the MIS literature (Bailey & Pearson 1983; Doll 1988; Lewis 1995; McKeen 1994). Today, user satisfaction continues to be strongly linked to adoption success and is gaining in emphasis once again (Adamson & Shine 2003; Mahmood et al. 2000; Yan, Yingwu & Changfeng 2007). However, a perceived reduction in job satisfaction has been found to impair user adoption (Ghobakhloee et al. 2012; Zhou, Li & Lam 2008). Low satisfaction manifests in a number of ways, including a perceived loss of power (Markus 1983); feelings of inequality (Joshi 1991), feelings of incompetence (Menachemi et al. 2007) and strong doubts about how the change will benefit them (Marakas & Hornik 1996). The international design standard on ergonomic design of control rooms recommends designing control rooms that provide both emotional and job satisfaction (International Standards Organisation 2000). Perceived user satisfaction has been found to increase when benefits are anticipated when users have been involved in new technology projects, and when organisational support has been provided (Mahmood et al. 2000).

2.5.1.9 Employee fear of job loss (e.g. replaced by technology, unable to adapt)

One of the natural outcomes from more efficient machines and greater automation is that less staff are required to complete work tasks. In many cases, increased automation will threaten and cause actual job losses, particularly those who do not have the skills to operate the new system or who are technologically illiterate (Sheridan & Parasuraman 1999). Furthermore, the threat of job loss has been known to lead to disbelief in technology benefits (Balfe et al. 2012; Nguyen 2009) which further leads to user resistance. This is a particular concern for smaller organisations as a failure for users to adopt the new technology can threaten the survival and success of the organisation (Ghobakhloo et al. 2012).

2.5.1.10 Employee's experience of failed adoption of prior technologies

Experience has been found to moderate all factors that influence attitude before use (Kumar & Kumar 2003; Venkatesh et al. 2003). Therefore, positive experience with a new technology has been found to influence technology acceptance and adoption positively (Liaw & Huang 2003). Positive experiences with new technology instil trust (Gefen, Karahanna & Straub 2003), reduce uncertainty (Venkatesh et al. 2003; van Ittersum et al. 2012), help to evaluate compatibility, such as its consistency with prior experiences, existing needs, and values (Moore & Benbasat 1991), develop greater understanding of the benefits (Premkumar & Roberts 1999), and thus likely acceptance (Chau & Hu 2002). Training and being able to observe others using the technology can also provide opportunities for users to experience the technology and has been found to influence user satisfaction outcomes (Hsu, Lai & Yu-Te 2008).

In contrast, the experience of prior failed technology adoption (i.e. a negative experience) can lead to user resistance. For instance, those who have enjoyed using computers are more likely to adopt new systems than those who did not (Davis, Bagozzi & Warshaw 1989). Prior experiences with technology develop a schema about technology which has been found to influence attitude toward adoption (Yamada & Itsukushima 2013). For instance, anxiety can be induced from episodic memory associations from bad experiences (Hofmann, Ellard & Siegle 2012), and schema influences sensemaking and judgment and thus the action individuals will take (Morandin & Bergami 2014). Experience has been found to be the biggest predictor of self-efficacy (Liaw & Huang 2003). Thus failed attempts to adopt a technology in the past may have an influence on the individual's self-efficacy, and thus a higher likelihood of user resistance.

2.5.1.11 Employee need to understand why the new technology is introduced

Business management research conducted on technology adoption has found that organisational change and adoption of new technology is more successful when employees understand what is required of them in regards to their role during the change process (Luecke 2003). Researchers have also found that information provided about the change, before the process begins, helps to prepare employees mentally, and thus they are more open toward the change (Wanberg & Banas 2000). The process of acquiring an

understanding helps potential users to develop a mental model of the new system (Kim 1993). As uncertainty decreases sensemaking expands which further helps to develop more accurate expectations, beliefs and attitudes (Burton, Westen & Kowalski 2009; Saeed et al. 2010). Support to help users understand the effects of the change is seen as a management responsibility (Nguyen 2009). Thus, communication between management and users is very important during early stages of technology development (Project Management Institute 2003). Furthermore, individual experience and that of others (Bandura 1986) with the new technology has been found to increase understanding about the potential benefits (Venkatesh et al. 2003).

2.5.1.12 Unlearning old habits or procedures

Unlearning is a relatively new concept that has been found to be a barrier to the pace and success of change and innovation (Becker 2008; Nayyar 2008; Pighin & Marzona 2011). Unlearning has been described as the process of 'throwing away concepts learnt in the past to give space for possible new learning' (Pighin & Marzona 2011, p. 59). Unwanted yet retained knowledge, can interfere with the desirable use of new technology. For instance, concepts or knowledge to be discarded (or unlearned) is regarded as obsolete or misleading due to changed realities and growth in understanding (Hedberg 1981). Therefore, if left unaddressed, unlearning can become a barrier to an organisation's innovation capacity (Becker 2008). For safety-critical organisations unlearning can pose a risk to safety. If the adoption of new technology is significantly slowed by the unlearning-learning process, a number of negative states can result, such as anxiety and disorientation, a state known as technostress (Brod 1984). Technostress as a condition continues to evolve due to technological advancement and thus introduces new issues and challenges for organisations and innovation in general (Ennis 2005). More importantly, under conditions of extreme stress requiring an immediate response, operators have been found to revert back to old operational knowledge unconsciously which has led to fatalities. For instance, due to unexpected fog on the ground and a need for urgency, an Air Force pilot reverted back to earlier learned practices, and thus mistakenly interpreted the recently fitted new altimeter which led to his death (Hendrick 2008).

Finally, experts and more experienced individuals find it more difficult to unlearn due to the level of invested time taken to learn what they know (Becker 2008; Zell 2003). Much of this learning has been internalised at the level of tacit knowledge, which has been found to be more difficult to unlearn than explicit knowledge (Becker 2008). A reason for this is because it is harder to articulate (McDermott 1999) and thus acknowledge its existence. Furthermore, operators who have invested a great deal in current knowledge may be reluctant to unlearn and adopt the change (Knowles & Saxberg 1988). Therefore, learning and unlearning requires resourcing (Schmidt, Houwer & Besner 2010). Thus unlearning is also a human factor issue important to technology adoption.

2.5.2 Facilitating conditions

Facilitating conditions are those that provide conducive opportunities for individuals to come to adopt new technology and therefore are a human factors concern for technology adoption in control rooms.

2.5.2.1 Managerial support of additional resources (e.g. time, training)

Managerial support is expressed by how willingly management resource change, allocate time and encourage their workers to use the new technology. Studies have found that management support can moderately increase IT success (Petter, deLone & McLean 2013, p. 27). Lack of available resources is a recognised constraint that must be considered during the planning stages of a new technology project (Project Management Institute 2013), particularly for smaller businesses. In general, larger organisations are better equipped to achieve technology adoption success, since they are better resourced (Astebro 2002; Faria, Fenn & Bruce 2003; Forman 2005). Some researchers conclude that the most critical factor for successful technology adoption is the availability of financial resources (Ghobakhloo et al. 2012). The reasons provided were that larger organisations are better able to absorb indirect costs associated with new technology, such as loss of productivity and downtime, the necessity for increased training and motivation requirements, and unexpected maintenance and development costs (Love et al. 2005; Seyal & Pijpers 2004).

Another resource requirement identified by researchers is the need for sufficient manpower (both operators and managers) to maintain plant safety during the transitioning

process to the new system (Huber et al. 2009). Overall, management support in this respect was found to influence user satisfaction, user perception of the potential benefits, and the perceived level of impact on the worker's job significantly (Santhanam, Guimaraes & George 2000). Further, studies have found that the support that comes from top management was found to be the most effective at helping end users through the technology adoption process (Hsu, Lai & Yu-Te. 2008).

2.5.2.2 Piloting the new technology before implementation

Due to the complex and dynamic nature of sociotechnical systems, the design and implementation of new technology are challenging (Berg 2004). To pilot a new system small scale can provide an opportunity to obtain feedback on design flaws and other potential problems before full-scale deployment (Lee 2005; Agency for Healthcare Research and Quality 2012). Additionally, user-centred evaluations during pilot programs have been recommended as an effective way to identify usability problems (International Standards Organisation 2010, p. 7 s4.4). However, researchers are finding that pilot programs are not an effective way to introduce new systems.

Berg (2004) reports that difficult technical and organisational problems that arise during pilot programs can threaten implementation success. Bansler and Havn (2009) argue that pilot programs rarely address usability or the usefulness of the proposed system and therefore these areas go unaddressed. It has been suggested that due to ambiguity and uncertainty associated with implementing new technology that implementation cannot be fully planned or controlled (Berg 2004). Rather, more flexible processes are recommended that are iterative and incremental, and that embrace continuous learning, improvisation and experimentation (Heeks 2006).

Unresolved issues and problems associated with the implementation of new technology often stem back to its design (Sambamnurthy & Subramani 2005). Butler and Murphy (2007) explain that design concepts are often developed from a functionalist paradigm and thus ignore ontological (existing concerns) and epistemological (tacit knowledge) factors. Hence, solutions that focus on functionality fail to address the issues that actually exist. As a consequence, the rigid and highly structured design processes may not be well suited to today's dynamic working climate (Heeks 2006). To improve the design of Knowledge

Management Systems (KMS), Butler and Murphy (2007) used participatory action research. They focused on perceptual-bodily experiences of organisational actors while participating in knowledge sharing, to enable the sharing of tacit knowledge.

Berg (2001) offers three myths associated with implementing new IT systems that explain why many implementation processes fail, namely: (1) implementation is the technical realisation of a planned system for the organisation, (2) implementation can be left to the IT department, and (3) it is possible to plan the implementation and required organisational redesign. Moving on from these myths, Berg (2001) offers that implementation (1) is a mutual process of organisational transformation, (2) can only be successful if central management and future users support the process, (3) implementation cannot be rigidly planned, but a delicate balancing act between initiating organisational change and leveraging the new technology to assist with this change.

2.5.2.3 Technology/co-worker support networks facilitated by management

Knowledge sharing through interpersonal communication has been found an effective way to encourage technology adoption by members of the social network (Newell, Swan & Galliers 2000; Rogers 2003). Peer support that is encouraged by management provides intended technology adopters with a certain level of reassurance that helps them to adopt the new system (Becker 2008). Furthermore, organisations that have been found more supportive are likely to experience more positive technology adoption outcomes (Jones, Jimmieson & Griffiths 2005). Communication between peers, also called horizontal communication, is essential for the dissemination of knowledge about the new technology (Rogers 2003). Therefore, the sharing of knowledge amongst peers is extremely important for successful adoption within an organisation.

As well as social support, technical support is also necessary for successful technology adoption. For instance, scholars have found that technology adoption by end users is more successful when there is a sufficient number of technical support staff, and when these staff are available at times of need (Dewar & Dutton 1986). This is particularly so for smaller organisations that are more likely to require external expertise and services, particularly during the early deployment stages of new systems (Calderia & Ward 2003).

2.5.3 Environmental Factors

Environmental factors include all factors related to the new technology's operational setting.

2.5.3.1 The new technology's ability to interact with existing systems

Recommendations made by researchers agree that new technology needs to be compatible with its new environment for system performance and worker wellbeing. Environmental factors include the physical work environment (Project Management Institute 2013), existing infrastructure, organisational culture and values (Beatty, Shim & Jones 2011), and human systems (Booher 2005; Pew & Mavor 2007). Associated with systems performance, is the relationship between successful adoption of new technologies and system compatibility factors. Researchers have found that adoption is more successful when the new technology is compatible with user values, experience and needs (Luecke 2003; Rogers 2003). Furthermore, process compatibility has been found to influence user adoption (Ghobakhloo et al. 2012; Premkumar 2003). Conversely, poor interaction with existing systems has been identified as an environmental factor that can negatively influence work performance (Project Management Institute 2013). While the advice to design for the context of use is strongly recommended (International Standards Organisation 2010), it is not something that is easily accomplished (Lewis 2014). Therefore, system compatibility is a human factors concern for the adoption of new technology.

2.5.3.2 Physical work environment

The work environment represents the context of use and contains physical factors that influence worker performance (Hameed & Amjad 2009; Saleem et al. 2012). Physical attributes such as noise, air quality, temperature, humidity, vibration and lighting place sensory demands on workers (Grandjean 1968). Poorly designed work spaces, systems and interfaces can contribute to sensory fatigue and disrupt cognitive processes (Grandjean 1968), produce psychological stress (Cohen & Spacapan 1983) and human error (Reason 1997). It has been advised, that the physical work environment needs to be considered holistically, taking all environmental factors into consideration (Parsons 2000).

Physical workplace conditions found to contribute to greater work efficiency and effectiveness included those that were less noisy, where furniture was flexible enough to cater for individual needs and where thermal comfort was provided (Saleem et al. 2012). Academic participants subjected to three different temperatures found the cooler temperatures of 17° degrees Celsius and below, and warmer temperatures 28 degrees Celsius and higher less comfortable. Furthermore, they noted that their workload became more arduous resulting in reduced productivity. However, 21 degrees Celsius was found to be most productive temperature setting (Lan, Lian & Pan 2010). Other studies have found similar results, with temperatures over 25 degrees Celsius found to lower productivity gains (Niemela et al. 2002). The spatial arrangement of furniture and equipment was also found to influence productivity (Saleem et al. 2012).

The literature on human factors and in particular neuro-ergonomics supports the argument that the physical work environment influences how the brain functions and thus work performance (Parasuraman 2011). The human factors research community stress that human error reflects the cumulative effects of many factors. Aside from the lack of maintenance, insufficient training, and poorly designed systems and interfaces, organisational pressures contribute to poor work performance (Reason 1997). Therefore, by extension, organisational pressures can influence how efficiently new technology will be adopted.

Another consideration is that changes to the work environment when new technology is introduced can potentially change previous functionality. Experts urge design teams to design for the context of use (International Standards Organisation 2010, s. 6.2.1). Scholars have found that the adoption of new technology has been undermined if due consideration of existing systems and existing infrastructure has been lacking (Beatty, Shim & Jones 2001; Hong & Zhu 2006; Moore 2002).

2.5.3.3 The influence of workflow disruption

Workflow disruptions have also been found to undermine work quality (Cain & Haque 2008). Often overlooked, are the indirect costs associated with the introduction of new technology. Such costs include lost productivity and time as adoption takes place, and thus employees are most directly impacted by these project by-products (Love et al. 2005). It can

be difficult to know the level of disruption until it is fully realised upon implementation and thus a human factors concern for technology adoption.

2.5.3.4 Level of task/job demand changes to employee's role

The level of task or job changes can also be difficult to evaluate and is often not apparent until the new technology has been tested by users. As with workflow disruptions, changes to the individual task or job can influence an employee's willingness to change and adopt a new system. For instance, experts have a harder time unlearning information that they have accumulated over many years (Becker 2008; Zell 2003). Furthermore, changes to the controller's role, due to new technology can introduce new complexities and this has been found to place additional workload demands on controllers as they learn to cope (Balfe et al. 2012). Furthermore, as the opening chapter identified, where technology reduces the controller's role as chief decision maker, these people have been known to reject new technology (Bekier, Molesworth & Williamson 2012). Therefore, changing job demands have been found to introduce new complexities into the control room, increase workload during the adjustment period, and possibly result in system rejection if the role has changed to the point that controllers no long feel they can adequately continue to maintain safety.

2.5.3.5 Influence from others (e.g. colleague, superiors)

As with support networks, mentioned earlier, social systems within an organisation can influence an individual's desire and ability to adopt a new system. In general, people defer to others, primarily trusted peers when they adopt new systems (Rogers 2003; Sun 2013). Co-workers recognise that early adopters have consulted technical information to decrease their level of uncertainty about new technology. As a result, trusted peers who are early adopters are often consulted by members of their social system (Rogers 2003). This sharing of knowledge between social system members has been found to be a very effective means of improving technology adoption outcomes within this social network (Burkhardt & Brass 1990; Rogers 2003).

Managers within the social system can also make decisions and take action that can influence technology adoption success. For instance, allowing employees to maintain social linkages during the change process, permits social learning to continue (Bandura 1989; Rogers 2003), and allows users to exchange tacit knowledge which may not be available

from other means (McDermott 2000). Management can influence employee technology adoption by the amount of time allowed to learn and experience the new system, how they resource projects, the type of training and support they provide, and how they manage the technology adoption process (Bruque & Moyan-Fuentes 2007; Sarosa & Zowghi 2003). Management can also influence the individual's satisfaction and implementation success by encouraging user involvement and participation in new technology projects (Ghobakhloo et al. 2012). Finally, general organisational culture has also been found to influence technology adoption success (Bruque & Moyano-Fuentes 2007; Riolli & Savicki 2003). Therefore, significant others (i.e. trusted peers, social networks, management, and organisational factors) have been found to play an important role in more successful technology adoption.

2.5.4 Organisational matters

For the purposes of this thesis, organisational conditions are the institutional forces that affect resourcing, performance and operations. Conditions within an organisation can be influenced by internal and external forces. External influences that affect the functioning of an organisation, include regulatory agencies, competitors, customers, suppliers and public pressure. Internal influences are the values, leadership styles, and institutional structures and entities that influence company practices and choices.

2.5.4.1 Management structure

Management structures have been identified as an environmental factor that influences work performance (Project Management Institute 2013). Rigid structures within organisations can be a barrier to learning (Gieskes, Hyland & Magnusson 2002) and technology adoption (Calderia & Ward 2003; Ghobakhloo et al. 2012). For instance, once established, organisational knowledge in the form of policies, structures, procedures, practices and process can be hard to change and as a result, often fall behind functional changes within the organisation. Therefore, past behaviour that continues to be encouraged and reinforced that is not conducive to the adoption of the new system or new organisational processes can undermine implementation efforts (Delahaye 2005). The social systems and communication structures within organisations have also been found to hinder or facilitate technology adoption (Rogers 2003). Furthermore, the ability for organisations to unlearn old practices can be undermined by existing organisational memory, culture, power,

politics and organisational filters (Becker 2008). The larger the organisation and the longer it has functioned within a status quo can also have an influencing factor on technology adoption (Sawang & Unsworth 2011).

Overall, larger organisations have been found to experience greater success when introducing new technology due to a higher level of available resources (Astebro 2002; Forman 2005). However, as the organisation increases in size and structures within the organisation develop, the successful introduction of new technology becomes heavily reliant on managerial commitment (Becker 2008). Managers can help to gain the trust of workers by utilising people who convey clarity and transparency. However, these practices are less common in organisations with hierarchical structures (Griffiths & Arenas 2014).

Furthermore, Weick and Sutcliffe (2007) warn that rigid hierarchies have certain vulnerabilities. For instance, errors made by management at the top of the organisation influence work at the bottom end (i.e. workers) and the combined effect of errors at both extremities contributes to a much worse and far more complex situation. Thus when designing new technology, errors made higher up the ladder, will filter down and eventually impact the work performance, and thus contribute an adoption concern.

2.5.4.2 Shared decision-making between employees and managers

In organisational settings, it is widely accepted that decision-making is a key management process and thus, typically a responsibility of managers (Project Management Institute 2013). However, it has also been found that effective teamwork and shared decision-making is critical for organisations where safety is paramount (Baker, Day & Salas 2006; Wilson et al. 2005). For instance, involvement of domain experts (i.e. intended users) in new technology projects and change decisions has been found to encourage greater openness toward change (Wangerg & Banas 2000), develops a stronger sense of ownership and reduced user resistance to change (Fink 1998), is linked to more positive user adoption outcomes (Bruque & Moyano-Fuentes 2007; Calderia & Ward 2003; Ghobakhloo et al. 2012), and therefore leads to more successful implementation (Amoako-Gyampah 2007). Therefore, for end users of systems to be given the opportunity to participate in technology decision-making, management endorsement is necessary. Therefore, to achieve efficient technology transfer,

shared decision-making between employees and managers has been found to encourage more positive management of change and technology adoption outcomes.

2.5.5 User involvement

For some time in the field of MIS, it has been widely accepted that user input into new IS increases likely implementation success (Abelein, Sharp & Paech 2013; Harris & Weistroffer 2009; Hwang & Thorn 1999; Lucas 1978; Petter, deLone & McLean 2013). This has been found particularly so for the introduction of complex systems (Harris & Weistroffer 2009). Benefits from user input were reported to contribute to improvements to system quality through more accurate user requirements, the avoidance of unwanted and costly features, improvements to user acceptance, a greater understanding of the system resulted in more competent use, and increased user participation in organisational decision-making (Damodaran 1996). However, in an organisational setting, user input opportunities are largely dependent upon the way in which the organisation handles acquisition practices.

The interest in user input began due to the rising number of failed projects during the IT boom of the 1970s and 1980s. Most problems were only realised upon implementation, at which point many design problems were intractable due to the costs involved in the redesign and thus ran the risk of user rejection and failure (Damodaran 1996). In 1995, project failure reached an all-time high. A study of new IT projects found that 31.1% were impaired (cancelled), 52.7% were challenged (i.e. over budget, exceeding time estimate, and offered fewer specified features and functions), and only 16.2% were considered a success according to the following criteria: 'completed on time and on budget, and with all features and functions as initially specified' (The Standish Group 1995, p. 2). Lack of user input was rated the top reason for project failure, followed closely behind with incomplete requirements and specifications, and changing requirements and specifications. Based on surveyed participants, the Standish Group (1995) found that user involvement was the primary reason for project success. The next top reason was support from executive management and a specific statement of requirements. In light of these events, MIS researchers were keen to help reduce failure rates and thus sought to better understand user involvement and how it could (if it did) influence project success.

During the 1980s, MIS researchers discovered that user input and the link to project success could not be supported and that user input was not well understood (Olson & Ives 1981). A review of empirical studies, dating back to 1959 only found a positive link between user involvement and project success in one-third of the studies reviewed (Olson & Ives 1981). Similar results were also found a decade later from an examination of more recent empirical studies (Cavaye 1995; Guimaraes & Igbaria 1997). Flaws in methodology and inconsistencies between studies, regarding: the use of terminology, measurements used to examine user involvement and success was also noted (Cavaye 1995; Ives & Olson 1984). Furthermore, there was some confusion as to what user involvement actually entailed and what type of involvement produced the best results.

Two related terms were contributing to this confusion. Researchers were using *user participation* and *user involvement* inconsistently making study comparisons difficult. Furthermore, information technology developers and users were also found to differ on perceptions of user involvement (Foster & Franz 1999).To resolve this confusion, Barki and Hartwick (1989, p. 53) made a distinction between the two closely related terms and defined *user involvement* as: 'a subjective psychological state reflecting the importance and personal relevance of a system to the user' while *user participation* was defined as: 'a set of behaviours or activities performed by users in the system development process.' However, the usage of the terms continues to evolve and user involvement has been reported to more recently representing both the psychological and the participatory meanings (Harris & Weistroffer 2009).

In the search for the best way to involve users, scholars noted that deeper forms of participation had the greatest influence on user satisfaction and system quality. For instance, some scholars noted that as mute participation progressed to voicing an opinion, to having a choice, and then opportunity to voice an opinion and make a choice, the user perceived more procedural justice, and control over the product outcome (Hunton 1996; Hunton & Beeler 1997). Furthermore, user involvement during prioritisation and negotiation processes was found to encourage continued involvement in other parts of the process, such as the design stage (Palanisamy 2001). However, participation that was perceived to be a token gesture or participation forced on users was found to significantly undermine user satisfaction (Kirsch & Beath 1996). Furthermore, it was noted that at a certain point, user

involvement became ineffective and at that point was perceived to be a waste of resources (Lawrence et al. 2002).

Reviews conducted more recently are finding that studies are reporting stronger linkages between user involvement and project success (Abelein, Sharp & Paech 2013; Harris & Weistroffer 2009; Petter, deLone & McLean 2013). However, one review found that user involvement positively influenced user satisfaction, usage and organisational impact, but not information quality, service quality of quality of the system (Petter, deLone & McLean 2013). These reviews show that while user involvement stands to improve the implementation process, user involvement in all aspects of the design process does not necessarily produce desirable results. This suggests that the most effective way to involve users is to do so mindfully.

2.5.5.1 Some key findings in the literature

Types of user involvement have been categorised and defined in three ways: (1) Information (users provide and/or receive information), (2) Consultative (users comment on a predefined service or range of facilities, (3) Participative (users influence decisions relating to the whole system). While, mechanisms for which users can become involved in decision-making include (Damodaran 1996, pp. 365-366):

- Membership of steering/advisory committees.
- Membership of design teams.
- Membership of problem-solving groups.
- Consultation with individuals or groups.
- Prototypes/simulations
- Quality assurance procedures.

Harris and Weistroffer (2009) share six lessons drawn from a synthesis of ideas by the review they conducted.

- The degree of user involvement matters. The more users are involved the more satisfied they become (see Discenza et al. 2008)

- System complexity matters. As system complexity increases, user involvement becomes more important.
- Activities users are involved in matters. Core to system success, users should be involved in (1) feasibility studies, (2) determining information requirements, (3) defining forms of input and output, (4) defining report and screen formats, and (5) help with the final installation.
- Management style matters. People-oriented, rather than task-oriented managers are better able to communicate with users in times when fear and uncertainty are high.
- Who to involve matters. Users with high functional expertise will feel left out and may develop a negative attitude toward the new product if not involved and hence should be involved.
- The amount of user involvement matters. There is an optimal level of involvement that is productive. The amount of user involvement that is optimal is not well understood.

As evident by the recommendations made by the authors above, the term *user involvement* is frequently used to encompass both direct (i.e. user participation) and indirect (i.e. user involvement) contact, making it important for researchers to ensure terminology used in studies is clearly defined. The most recent review to date reported that both user participation and user involvement were found to contribute to system quality and user satisfaction and thus system success (Abelein, Sharp & Paech 2013). However, while they found greater system success was achieved when users were actively involved in the development process (i.e. user participation), they also found that when the system had higher personal relevance and importance to the user (i.e. user involvement) gains toward success were also achieved (Abelein, Sharp & Paech 2013).

Finally, collaboration and sharing of knowledge have been found to encourage group sensemaking of the problem and what needs to be done to successfully resolve the problem. Scholars have found that by sharing knowledge of the problem, greater mindfulness and a shared understanding develops amongst collaborators. For instance, managers and designers have been found to become more aware of the user's needs. This

has resulted in the allocation of more realistic resources by management (Sammon 2008), and improved design choices by developers (Dervin 2003). The benefit to end users is that they have an avenue to express their needs, while at the same time developing improved knowledge about the pending change (Wanberg & Banas 2000), all of which contributes to an improved potential for success of the project. Therefore, social discourses that encourage the sharing of knowledge not only help to turn tacit knowledge into design specifications, they often result in better-resourced projects that achieve greater user confidence.

2.6 Theories on Design

2.6.1 Project management perspective

Project management provides the governance and overarching oversight for the design of new technologies and thus consideration of how projects are managed is very important. However, as with other disciplines, project management in itself has its own motivations, values and success criteria. For instance, a successfully designed project has been defined by the Standish Group (1995) as one that has met three criteria: (1) completed on time, (2) on a budget, and (3) with all features and functions as initially specified. Amongst other things, to achieve these goals, best practice project management asserts that when the scope of a new technology project is being developed major deliverables must be established with consideration of existing conditions and constraints (Project Management Institute 2013).

The above goals are often managed in a 'technocentric' manner. That is, all implementation objectives from design through to 'going live' as well as user training are expressed in technical terms. Unfortunately, this strategy has been linked to poor or failed implementation (Eason 2016). As modern control systems become increasingly integrated and sociotechnical in nature, implementation processes need to take the needs of the human system into greater consideration. Thus, the opportunity for human factors intervention strategies (Section 2.6.2.3) is increasingly important.

Furthermore, while the success criteria for project managers may be different across disciplines, to address existing conditions and constraints is important to all stakeholders involved.In an organisational setting, many types of constraints need to be considered:

regulatory, financial, human resources, physical restrictions, existing systems, public perception and the people who will be using the products. An example of how one constraint can influence the product's design can be quickly realised when aiming to keep within budget. Factors that may be impacted by financial constraints could be time available for project completion, materials and supplier selection, features, post implementation services, and who might be chosen to be involved in the project's design and implementation processes (Project Management Institute 2013).

2.6.2 Human factors perspective

Human factors is a design science concerned about understanding and improving the interactions among humans and other system elements (International Ergonomics Association 2016). To achieve a holistic approach, human factors is multidisciplinary (Wilson & Sharples 2015).

2.6.2.1 Domains of human factors

Broad domains of human factors can be categorised into five areas, physical, cognitive, social, environmental and organisational. Examples of areas of interest include (Hendrick 1995; International Ergonomics Association 2016; Proctor & van Zandt 2008; Wilson & Sharples 2015):

- *Physical ergonomics*: concerned with the human anatomy, working postures and repetitive movement, body measurements (anthropometrics) for physical fit, reach, clearance, comfort; posture and lifting concerned with manual handling, tolerance and physical workload; workplace and workstation layout; equipment and tool selection and design; line of sight, musculoskeletal disorders, and design of displays and controls.
- *Cognitive ergonomics*: concerned with mental processes, sensing, perception, information processing, memory, reasoning, decision-making, problem-solving, motor response (reactions) human-computer interface design, labelling, reliability, fault diagnosis, communication, mental workload, mental fatigue, and stress.

- *Social:* attitude, motivation, satisfaction, teamwork, coordination, job design, shift design, patterns of work, pace, psychological impacts, and stress.
- *Environmental influences*: temperature, acoustics and noise, light and glare, vibration and air and water quality.
- *Organisational ergonomics*: macroergonomic concerns to optimise overall sociotechnical systems, such as organisational structure, culture, values, working paradigms, policies and processes, crew resource management, design paradigms, community concerns, communication structures, implementation of change and quality management.
- *Systems ergonomics*: the holistic approach to design and evaluation that integrates all the above ergonomic concerns.

2.6.2.2 Human factors integration domains

Commonly used in safety-critical industries, is a set of defined HFI domains which are often referred to as human-systems integration. These domains are intended to integrate the human system into the design of the whole system. The process involves identifying and reconciling human related issues that arise as humans interact within their work environments (Clark & Goulder 2002).

Human factors integration began to develop as early as the 1920s as industrial engineering began to accommodate psychological aspects of work (Human Systems Engineering Branch 2010). Primarily led by the U.S. Department of Defence HFI has evolved to encompass nine functional areas called domains related to human systems, namely: manpower, personnel, training, human factors engineering, occupational health, safety, environment, survivability, and habitability (Human Performance Optimization Division 2009, p. 84-87). The nine domains are briefly described below:

Human factors engineering – is the holistic approach to optimise human interactions with other system elements. Human capabilities and limitation are taken into consideration during the design of new technology, along with user interface to enable human performance in operation, maintenance, support and sustainment of the system.

Manpower – the number and combination of personnel that are authorised, available to train, operate, maintain and support each system.

Personnel – skills, experience, knowledge, abilities and aptitudes of staff in accordance with the operation, maintenance and support at the time a new technology is fielded (deployed). Domain expertise must be considered.

Training – instruction and resources to support personnel with the achievement of ability, requisite knowledge and skills to be able to operate, maintain and support a system appropriately. Training ranges from basic and technical certification to more advanced and professional qualifications, to post graduate level.

Occupational Health – design considerations must optimise the health and wellbeing of personnel by minimising the risk to acute or chronic illness.

Safety – design considerations must maximise interface operability, without leading to failures or undermining safety. To minimise risk to safety, hazards and risk must be identified, assessed and addressed throughout systems engineering and systems management processes.

Environmental concerns – that influence human performance related to water, temperature, air quality, space, cyberspace, vibration and light. Environmental concerns also relate to protecting systems from the environment and protecting the environment from system operation, sustainment and disposal.

Habitability and survivability - these two domains are mainly applied in the military due to the dangerous environments that can unexpectedly arise. Habitability relates to living and working conditions essential to sustain the working morale, health, safety and wellbeing of workers. Particularly those that influence work performance. Survivability relates to the ability for the system (human and technology) to withstand the risk of failure, loss of capability, damage, and injury. Matters of vulnerability, susceptibility and recoverability and also related to survivability.

2.6.2.3 Human factors analytic tools, methods and techniques

Human factors practitioners have developed and use many methods and tools to help them evaluate and analyse human factors related concerns that influence how humans interact with other system elements. These methods and tools have been described as the 'technology' that human factors practitioners have been called *human-systems interface technology* (Hendrick 2000). Hendrick identifies five categories of human-systems interface, namely: human-machine interface (hardware ergonomics); human-environment interface (environmental ergonomics); human-software interface (cognitive ergonomics); Human-job interface (job design ergonomics); and human-organisational interface (macroergonomics).

Wilson and Sharples (2015) identified six core method types used by the human factors community. These are briefly outlined below.

a. *General methods*

General methods are used for a range of information gathering, design and evaluation goals across the work system. Examples include interviews, questionnaires, observation, focus groups, workshops, reviews, checklists, flowcharts, process charts, etc.

b. *Collection of information about people, equipment, and environment*

Typically data collection techniques provide baseline information on either an individual, tasks or environment's state and characteristics. The inherent states of humans include anthropometry, age, attitude, motivations, and desires, working memory. Knowledge gathered about the work environment can include: room dimensions, placement of equipment, current thermal and lighting states. For equipment, information about purpose, function, reliability, dimensions, and placement, may be considered.

c. *Analysis and design*

Analytic methods, tools and techniques are those that directly support the design/redesign process through analysis and design inputs. Analysis of current and future systems can become design inputs when they provide links between the data collected and underlying influences. Specifications with reasoned justification can become design requirements and criteria to aid meaningful collaboration with engineers and other designers. From a

synthesis of data, the development of ergonomically sound concepts, prototypes and final designs can be achieved.

d. Evaluation of user-machine performance

Evaluative methods typically help to benchmark and evaluate performance outputs of a system, and the factors that may influence those outputs for existing and new systems. They can be used to evaluate viability and cost-benefits. System performance can be measured in: time, counts of errors to complete a sequence of tasks, the level of quality of work outcomes, and the willingness to change direction. System performance measurements must account for the extent to which the system is explored and evaluate how effective the human factors contribution had on design performance.

e. Evaluation of demands on and effects on people

Data captured from people about their physiological and psychological responses to systems, include: their experiences, influences on task completion, physiological and psychological changes, as well as fatigue and discomfort levels. Furthermore, work demands are evaluated by examining the effects that different tasks, working environments, and equipment have on human performance. Such evaluations can include subjective ratings by workers, observations, or through the recording of facial expressions to determine those that infer emotional states.

f. Management and implementation of ergonomics:

The human factors methods, tools and techniques used for this category need to support the management of HFI programmes in such a way as to encourage and enable human factors to be embedded into normal organisational practices. Where a dedicated human factors position or team is not located within the organisation, it may be necessary to use indirect methods. Approaches usually address participatory design, systems thinking, collaborative work amongst other disciplines, the sharing of toolkits to support HFI, and methods that promote greater awareness and understanding of the human factors contribution and when specialist human factors professionals are needed.

g. Implementation strategies:

A number of human factors methods exist that can contribute to the implementation of new technology. Some help to assimilate the human into the technical system through training, and interface and workstation design. However, many more interventions are possible if the change management process is framed in terms of the work system, rather than the technology. To frame change in terms of the work system requires acknowledgement that new technologies have consequences on the work system and thus require a sociotechnical intervention (Eason 2015). Methods that help to engage the workforce through the change are most effective and promote long-term capability of the workforce. Eason (2015) identified four mechanisms that aid engagement, namely: participatory ergonomics, user-centred design, the inclusion of change agents and change facilitators and review techniques.

Participatory ergonomics: Participation of the workforce during the change has been found fundamental to change success. However, not all forms of participation involve end-users of the workforce (Section 2.6.2.9). To be considered true participation, the workforce must be involved early and able to make decisions about the system they will use (Wilson 1991). Therefore the benefits from participation are dependent upon the richness of the participation. Many studies support the notion that participatory ergonomics and participatory design (Section 2.6.2.8) provides the motivation and satisfaction that supports willing acceptance and adoption of new technologies (Husin, Evans & Deegan 2016; McKeen, Guimaraes & Wetherbe 1994; Markus & Mao 2004; Subramanyam, Weisstein & Krishnan 2010).

User-centred design: User-centred design is a subset of human-centred design (Section 2.6.2.7). User-centred design involves a variety of techniques to help capture and cater for the needs of end users. This may help end users articulate their design requirements, aid end users through the evaluation of prototypes, and support them through the implementation stages (Proctor & van Zandt 2008).

Change agents: It is common for organisations to engage and charge local staff with the responsibility to facilitate and manage the change within the organisation (Hall & Hord

2010). Change agents are often human factors engineers who play a pivotal role in the design and execution of participation opportunities (Markus & Mao 2004). Involved in new technology projects, change agents can become an important communication channel between the technical design team and the end user (Eason et al. 2012). *Review techniques:* Techniques that encourage the workforce to reflect on their current working conditions, or the new design, to propose improvements (Bødker 2000; Eklund 2000). Review techniques may include usability testing, audits, computer simulated user scenarios, checklists, card sorting, user experience testing and interviews (De Matos et al. 2013; Hjelseth, Morrison & Nordby 2015).

2.6.2.4 Design critical success criteria

In the pursuit of improved HFI during systems development, Pew and Mavor (2007) examined five award-winning new technology projects to determine critical success criteria. Results found five important principles of design for human-intense complex systems, as outlined below (Pew & Mavor 2007, p. 53).

- Stakeholder satisficing

Operational or developmental stakeholders have refused to cooperate when they perceive a system outcome to be unsatisfactory. Refusal to cooperate indicates an unsuccessful system. Stakeholder satisficing involves three steps. The first step is to identify stakeholders who are critical to the success of the project and to capture their proposed values. The second step is to achieve an agreed upon set of system requirements, plans, and solutions through a process of negotiation. The third step involves managing any proposed changes so that the mutually satisfactory outcome can be maintained. These steps help to make stakeholder satisficing specifically and explicitly stated.

- Incremental definition

The incremental definition requires the commitment of all stakeholders. Thus recognition that requirements and commitment cannot be pre-specified is paramount. This design principle acknowledges that user requirements and solutions are better achieved through a process of discovery to allow human-system requirements to emerge. Discovery methods

include prototyping, operational exercises and the trialling of early system capabilities. By way of a cyclic process, commitment, understanding, trust, and definition evolvement.

- Iterative evolutionary growth

Evolutionary and incremental design approaches refine design requirements, solutions and plans iteratively in a cyclic manner. Iterative design encourages projects to learn of performance and operational requirements throughout project development and has been found to achieve earlier and more efficient capturing of these requirements.

- Concurrent engineering

This design principle requires an integrated project approach that allows for process definition, while the engineering of requirements and solutions are to be conducted concurrently. During the latter stages of design, development of current-system increments occurs concurrently with the reworking and re-baselining of the next-increment of requirements, solutions and plans. The aim is to achieve early fielding of core capabilities, continuous adaptation to change and more efficient growth of the system without having to wait for the each requirement or subsystem to be defined.

- Risk management

The design is to be risk-driven. The level of design intensity is positively correlated with the degree of risk associated with the product or processes. Thus high-risk components, such as a user interface, will receive higher level design activity. This is to ensure stakeholder commitment at particular design anchor points. In low-risk cases such as the design of interactive graphic user interface builder capabilities, requirements should be allowed to evolve to meet user needs without needing to spend the time to update requirements documents.

Finally, in support of system success, Pew and Mavor (2007) recommend drawing on the strengths of existing systems development models, such as: V model, concurrent engineering, spiral, agile and lean process models.

2.6.2.5 Dimensions of design

Heeks (2006) suggests that seven dimensions of design need to be considered for effective integration of human factors. These dimensions are: information, technology, process, objective and values, staffing and skills, management systems and structures and other resources. Each dimension lies on a continuum between the *design* outcome and the pre-existing *reality*, called the design-reality gap. Heeks makes the assumption that a design that matches its previous reality of use, will be more successful than one that creates large changes. Each dimension is based on a similarity continuum, as briefly outlined below (2006, p. 128).

- The *Information* dimension extends from information that is presented in a way that fully reflects the needs and thought processes of the users to being in conflict with user needs and thought processes.
- The *technology* dimension extends from the same to being vastly different from current technology.
- The *Process* dimension relates to work processes that are affected by function allocation of the design. Therefore, the dimension extends from the same to vastly different to the old system.
- The *objective and value* dimension relates to how well the objective of the new design meets the values of the users.
- The *staffing and skills* dimension relates to the level of difficulty in the use of the new technology.
- The *management systems and structures* dimension relates to the level of change in management systems and structures that are created by the new technology, from similar to vastly different.
- The *other resources* dimension relates to whether the assigned resources (time and cost) were adequate to meet the design requirements.

2.6.2.6 Iterative design

Many years ago Chapanis (1965a) highlighted the need for an iterative design process that continues to be applicable today. He stressed that assignment decisions should not be fixed

and immutable but must be continually re-evaluated. He offers some general approaches to the problem:

1. System specifications are to be presented in great detail and include: what the technology is supposed to do, the environment it will operate in, the inputs it will receive, the operations it will perform on these inputs, and outputs it is supposed to produce. Additionally, all the constraints must be identified and attended to. Some examples include: engineering, environmental, economic and social.
2. All system functions must be identified and analysed to prepare a detailed list of functions which the system is to perform. Chapanis advises avoiding vague words, but to use highly specific instructions that are operational in character.
3. Tentative functional assignments are to be assigned to the human and the system. He advises considering what is more common, what is best for the operation of the system as a whole, and states that some decisions will be obvious, some will be based on best judgement, while some will have to wait.
4. Once assigned, evaluate the sum total of functions assigned to the human to ensure that the job remains interesting, motivating and challenging to the human operator. Chapanis suggests that people work best at some medium level of difficulty; otherwise they will become ineffective due to boredom, fatigue and inattention.

From very early on, Chapanis (1965b) recognised the challenges associated with dealing with integrated human behaviour, with all is nuances, richness, variety and complexity. Chapanis states that the problem between humans and machines is not a human-machine problem, but rather, human-human problem, namely the human user and the human designer. Thus, Chapanis identified the conditions that have now become known as the designer-user gap. This condition continues today.

2.6.2.7 Human-centred design

Human-centred design involves designing for people (Attrill 2015). It is an interactive system development process that focuses on optimising systems with humans and machines in a complementary way. The approach aims to emphasise and maximise the strengths, features, and capability of both humans and the machines (International Standards Organisation 2000). Increasingly, designers are seeing value in placing greater emphasis on

the actual user population. User-centred design has been described as a subset of human-centred design that involves designing for users, not just general humans (Attrill 2015). Thus the design process focuses on a particular user population. Designers suggest that user-centred evaluation (based on users' perspective) can help to gain an improved understanding of user needs, and actual use of a product. Therefore, user evaluations are required throughout the design lifecycle, from initial design concepts through to long-term use (Wickens et al. 2004). Scholars also offer that to truly design in a user-centred manner, the users must be put first in design decision making (Wallach & Scholz 2012).

2.6.2.8 Participatory design

Participatory design provides a means for ensuring that end users become informants and co-designers for technological artefacts that stand to benefit them (Simon 2010). This stance stems from a democratic recognition that users have a right to be involved in the development of new technology that will impact them (Ehn 1993). Participation aims to increase user satisfaction and is used to harness the energy and expertise of end users, as trusted domain experts. Their involvement acknowledges that their contribution is appreciated. Participatory design is not limited to processes that utilise a select few user representatives, have well-defined agendas and have time-limits. Rather, they are often less restrictive. Although the benefits and uses are much broader, participatory design processes are well suited for the establishment of advisory boards and prototyping focus groups (Bowen 2010).

2.6.2.9 User participation versus user involvement

Different disciplines can use terms differently and these terms can come to mean different things over time, and seem to have a way of being watered down and becoming less effective. For instance, one way to incorporate user contextual data is through user participation when designing new technology. To find the evidence that user participation is effective when designing safety interventions and designing new technology is a current topic of interest amongst human factors researchers (Day 2013; Rivilis et al. 2008; Vink, Imada & Zink 2008). However, the benefits of user participation are not new. As early as the 1960s, user participation was considered critical to the successful development of MISs in terms of user satisfaction, quality, and system use (Ives & Olson 1984; Tait & Vessey 1988).

However, examination of the benefits during the 1980s found contradictory results (Ives & Olson 1984; Pettingell, Marshall & Remington 1988; Straub & Trower 1988). One weakness found to undermine the collective results on user involvement and user participation was that the two terms were being used indiscriminately and often to mean the same thing when others have suggested they are two distinct concepts (Barki & Hartwick 1989).

A review conducted by Barki and Hartwick (1989) found that IT designers were using *user involvement* to indicate actual participation when the user has contributed during the design process (Vroom & Jago 1988). However, others have viewed user involvement as an expression of their beliefs or feelings toward a particular item (Sherif, Sherif & Nebergall 1965). Therefore Barki and Hartwick (1989) felt a distinction needed to be made between the two terms, because study comparisons regarding the efficacy of user involvement were becoming problematic (Ives & Olson 1984). Thus, user involvement has been defined as a 'subjective psychological state reflecting the importance and personal relevance of a system to the user' and user participation as 'a set of behaviours or activities performed by users in the system development process' (Barki & Hartwick 1989, p. 53).

The discussion in the literature, suggests that *user involvement* evolved into representing the user's psychological state as a means to justify that the critical success criteria were met without actually having to include the participation of users in design activities. Designers appreciate that user participation can be difficult to achieve, add to costs and will consume time (Lewis 2014). Thus, the new nuances that developed for what *user involvement* entailed may have simply been a more expeditious way to claim that user involvement was included in the design. Thus for the purposes of this thesis, the original intent of the phrase 'user involvement' as synonymous with 'user participation' remains.

2.6.2.10 Usability (ease of use)

From a design point of view, human factors engineers have also been conducting research in usability specifically. Usability primarily focuses on the interface between the human and the machine (Hornbaek 2006; Jacobsson & Linderoth 2010; McFarland & Hamilton 2006; Nielsen 1991; Spool 2005). Although 30 years of research has been conducted, an accepted definition for usability has yet to be determined. A problem identified with defining and achieving usability is that usability is not a specific property of something and therefore not

easily measured (Hertzum 2010). Rather, usability is a property that only emerges when users, products, tasks and the environment interact (Lewis 2014). Subjective definitions, such as user-friendly are considered too vague to measure or diagnose. Bevan, Kirakowski and Maissel (1991, p. 1) proposed the following definition:

> The ease of use and acceptability of a product for a particular class of users carrying out specific tasks in a specific environment. Criterion levels for measurements of attitude and user performance determine whether the design of the product is successful in achieving usability.

Usability is conceived in two ways, namely 'summative' and 'formative' and differences between the two prevent the development of a suitable definition that can cover both (Lewis 2012). Summative usability is measurement-based and focuses on metrics associated with meeting global task and product goals; while formative usability is diagnostic and focuses on detecting usability problems and designing ways to reduce their impact (Lewis 2014).

For the purposes of this thesis and in consideration of other viewpoints, the definition adopted for usability is: 'the effective and efficient use of an object that is compatible with human needs attributes, processes and wellbeing.'

2.6.2.11 Automation design principles

To guide HFI into the design of new technologies that are highly automated, a number of design principles and been developed. Principles for the introduction of progressively automated systems are of rising interest to rail companies. However, limited research has been conducted outside the laboratory. A recent study (Balfe et al. 2012) gathered controller experiences on the UK network's most advanced form of automation currently in use, the Automatic Route Setting (ARS) system. Ten comprehensive interviews extracted strengths and weaknesses of the system. From this data, ten guiding principles of automation developed, as itemised below.

Principle No. 1 Reliable – the automation should function consistently to maintain operator trust in the system. Reliability here refers to repeated consistent functioning as described by Sheridan (1999).

Principle No. 2 Competent – to correctly perform tasks in accordance with the information that has been input. Authors noted that control failures as a result of programming (i.e. system behaved as designed, but not desirable) demonstrate incompetence rather than unreliability. Empirical evidence has shown that any weakness in the system will reduce operator likelihood of continued usage. Other studies have also identified this principle. However, competence is frequently referred to as reliability (Riley 1994; Moray et al. 2000).

Principle No. 3 Visible – All relevant information for decision making should be readily available to the operator at any moment in time, in a format that is clear and easily interpreted, as recommended by Billings (1991) and Endsley (1996). Automation that hides information of possible interest to operators, and therefore 'invisible' to the operators is strongly advised against for reasons that it undermines system functionality and safety (Dekker 2004).

Principle No. 4 Observable – provides effective and immediate feedback to the operator in order to allow them to maintain continual awareness of the system's state. To stay abreast of system actions and movement requires knowledge of uninterrupted automation state, activity and intentions (Parasuraman & Riley 1997). Furthermore, insufficient feedback can catch operators unawares and lead to them being surprised at inopportune moments (Woods 1997). Norman (1998) used the term transparency to describe the same concept.

Principle No. 5 Understandable – All actions undertaken by the automation must be understandable to the operator given the current situation, environment and state of the system. System understanding allows the operator to develop a mental model of how the automation behaves which in turn enables predictions to be made on future behaviour (Sheridan 1999), and surprise events are less likely to occur (Sarter et al. 1997). Norman (1988) suggests that to design a product that is totally understood by the operator requires a deep understanding of the intended user and this understanding must be conveyed by the appearance of the technology and be self-explanatory. Norman (1998, p. xii) refers to understandable products that have 'natural mapping'. While a good understanding is required to know what information has been taken into account (Hopkin & Wise 1996), it is not considered necessary to extend understanding to know how individual algorithms work (Lenior et al. 2006).

Principle No. 6 Directable – The operator can direct the automation efficiently and effectively, to allow him or her to take on a strategic role (Dekker 2004). Without the power to direct the automation, the operator becomes virtually powerless when things go awry (Christoffersen & Woods 2001). Various benefits have been proved to result from cooperative systems, including: improved ability to achieve goals (Woods 1997), greater provision for situational awareness, a reduction in mental workload and improvements to overall system performance (Miller et al. 2005).

Principle No. 7 Robust – ability to function under a variety of situations, not just during normal operations, as is described by Sheridan (1999). To be considered robust, the automation should be more helpful during the toughest (highest workload) working conditions and less so during low workload conditions (Billings 1997). Balfe et al. (2012) acknowledge that in practical terms Billing's advice would be difficult to achieve. However, they recommend at a minimum that the automation would be helpful rather than a burden during periods of high workload.

Principle No. 8 Accountable – The operator is in charge of the automation and responsible for overall performance, as is also recommended by Miller and Parasuraman (2007). Sheridan (1999) believes that the operator should be able to override the system whenever deemed necessary, and research suggests that any ambiguity as to who does what will result in operators being less likely to intervene (Mosier et al. 1994). Autonomous automation with no accountability to the operator cannot be controlled and therefore undermine contingency work (Woods 1997). Balfe et al. (2012) concluded that an ideal situation would see automation accountable to the operator thus allowing the operator to be responsible for overall system performance. However, in reality, Balfe and colleagues found that not all controllers were willing to accept full responsibility for system performance.

Principle No. 9 Proactive Control – ability to support the operator to predict and control ahead to avoid reactive controlling. The ability to predict improves situational awareness and accommodates for anticipatory planning, while monitoring the system over time, for the prevention of unwanted events (Dekker 2004; Endsley 1996; Sandblad et al. 2002).

Principle No. 10 Skill Degradation – able to incorporate a strategy to guard against operator skill degradation. Increased automation progressively removes the operator from direct control and researchers are concerned that lack of practice will leave controllers ill-equipped to adequately take over when the automation reaches it limits (Endsley & Kiris 1995; Hoc 2000). Bainbridge (1983) suggests that skill degradation is a natural consequence of automation and undesirable. In cases where systems are highly automated Balfe et al. (2012) offer that skills may be retainable through practice on high fidelity simulators.

It should be noted that these principles are often interrelated in that it can be argued that proactive control is not achievable unless the automation is fully understood by the operator and he or she can direct and assume a higher strategic role than the automation. These ten guiding principles are expected to have broad application across other domains (Balfe et al. 2012).

2.6.2.12 Problems with human factors in design

Increasingly, human factors engineers are being given a prominent place amongst design teams, however, this is not always the case. While recommended by the industry experts involved in the development of ISO 11064 the International Standard on Control Room Design (International Standard Organization 2006), involvement of human factors engineers in project design is frequently left out or marginalised during major engineering design projects (Rogers & Armstrong 1977) and remains problematic today (Grimes, Wright & Hillier 2012). One reason suggested by Carey (2007, p. 501) is that system designs focus primarily on the hard, equipment elements. Consequently, human factors cannot be fully integrated. Others argue that submissions for design specifications are not usable by the design team.

Human factors engineers have been criticised for how they have expressed requirements, and thus too impractical to include in the design specifications. Fifty years ago, human factors documentation was criticised for being full of verbosity, pomposity, obscurity and difficult to read (Chapanis 1965b); and vague or too general (Rogers & Armstrong 1977). Words like decision making, sensing, perceiving, monitoring, shunting, short term memory, scanning, coding, and the like are not specific enough to be incorporated into the design (Chapanis 1965a). Function allocation statements between human and technical

components have also suffered criticism for being highly generalised, misleading and often wrong (Chapanis 1965a). Documents submitted to design teams continue to be problematic.

Human factors integration plans (HFIPs) are often shelved and never looked at again because they are frequently overly theoretical and too long. The substance can become lost in the words and therefore lack practical application. Grimes, Wright and Hillier (2012) suggest that this over complication results in critical design changes that are simply lost in the detail (Grimes, Wright and Hillier (2012). Another problem is the bevvy of incomprehensible instruction manuals, operator manuals and maintenance manuals that continue to accompany new technologies, another task that belongs to human factors personnel and requires resolution (Chapanis 1965b).

Chapanis (1996, p. xi) argues that in a design team, it is the task of human factors engineers to write specifications that engineers, designers and programmers can use without any further help from human-factors experts. However, Chapanis affirms that deficiencies in technical writing are universal due to a lack of recognition that technical writing is a skill.Thus, the task of translating general guidelines and user needs into project-specific specifications remains problematic today and remains an area that requires further attention and research.

2.6.2.13 Systems thinking

To resolve problems incurred by interactions with the design of new technology, system's engineers and human factors engineers often adopt a systems thinking approach. Systems thinking is a way of comprehending system complexity. It involves skills in thinking, learning and understanding. It has been defined as 'the art of seeking to understand a reality that emphasises the relationships between a system's parts, rather than the parts themselves' (van Mai & Bosch 2010, p. 7).

Four levels of thinking have been identified, namely: events, patterns, systemic structures and mental models. A graphic representation of the four levels of system thinking is illustrated in Figure 2:12. Event level thinking is the easiest because events are easier to learn about and thus using the analogy of an iceberg, they are exposed above the water line in Figure 2:12. To follow the analogy further, as the water becomes deeper, the more

difficult it is to learn about and understand the underlying issues that cause and explain events that arise (Bosch, Maani & Smith 2007, p. 59; Maani & Cavana 2007). Each level is briefly described below.

Events. The first is the most superficial of the four levels. Event level thinking occurs when individuals become aware of things in their world, a consequence of change. Events represent symptoms of deeper issues and often generate quick fixes from a reactive approach toward discomfort resolution.

Patterns. Pattern level thinking involves the identification of linkages amongst groups of events. Patterns provide rich and meaningful information as they reveal changes and trends over time.

Systemic structures. Critical thinking that leads to an understanding of *how* patterns relate and affect each other is systemic structures thinking.

Mental models. This level of thinking rarely surfaces. At this level, we try to understand *why* things work and behave the way they do. Mental models are explanatory causal frameworks that facilitate the construction of an individual's reality and thus reflect the individual's unique beliefs, values and assumptions. An individual's mental model thus underlies why and how an individual may do something. Although critically important, mental models are difficult to articulate and therefore obscure to the individual and to others. This obscurity hinders meaningful dialogues needed for the development of a collective understanding and the achievement of a common vision and action.

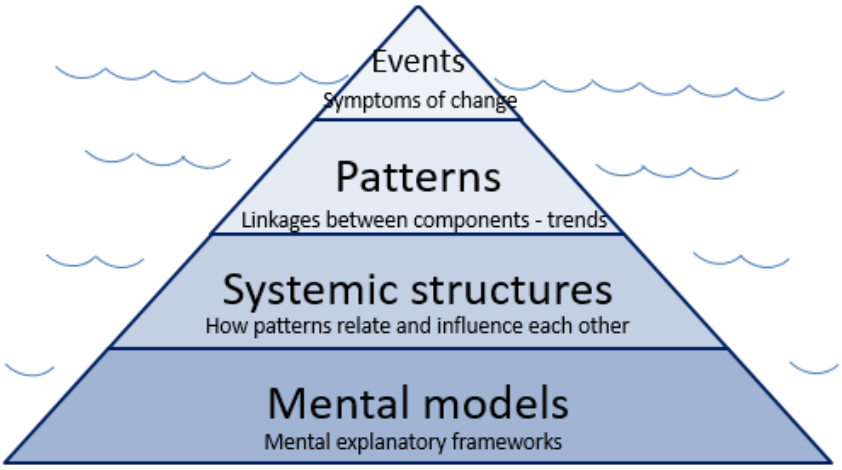

Figure 2:12 Four levels of thinking model

Adapted from Bosch, Maani & Smith (2007, p. 60)

The obscurity of mental models explains why the achievement of a compatible conceptual model of the design of new systems is challenging. For instance, stakeholders differ in both implicit and explicit understandings (mental models) of how the design should proceed (Ross & Abel 2000). However, it has been found that to communicate effectively stakeholders don't have to think in the same way, but be able to understand how the other person is thinking (Bosch, Ross & Beeton 2003). Therefore, opportunities that encourage insight sharing can help to operationalise systems thinking in support of bringing together a group of individuals who may have divergent views and different perspectives to form a common understanding of a problem (Bosch, Maani & Smith 2007).

To operationalise systems thinking amongst divergent stakeholders, many human factors engineers use participatory processes to develop mind maps such as: causal loop diagrams, and stock and flow modelling (Bosch, Maani & Smith 2007).

2.6.3 Systems development processes

To provide a systems engineering perspective, systems design processes are briefly discussed along with some available Australian and International Standards for the ergonomic design of control room technologies.

2.6.3.1 Critical success criteria (IT)

Abelein, Sharp and Paech (2013, p 20) organised the success criteria used in studies into six categories and offer these as a starting point for future studies.

- User satisfaction (i.e. user's degree of favourability toward the system and the mechanics of interaction, including usefulness and acceptance)
- System usage (i.e. Frequency of use of the developed system)
- System quality (i.e. system's functional suitability, reliability, usability, performance efficiency, compatibility, security, maintainability, and portability)
- Project in time and budget (i.e. project efficiency and effectiveness – schedules, budget, and work quality)
- Ease of use (i.e. degree to which the user expects the new system to be free from effort; and its system friendliness and handling in use)
- Data quality (i.e. degree to which the characteristics of data satisfy stated and implied needs when used under specified conditions; accuracy, consistency, and availability of data).

2.6.3.2 Systems development lifecycle process

Designers of both hardware and software componentry utilise a variety of systems development lifecycle processes. Three main types have been identified, namely: tradition, second generation tradition, enhancing and adaptive models (Ambler & Lines 2012: Lepreux, Abed & Kolski 2003). A brief description of each is provided below.

Traditional models

Traditional design approaches for the design of machinery and other artefacts such as bridges developed during the industrial revolution were commonly called engineering design processes. This was due to their application to heavy industry. Traditional design approaches closely follow scientific principles and thus often described as 'principled design' (Clements & Battista 2000).

2.6.3.2.1 First generation traditional models

First generation design processes typically involved a series of steps that usually began with a recognised need, through to its final disposal (Ambler & Lines 2012). First generation

models were commonly used to manage major procurements by the Ministry of Defence in Britain. The CADMID life cycle encompassed the concept, assessment, demonstration, manufacture, in-service, and final disposal, as illustrated in Figure 2:13.

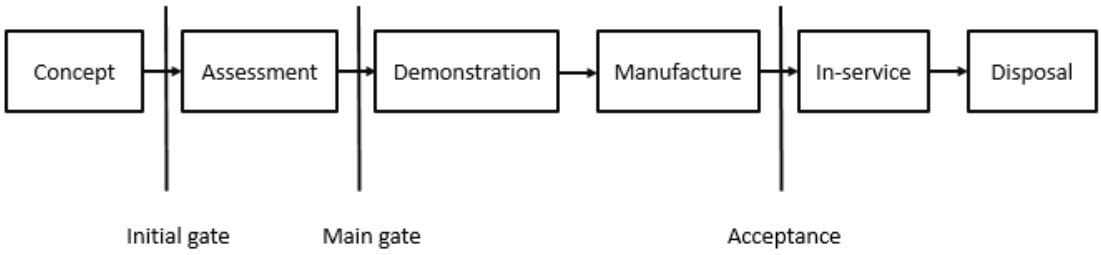

Figure 2:13 CADMID cycle
Source: Houghton, Balfe & Wilson (2015, p. 225)

The early engineering design processes were well structured and iterations between various steps were common. The process involved extensive pre-planning. The problem definition, success criteria and all requirements were captured at the beginning of the cycle and checked after manufacturing was complete at the acceptance stage.

Variants of this model have been developed for software development, each one, offering a unique contribution to meet modern complexities. These processes were named systems development life cycle (SDLC) models. With increased system integration, the SDLC models have become more common and are now used to design machinery, electronic devices and for the other business purposes (Day 2013). The waterfall model developed by Boehm (1981) was thought to offer a means for meeting industrial needs of software quality as well as productivity. This model reflects the natural downward stepwise progression of the design process. However, this process did not include the analysis or modelling of potential operator tasks. Rather, user requirements were drawn from the common sense of the most experienced designers (Lepreux, Abed & Kolski 2003). The V-model was developed by McDermid and Rapkin (1984) to encompass an additional process of design validation. The downward process for design plus an upward process for validation to ensure that the design met the requirements specified earlier, thus reflected by the V-shape of the model. This model is similar to the waterfall model in that it provides for limited iterations, but with the added advantage of attending to priority risks first through a process of risk evaluations.

2.6.3.2.2 Second generation traditional models

The first models to introduce design iterations explicitly have become known as second generation traditional models (Ambler & Lines 2012). The Spiral model (Boehm et al. 1984) explicitly included design iterations allowing for requirements to develop progressively and risks were attended to as they arose (Figure 2:14). However, again, user requirements were guided by the experience of the designer as with first generation models (Lepreux, Abed & Kolski 2003).

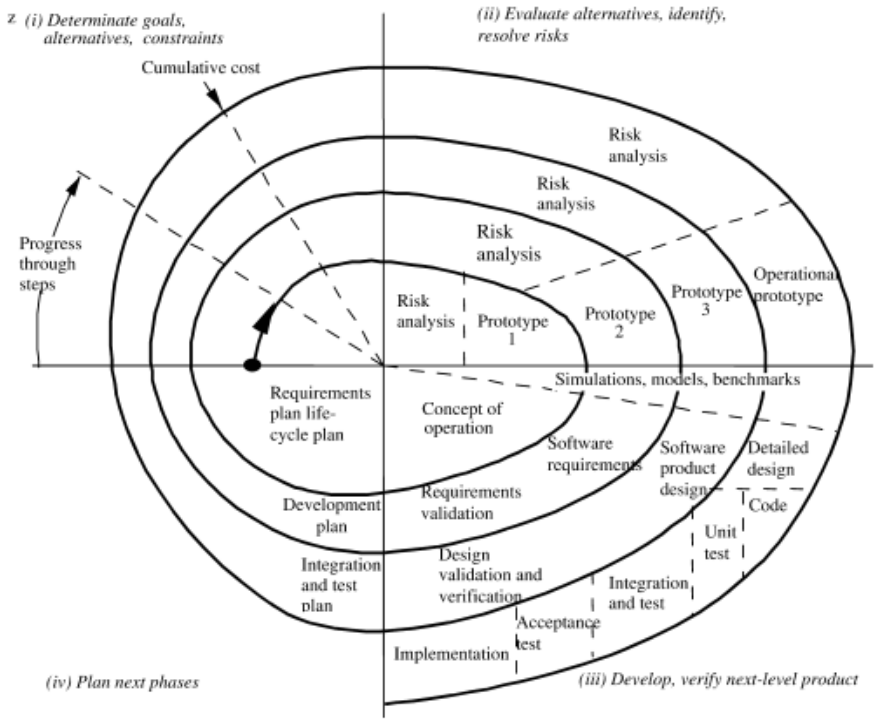

Figure 2:14 A Spiral model

Source: Lepreux, Abed & Kolski (2003, p. 249)

The Incremental model is similar to the spiral model, except that increments (iterations) are guided by experiments in operational testing (Arlat 1995 in Lepreux, Abed & Kolski 2003). However, again the exact specifications for the human-machine interaction were not explicitly attended to. Scholars state that the Incremental model is vulnerable to poorly designed human-machine interactions due to lack of explicit attention, but that the model shows promise for further development (Lepreux, Abed & Kolski 2003).

Traditional approaches and early software engineering have been described as 'technocentric', an approach that frames the technical object of the project in the central

position (Papert 1987). It has also been noted, that software development models that aim for rapid development are not well suited to the involvement of users and thus have been identified as potentially more technocentric than traditional industrial engineering models (Gasson 2003).

2. Enhanced models

During the 1990s designers have been exploring ways to develop interactive systems that approach the development under a new design paradigm. To reflect this changed paradigm, these development cycles are referred to as enriched cycles. These enriched cycles do not propose to cater for all aspects of the design process but do emphasise analysis and modelling of user tasks, human interactions through iterative prototyping (Lepreux, Abed & Kolski 2003). Some examples include the user interface design cycle by Hartson and Boehm-Davis (1993), the Curtis and Hefley model (1994) and the Star model by Hix (1995) (Figure 2:15).

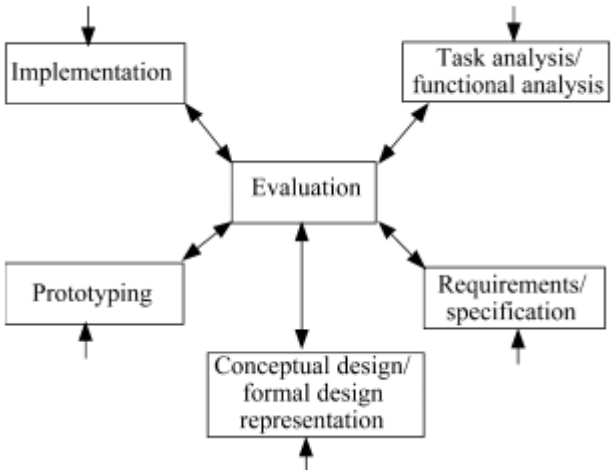

Figure 2:15 Star model

Source: Lepreux, Abed & Kolski (2003, p. 252)

3. Adaptive models

Unlike the traditional models, adaptive models have emerged. Adaptive systems development models begin the process without a fixed end-point. The end-point is considered to be complete when all stakeholders are satisfied with the product (Day 2013). Adaptive models emerged since 2000. Examples include the Agile SDLC model (Ambler &

Associates 2014), and Scrum Construction Lifecycle (Ambler & Associates 2014). However, these more adaptive models have been criticised for being unworkable, unrealistic expectations and undisciplined. These criticisms have led to the development of the Disciplined Agile model developed by Amber and Lines (2012). As societal demands continue to change and rising rates and business becomes less stable, top-down management decision making is being informed at the operational level allowing for bottom-up strategies (Hopper & Hopper 2009). In response, organic models are developing, such as the Organic SDLC model (Day 2010). This review of systems development models showed that models continue to develop to meet the needs of dynamic and progressively integrated systems of work.

2.6.3.3 Design standards related to human factors

Many design standards are consulted by designers to achieve a degree of quality assurance. A review of standards via the SAI Global On-Line Standard Service returned 648 International and four Australian Standards. A sample of standards considered potentially useful for HFI in a control room setting and their application can be found in Appendix A2.4. Design standards can be beneficial to design. However, they also have limitations.

1. **Benefits of standards**

A significant benefit of standards is that they are written from the perspectives of multiple experts. Thus, are based on a consensus of experts within a technical committee (International Organisation for Standardisation 2013b). A process of consultation helps the panel to develop and agree upon a baseline for a particular level of quality that the standard will assure (International Organisation for Standardisation 2013c). Compliance with design standards offers various advantages to organisations. The use of standards is commonplace amongst reputable designers because they help them to meet mandated requirements while increasing design efficiency (Buie 1999). Additionally, greater global marketability can be improved through greater customer confidence in the product developed (International Organisation for Standardisation 2013a). Being able to compete globally, meet regulatory requirements and offer an acceptable level of quality assurance efficiently is particularly useful for businesses during the current economic uncertainty.

2. Limitations of standards

While standards offer many benefits their limitations should also be taken into account. Below are a number of limitations identified in the literature. Standards have been criticised for being overly expensive and thus difficult to obtain (Bevan 2006). Others have complained that standards are either over or under prescriptive and thus may prevent the development of potentially better innovations, or fail to deliver on the quality claimed to provide (Stewart 2010). In comparison to technological advancement, standards take a number of years to develop. Thus, they run the risk of being obsolete before they can be used, particularly those that provide detailed specifications. Time taken to achieve a consensus amongst the standard developers can also delay its publication (Stewart 2010).

Standards have been criticised for being easily misunderstood. Scholars found that inexperienced designers struggled to achieve usability goals as set out in standard guidelines (Bevan 2006; Dos Santos et al. 2008; Nielsen 1991). This makes it difficult to purport to offer best-practice when it cannot be achieved when the standard is overly difficult to follow as intended. Standards developed for human factors guidance have been criticised for not using common design terminology, as offered by authors of ISO/TR 18529:0000 (International Standards Organisation 2000b).

Usability standards have been criticised for not catering for contextual needs of workplaces (Buie 1999; Stewart 2010). However, specific details of the user population, existing systems, and local constraints can only be addressed when the context of use is known. Therefore, to cater for context is not a realistic expectation of standard developers. As such, developers of standards openly explain that they cannot cater for contextual detail. This is evidence in the scope of all standards. For example, the scope of ISO 9241, Part 110 (International Standards Organisation 2006) outlines that only general guidelines are presented and makes no reference to the context of use or to existing technology.

One final limitation is that standards are not developed to offer industry best-practice. Rather, standards establish minimum standards to ensure that a minimal level of quality can be guaranteed (Crawford, Toft & Kift 2013; Stewart 2010). Catering for contextual needs

related to human interaction, is the dedicated role of human factors engineers, through their dedicated methods and tools, as outlined in Section 2:6.2.

2.6.4 Gaps in knowledge

The literature review of systems design approaches is seeing a shift towards greater flexibility. This shift stems from the recognition that user requirements cannot be captured in one sitting but must be allowed to evolve. This has ramifications for well-established approaches that take a more serial approach. However, scholars also recognise the extensive knowledge that has accrued over centuries of practices and note the importance of retaining the strengths of these more traditional processes if they are to achieve an optimal design under current conditions where systems are more highly integrated, dynamic and collaborative in nature. User-centred design is becoming an important approach for greater FHI. However, involving users throughout the design process is contradictory to design principles of more traditional approaches creating tension within the design arena, suggesting, that a design cultural shift is necessary.

The literature has highlighted a number of obstacles to improved HFI. These are briefly discussed below.

2.6.4.1 Obstacle 1: Pressure to increase system capacity while reducing costs

A significant number of new technology projects are currently underway in the transport and many other safety-critical industries across the world to centralise control across the country and to create economic benefits. One strategy to reduce costs is to centralise operations through greater automation (Balfe et al. 2012). Therefore, greater automation is playing a much more significant role in productivity gains. One pertinent example is evidence in Britain. Network Rail plan to replace 800 signal boxes with 12 national centres by 2019, each equipped with the new Automatic Route Setting (ARS) system. This shift is expected to produce significant economic benefits (Network Rail 2015). Therefore, greater automation is often found to be the solution to reduce costs and to increase system capacity.

2.6.4.2 Obstacle 2: Automation is not always delivering on expectations

Increasingly, new technology is synonymous with increased automation. Traditionally, automation has failed the human operator in regards to functioning that allows for appropriate human interaction (Bainbridge 1983; Sarter, Woods & Billings 1997). It is well known that computer-based technologies can be automated to sense, store, compile and condense vast quantities of information in a much faster timeframe than humans can (Ranisavljević, Spasić & Mladenović-Ranisavljević 2012). However, with the advancements in decision-making aids and artificial intelligence the future role and safety of the human is often questioned (Chen 2014). One challenge to software developers is to account for contextual variables, such as: current weather conditions, the present level of traffic, and the existing condition of equipment, company needs and expectations, which traditionally necessitate the need for human operators (Garland 1991).

Another challenge for designers is that increased automation also introduces new interactions with unexpected ramifications. For instance, recent studies report that automation has caused: undesirable changes to the controllers' role (Joe et al. 2014); difficulty monitoring, staying vigilant and avoiding complacency (Joe et al. 2014); reduced situational awareness or being left out-of-the-loop (Farrington-Darby et al. 2006; Joe et al. 2014). Automation has been noted to reduce the operator's ability to develop an accurate mental model of the system (Pickup at al. 2007; Pickup, Wilson & Lowe 2010). Workloads are on the rise as perceived workload covered by automation is compensated by increasing areas of authority which increase traffic management demands (Megaw 2005; Nemeth 2004; Pickup et al. 2007; Pickup, Wilson & Lowe 2010; Pighin & Marzona 2011). Operators have reported difficulty understanding what the automation is doing (Balfe et al. 2012; Joe et al. 2014), while others have rising concerns over deterioration of skills (Balfe et al. 2012; Kauppi et al. 2006), issues over trust (Bekier, Molesworth & Williamson 2012; Moray, Inagaki & Itoh 2000), and increased levels of stress and boredom (Ennis 2005). Finally, scholars have noted the emergence of new complexities (Balfe et al. 2012) and new types of human error (Jo et al. 2014).

2.6.4.3 Obstacle 3: Need for improved human-automation teamwork

Emergent research is suggesting that operational safety in the future will be reliant on competent systems whereby the human and technical elements work together as a team (Joe et al. 2014; Lüdtke et al. 2012). The effect of automation on teamwork is not well understood and inconsistent assessment approaches are producing contradictory results. Some research results only indicate that automation qualitatively changes the nature of communication (Johannesen, Cook & Woods 1994; Bowers et al. 1993). Other studies have found positive results whereby communication and coordination were improved (Wright et al. 2005). More recent research is finding that certain attributes that support human interaction can make automation a useful team member (Balfe et al. 2012; Ferreira & Balfe 2014). However, there are few studies conducted in this area.

2.6.4.4 Obstacle 4: Technology advances quicker than scientific knowledge

A constant challenge to effective HFI is that technological advancement moves much quicker than the scientific community can grow a body of knowledge. Hence, human factors engineers (HFEs) are presented with an ever-increasing array of problems that do not have readily available evidence-based solutions. In such circumstances, HFEs are required to break new ground and to forge ahead in order to make design decisions that are based somewhat on science plus a great deal of trial and error (Chapanis 2015). Therefore, trial and error design approaches are necessary to validate and verify that user needs and human factors have been integrated. However, multiple iterations take the time to achieve optimal results and thus need recognition and resourcing to accommodate for these design approaches (Chapanis 2015). In recognition of the gap between technology advancement and scientific knowledge, human factors experts continually call for new HFI tools and techniques, to keep pace with emergent complexity (Balfe et al. 2012; Pew & Mavor 2007; Woods 2002).

2.6.4.5 Obstacle 5: Tension in the design team

The review of the literature, revealed a number of tensions that exist within design teams. To the annoyance of human factors experts, human factors related design activities are frequently introduced too late in the design process to be able to protect against potential problems that emerge later (Norman 2010). One reason offered for late involvement is that

HFI is often met with opposition, as illustrated in the previous section. Thus the power to influence the direction of a project, or to sway decision-making in support of user needs can be significantly undermined by opinions that assert that human factors is purely common sense and therefore does not need a professional to address such matters (Wilson & Sharples 2015). It can be difficult for engineers to appreciate alternative approaches that seem to contradict the methods that they have practised and gained confidence in over many years. Consequently, the iterative, trial and error design practice frequently used by HFEs, can appear unprofessional to those who approach design in a far more structured manner (Chapanis 2015). Frequently HFEs are thus perceived as somehow out of step with the other engineering disciplines who have more similar educational backgrounds (Houghton, Balfe & Wilson 2015). Human factors engineers have also been criticised for lacking experience and the necessary design tools to analyse pre-concepts (Booher 2005). Norman (2010) explains that human factors experts are primarily scientists and thus are less equipped to design, a condition he refers to as a research-practitioner gap.

Similarly, many IT developers are pushing for more adaptive systems development models. This group of designers place less emphasis on extensive pre-planning and prefer to allow the problem definition and user requirements to evolve throughout the design process (Ambler & Lines 2012; Douglass & Ekas 2012; McNeill 2013). In contrast, first and second generation traditional design approaches prefer to be highly organised before the design process begins, with a definite problem definition and all user requirements gathered upfront (Ambler 2014; Optimus Information 2016).

Another source of tension is that industrial engineers consider themselves to be real world problem solvers who pride themselves on well-developed design processes. However, well-structured processes have been criticised for being better suited to well-defined solutions and are thus too inflexible for the messy real world problems that are more difficult to define (Norman 2010). Furthermore, Norman (2010) offers that modern day problems require right-brain big picture thinking, rather than the left-brain logic that engineers pride themselves in. Engineers have also been criticised in a number of other ways found to influence the power of influence of HFEs. For instance, engineers have been criticised for ignoring or relying on logic and educated guess work when human factors support is not

readily available. Industrial engineers have also been criticised for not knowing who might be able to help, and for not knowing how to work with others (Chapanis 2015).

Nevertheless, the debate regarding how to best design continues. Human factors experts are calling for greater appreciation of their iterative, trial and error methods (Norman 2010; Pew & Mavor 2007). Furthermore, while some human factors engineers are happy to have their activities embedded into an existing engineering design processes (Houghton, Balfe & Wilson 2015; International Standards Organisation 2000; Pew & Mavor 2007), others are not (Ambler & Lines 2012). Some scholars suggest that a traditionalist approach is not conducive to human factors practices and actively works against reducing the design-user gap (Butler & Murphy 2007; Heeks 2006; Norman 2010). Similarly, IT developers are opposed to the more traditional methods and are pushing for more agile systems development that spends less time in planning and more time during development (Ambler & Lines 2012; Douglass & Ekas 2012; McNeill 2013). Also in the mix, industrial engineers are calling for a return to more traditional practices (Kern 1995). The publication date of the previous comment shows that adaptive design processes have been having an influence for many years and still the debate has not been resolved. Thus preferred practices, terminology, and language continue to cause misunderstandings and conflict amongst members of the multidisciplinary design team (Norman 2010). To help resolve this tension, scholars are calling for greater collaboration between the design team disciplines. That is, to not only produce a multidisciplinary product but to produce a transdisciplinary outcome. Toft (2007) notes that this can only be achieved when the various disciplines come together to create and innovate. Thus, although the human factors discipline emerged some 60 years ago, conflict in the design team continues.

2.6.4.6 Obstacle 6: Engineering design process is not well supported

In consideration of the lack of cooperation within the design team, human factors scholars exhort that neither the engineering nor the human factors disciplines are adequately equipped to fully integrate human factors (Norman 2010; Pew & Mavor 2007). Thus, some believe that no engineering design processes are adequately supported to achieve HFI (Ferreira & Balfe 2014). Norman (2010) offers that this breakdown is a product of current education. Therefore, unless some of the interdisciplinary tensions can be resolved, calls for

early human factors involvement in the design process are likely to go unheeded (Woods 2002). The type of cultural change within organisations identified as necessary to support and promote HFI is reliant on senior leaders to articulate and finance the change (Harris, Hart & Shields 2005).

In the meantime, inadequate integration of human factors can leave new technology at risk of being rejected by users or introduce risk to safe control. Furthermore, poor understanding of HFI by project managers and those providing the funding have been found to result in a lack the commitment to assign priority to these activities (Pew & Marvor 2007). Therefore, user trust and acceptance of new technology is reliant upon effective HFI which further relies on an HFI-supported systems development process.

2.6.4.7 Final comments

The obstacles presented here highlight that resolution to these obstacles is not found in the literature. The literature shows that there is much debate about how to best approach the design of more complex integrated systems. Consequently, there is a knowledge gap on how to resolve the disconnect that occurs when designs do not adequately support the needs of users, and thus the design-user gap persists and is likely to continue exist unless greater appreciation of alternative approaches and improved collaboration can be achieved.

2.7 Conclusion

The literature review has revealed gaps in knowledge in a number of critical areas. Technology adoption in mandatory situations is poorly understood. Studies in this area have primarily focused on the factors that determine or moderate likely acceptance. However, in a control-room environment, it is imperative that end users not only adopt effectively and efficiently but that they come to adopt expertly. Thus, in mandatory situations, a significant technology adoption gap is apparent.

Complicating the resolution of the technology adoption gap is that control systems are progressively integrating computer-based technologies. The addition of software is adding a third dimension to an already challenged design process that struggles to integrate human factors. A number of obstacles have been identified in the literature that contributes to poor HFI. These obstacles make knowing how to integrate human, hardware and software

elements more challenging and is highly debated. Thus, in light of progressive system integration, some of the MIS literature on technology adoption and technology acceptance of information systems may support improved practice and thus be transferable to a control-room context. However, few studies have focused on technology adoption in safety-critical environments. Thus knowing how to resolve the disconnect that occurs when designs do not adequately support the needs of users, is a growing concern amongst the safety-critical community. Consequently, a desire to close the design-user gap is highly sought after.

Some scholars have put forward that in mandatory situations, an understanding of how end users come to adopt may be more useful than predicting likely uptake. Knowledge of this kind is anticipated to help decision-makers improve implementation strategies in organisations. The sensemaking perspective has been offered as a plausible means of gaining insight into how technology adoption occurs in organisational settings. However, research is sparse and theories continue to develop.

This literature review has revealed a number of critical areas that are poorly understood. Furthermore, the literature cannot adequately explain to what degree the design-user gap may have on technology adoption in the future, and what impact newly integrated technologies will have on safety and thus the efficacy of accident prevention interventions. Due to these gaps in knowledge, it is clear that the context in which problems arise is not known and to resolve these big questions is not available in the current literature.

Chapter 3. Methods

3.1 Introduction

Two critical areas will be addressed to reduce the gap in understanding associated with the introduction of progressively integrated new control-room technologies.

- The technology adoption gap in mandatory and safety-critical situations
- The design-user gap by investigating viewpoints on design approaches.

Research Aim and Objectives

The aim of this research is to better understand how to optimise the introduction of new technology into safety-critical work environments such as control rooms. Three objectives and associated research questions were devised to support this aim.

Objective One: To explore the underlying factors that influence end-user technology adoption in a modern control-room environment.

- Research Question 1: What technology adoption concerns do stakeholders of control-room technology have and do these opinions differ?
- Research Question 2: Does sensemaking play a role in technology adoption and in what way?
- Research Question 3: What factors help or hinder end-user adoption of control-room technology?

Objective Two: To explore viewpoints on how to best approach new technology projects for control rooms.

- Research Question 4: What viewpoints exist on the best way to approach new technology projects?
- Research Question 5: How might these viewpoints influence end-user adoption of future new technologies?

Objective Three: To develop recommendations for optimising the introduction of new control-room technology.

Research Scope

The research undertaken for this thesis draws on the participation of six business units from five organisations. The study represents three safety-critical industries, namely: aviation, rail, and power processing and distribution.

3.2 Research Design Overview

A two-phase study design was adopted. Treatment of the data collected in the first phase aligns with mixed method descriptions outlined by Creswell (2003, 2009). Q methodology was used in the second phase of the study and data collection and treatment followed the process as described by Brown (1980). The literature review (Chapter 2) provides the theoretical basis for this study, and the sensemaking perspective utilised to investigate technology adoption further has been drawn from the foundational work undertaken by Weick (1995).

Phase one of this study explored factors that influence the technology adoption gap in control rooms. The analysis drew on two data sources, a semi-structured interview protocol and a survey questionnaire. Controllers were interviewed to capture their experiences and preferences toward technology adoption, while the survey was used to capture opinions and comments from control-room technology stakeholders, namely: Managers, Designers, Evaluators and End Users. Sampling was purposive and the questionnaire was therefore only made available to individuals of organisational bodies deemed pertinent to the study. The defining mixed methods characteristics are: (1) concurrent timing of both qualitative and quantitative data collection, (2) equal weighting to both data sources, (3) mixing of methods involved embedding the qualitative into the quantitative results to enhance statistical significance, and (4) implicit and explicit theorising was drawn from the data allowing for the reporting of both statistical and acknowledged significance. Results from phase one produced the first set of results reported in this thesis (Chapter 4). See Appendix A3.1 for a description of these mixed methods characteristics.

Phase two of this study utilised Q methodology to investigate viewpoints on how to best approach new technology projects for control rooms. It was anticipated that stakeholder viewpoints might provide insight into closing the design-user gap. The analysis involved both

quantitative and qualitative data in determining salient viewpoints, while qualitative methods were undertaken to enable interpretation during the final analysis. In this study, the qualitative data was treated with greater importance when interpreting the results. Interpretation of the results allowed for implicit theorising and produced the second set of results reported in this thesis (Chapter 5). See Appendix A3.2 for a description of Q methodology. From a synthesis of study results, recommendations were devised for the optimisation of future control-room technology.

The research framework followed in this thesis is illustrated in Figure 3:1. In the framework, the data sets for phase one are equally weighted (QUAN, QUAL). In phase two, the qualitative data takes primacy (quan, QUAL).

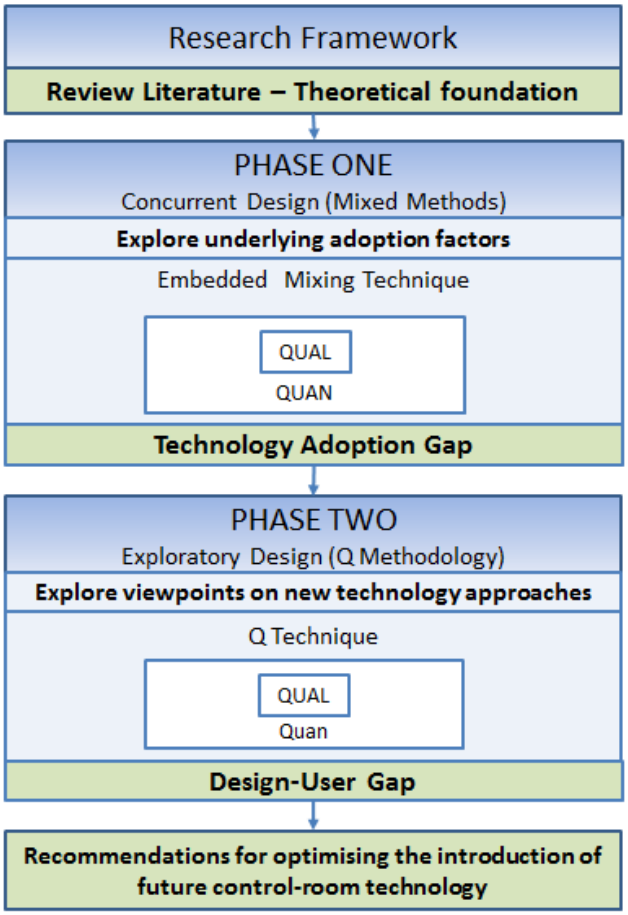

Figure 3:1 Research framework

3.3 Phase One

3.3.1 Context familiarisation

Familiarisation of the control room context was achieved through field observations. This entailed quietly observing the working environment. The operations managers or site supervisors further explained what the various controllers were doing and in general what was going on in the control room. In some cases, these discussions were conducted in a room adjacent to the control room and the controllers were observed through a glass window. At other times, the observation was allowed inside the control room. During observations, care was taken to not disturb or become intrusive during the visit. Any subsequent questions were answered by controllers as interviews progressed.

3.3.2 Research instruments

Two research instruments were employed during this phase of the research.

3.3.2.1 Survey development

A survey entitled*: The Adoption of New Technology in Control Rooms* (Appendix A3.3) was established in paper and online forms using the Survey Monkey website application (www.surveymonkey.com). The survey contained four sections and was made available between October 2010 and September 2011. Section 1 was used to gather demographic details, and Section 2 was used to examine the value of end-user involvement. Section 3 gathered data on factors that influence systems and end-user adoption success, while Section 4 was used to explore technology adoption factors from a sensemaking perspective.

Multiple choice (Survey Section 1) and Likert-scale responses (Survey Sections 2 and 4) were used to collect quantitative data, while the data collected from two open-ended questions (Survey Section 3) were qualitative. The twenty-one technology adoption variables included in the fourth section of the survey are listed in Table 3:1. While all items in the survey were drawn from the literature, the open-ended questions were specifically included to ensure the topic scope was not limited by researcher bias toward selected items.

Table 3:1 List of technology adoption variables from a sensemaking perspective

No.	Variable	Personal application	Sensemaking
1	Employee openness to change	Psychographics	Create
2	Employee attitude (mental model)	Psychographics	Create
3	Employee computer abilities	Prior Experience	Create
4	The employee's experience of failed adoption of prior technologies	Prior Experience	Create
5	Employee fear of job loss (e.g. replaced by technology, unable to adapt)	Personal Concerns	Affect response
6	Employee fear of reduced job satisfaction	Personal Concerns	Affect response
7	Employee fear of reduced control of activity	Personal Concerns	Affect response
8	The age of the employee	Demographics	Interpret
9	The gender of the employee	Demographics	Interpret
10	End user's need to understand why the new technology is introduced	Awareness needs – what's in it for me?	Interpret
11	Level of workflow disruption	Work performance concerns – what does it mean for me?	Interpret
12	Level of task/job demand changes to employee's role	Work performance concerns	Interpret
13	Physical work environment (e.g. desks, chairs, screens, lighting)	Work performance concerns	Interpret
14	The new technology's ability to interact with existing systems	Work performance concerns	Interpret
15	Technology/co-worker support networks facilitated by management	Opportunity to learn – will I be supported?	Enact
16	Managerial support of additional resources (e.g. time, training)	Opportunity to learn	Enact
17	Piloting the new technology before implementation	Opportunity to learn	Enact
18	Shared decision-making between employees & management	Opportunity to learn	Enact
19	Influence from others (e.g. colleagues, superiors)	Opportunity to learn	Enact
20	Managerial structure of the organisation	Opportunity to learn	Enact
21	Unlearning old habits or procedures	Prior Experience	Enact

Although there are others, the variables were chosen for this study have properties that align well with each sensemaking process. Section 2.5 provided the theoretical basis for the inclusion of each sensemaking-adoption variable.

3.3.2.2 Interview protocol

In addition to the survey, data was also collected from a set of interview questions as listed in Table 3:2. The interview protocol was developed to explore the technology adoption experiences and preferences of end users of control-room technologies, labelled 'controllers' hereafter. Six semi-structured questions with associated prompts were used to focus the interview. The questions were quite broad to allow respondents the opportunity to voice what they felt was important. The associated prompts were used sparingly to avoid directing thought processes away from areas that would have otherwise been pertinent to the individual respondent. Interviewee responses drove the level of elaboration for each key question. The interview questions and associated probing prompts can be found in Appendix A3.4.

Table 3:2 List of interview questions

No.	Question
1	Tell me about the technologies in your control room. How do they help your work process?
2	In what way does your job rely on other people to do their job correctly?
3	When you suspect something major could go wrong, are you able to shut down the system?
4	Describe what happens when new technologies are introduced into your organisation and who is involved?
5	What factors do you think help or hinder the successful adoption of new technologies?
6	Closing comments –what would you tell someone intending to introduce a new technology?

3.3.3 Participants

The target population for this study were individuals who had a vested interest in the success of new technology in control-room settings. Therefore, participation was drawn from four broad stakeholder groups:

- Managers - i.e. high-end personnel whose decisions impact new technology/system outcomes, such as: organisational, financial, or project managers;

- Designer - i.e. individuals responsible for the technical design of new systems: technology innovators, architects, software developers, industrial engineers, manufacturers and suppliers of the product;
- Evaluators - i.e. research and development staff, human factors, safety and quality control professionals;
- End users - i.e. individuals who directly use technology to meet work tasks, such as: controllers, operators, relief staff and trainers.

3.3.3.1 Sampling procedure

The goal of sampling is to achieve a sample that reflects the target population as closely as possible with as little bias as possible within the sample selected (Kumar 2005). The target population sought for this study was control-room technology stakeholders. Participants for this study were considered and deemed pertinent to the research according to the following criteria: individuals who were associated with control rooms for high risk (safety-critical) industries in the following roles: management, technology, design, safety, quality, and/or human factors. Therefore, to achieve participation from the targeted population group, sampling was purposive (Miles & Huberman 1994).

Purposive sampling is non-probability sampling and is also referred to as judgmental sampling (Sarantakos 2004). Participants are chosen subjectively by the researcher on the basis that they hold particular knowledge relevant to the research (Frankfort-Nachmiasand & Nachmias 1992). After purposefully inviting organisations known to have control rooms to participate, interview participants were selected opportunistically. This technique is also known as a convenience (and volunteer) sampling and is very common as it is cost effective to the researcher (Laerd Dissertation 2012). While convenience sampling has been criticised for having limited generalisability (Explorable 2015), this research was not seeking opinions from the general public who may know little about the working conditions in safety-critical environments. Similarly, professional bodies deemed pertinent to the research were also purposively selected, allowing survey participants to voluntarily select in or out of participation. Since greater understanding was being sought on the processes that give rise to problems associated with technology adoption of control-room

technology, examination of the process was important and thus ideally suited to non-probability forms of sampling (Bryman 2008).

3.3.3.2 Recruitment of surveyed participants

Delegates from three conferences that the researcher attended and considered pertinent to this study were invited to participate in the survey. These conferences included: the Conference on Railway Engineering, held in September 2010, in Wellington New Zealand (CORE 2010); the International Control Room Conference, held in October 2010, in Paris France (ICOCO 2010); and the Human Factors and Ergonomics Society of Australia Conference, held in November 2010, in Twin Waters, Queensland (HFESA 2010). Paper-based surveys were added to delegate information packs at two conference venues (ICOCO 2010 and HFESA 2010), at the approval of conference convenors. The paper-based version of the survey contained a brief introduction to the study, researcher contact details, and information indicating where to leave the completed survey. Refer to Appendix A3.5 to review the paper-based invitation preamble. Delegates attending the CORE 2010 conference who indicated their interest via business card exchange were emailed the link to the online survey, post conference.

To source pertinent participants, as described earlier, relevant professional groups located within the *LinkedIn* website (www.LinkedIn.com) were selected. *LinkedIn* is a respected platform for professional networking that attracts members from around the world. Twenty-six professional groups related to technology and design, safety, human factors and high-risk industries were selected. Once membership to the group and permission to run the survey was approved by group moderators, a brief description of the survey and the link to the online survey was posted in the membership forum to recruit participation. Two subsequent posts were sent to remind potential participants about the survey and when the survey would close. Examples of these posts can be found in Appendix A3.5. Consent from survey participants was assumed when participants completed the survey.

3.3.3.3 Recruitment of interviewed participants

To gain participation from organisations known to have control rooms, a list of possible organisations was devised. Some introductions to pertinent organisations were made by the researcher's supervisors, while other organisations were contacted via an employee known

by the researcher. Email communication with contact personnel included the invitation to participate letter for review (Appendix A3.5). The letter outlined the aim of the research, the purpose of the interviews, the number and type of participants sought (i.e. about six control room operators), and the nominated duration for interviews. Managers were assured that the data would remain anonymous and would not be used for any other purpose. After agreement via email was achieved from relevant decision makers within the organisations, contact personnel for each business unit were emailed all relevant documentation that participants would receive: the list of questions to be asked, the preamble about the study, a consent form to be signed by interviewed participants, and a feedback form to be filled in by participants at the conclusion of the interview (Appendix A3.5).

To minimise potential bias, participation sought was as broad as possible. Participant organisations, as listed in Table 3:3 were selected to cover a reasonable geographic spread, a variety of industries, the inclusion of both regional and metropolitan centres, and organisations with multiple business units, where applicable. Furthermore, the level of experience was not a limiting criterion since newer staff may have recently needed to adopt new technology. Personnel available on the days that interviews were conducted were given an opportunity to participate. However, their availability was limited by potential workload, relief staff availability, interest, and motivation.

Available controllers were provided information to ensure they understood that their participation was not compulsory and that the data collected would be kept confidential. In this regard, sampling was opportunistic, as interview participation was dependent upon staff availability on the day and the time at which interviews were being conducted.

3.3.3.4 Participant organisations and associations

Table 3:3 Interview, survey and Q-survey participant organisations

Interview Date	Number of Participants	Role	Contact & Organisation	Industry
16-17 Dec 2010	8	1 Electrical Train Operator 7 Network controllers	Gordon Leech Gordon.Leech@qrnational.com.au QR National 320 Murray St Rockhampton 4700 QLD	Railways
1 Nov 2010	5	Plant Technicians	Jason Paull Jason.PAULL@stanwell.com Stanwell Corporation Ltd Stanwell 4700 QLD	Power
21 Jan 2011	5	Network Operators	Dale McLellan Dale.mclellan@ergon.com.au Ergon Energy Richardson Rd Rockhampton 4701 QLD	Power
21 Feb 2011	7	Air Traffic Controllers	Ross Blanchard Ross.Blanchard@AirservicesAustralia.com AirServices Australia, Rockhampton QLD	Air Traffic
1-2 Mar 2011	7	Air Traffic Controllers	Max Bice Max.Bice@AirservicesAustralia.com AirServices Australia, Brisbane QLD	Air Traffic
5-6 Apr 2011	4	1 Control Trainer 3 Signalmen	Wayne Walsh Wayne.Walsh@metrotrains.com.au Metro Trains Melbourne 3000 VIC	Railways
TOTALS	**36 Participants**		**5 Different Organisations**	**3 Industries**

Participation details of organisations, conferences and professional groups involved in this study can be found in Table 3:4.

Table 3:4 Participating organisations and associations

Date	Mode of participation	Organisations and Associations
12-14 Sep 2010	Survey & Q-survey	Conference on Railway Engineering (CORE 2010), Wellington, NZ
25-26 Oct 2010	Survey & Q-survey	The International Control Room Design Conference (ICOCO 2010), Paris, FR
31 Oct - 3 Nov 2010	Survey & Q-survey	The Human Factors and Ergonomics Society of Australia (HFESA 2010), Twin Waters, Queensland
16 Dec 2011	Interview & Q-survey	Queensland Rail (QR) National
1 Dec 2011	Interview & Q-survey	Stanwell Power Station, Stanwell

Date	Mode of participation	Organisations and Associations
25 Jan 2011	Interview & Q-survey	Ergon Energy, Rockhampton
21-22 Feb 2011	Interview & Q-survey	AirServices, Rockhampton
1 - 2 Mar 2011	Interview & Q-survey	AirServices, Brisbane
7 Apr 2011	Interview & Q-survey	AirServices, Melbourne
6-7 Apr 2011	Interview & Q-survey	Metro Trains, Melbourne
LinkedIn groups (Survey participants)	Survey only	Artificial Intelligence Australian Rail Association (ARA) Australian Railway Engineering Aviation and Aerospace Professionals Aviation Professionals Creative Design Pros Creative Designers and Writers End to End Web Developers FP7 Info & ICT Information Communication Technology Global Energy Professionals Human Factors Human Factors and Ergonomics Society of Australia Institute of Instrumental and Automation Australia Institute of Transport Engineering Linked Energy (EIX) OHS in Australia OHS Professionals Australia Open Service Innovation Open Source Project Managers Rail Group Safety Institute of Australia Smart Grids, Energy and Water Springer Human-Computer Integration Telecom Professionals The Enterprise Architecture Network

3.3.4 Data collection procedures

3.3.4.1 Survey

Delegates of two conferences completed paper-based surveys that were printed and included in delegate information packs. Completed surveys were left at the conference

secretary's desk and collected by the researcher. Responses from these paper-based surveys were then loaded onto the online version hosted on the Survey Monkey website. All other participants were required to complete the survey online directly within Survey Monkey (www.surveymonkey.com). All data was stored safely, with access to the data being password protected. The online survey was available between the 15th of October 2010 and the 18th of September 2011.

3.3.4.2 Interviews

Prior to the interviews, managers of control rooms or site supervisors in each location provided the researcher with an overview of their control room, the activities and roles within, and answered any questions thus providing the researcher with an informal familiarisation with the work environment. Interviews were conducted away from the participants' workstation to maintain response confidentiality, and to avoid potential distraction or disruption to workflow. Interviews were arranged at a time that suited the organisation and therefore, individual controllers rarely received advance warning. Thirty minutes were allocated for each interview.

Prior to commencement, participants were informed that their participation was voluntary, that they could withdraw at any time and how the interview would be conducted. The purpose of the interview was also explained (Appendix A3.5). Once an agreement to participate was achieved, participants signed a consent form and were given details of the researcher (Appendix A3.5). Before the interview commenced, permission was sought to use a digital voice recorder and participants were given a final opportunity to ask questions before the interview commenced. At the end of the interview, participants completed an interview feedback form to obtain proof that the research was conducted in accordance with its ethical approval (Appendix A3.5).

Once preliminary agreement and consent were achieved, interviews followed the recommended schedule offered by Robson (2002):

- Introductory comments – researcher read out the interview preamble which provided a background to the problem;

- List of topics in the form of key questions – guided by participant's responses, questions were asked in a flexible manner regarding sequence and wording. The purpose for each question was as follows:
    - Question 1 – to stimulate thinking on systems within the control system and to aid researcher understanding of systems in use;
    - Question 2 – to explore how tightly coupled (i.e. interconnection of elements) control systems function;
    - Question 3 – to explore the participant's actual level of control;
    - Question 4 – to explore tech adoption experiences and preferences;
    - Question 5 – to explore preferences and factors that help or hinder technology adoption.
- Set of associated prompts – used to elicit more information or to stimulate participant's thought processes;
- Closing comments – a final piece of advice was requested to explore issues of high importance. This also gave participants an opportunity to make any final comments or to address something missed. Finally, participants were thanked for their involvement in the study.

3.3.5 Data preparation

3.3.5.1 Survey

Once the data was collected, it was prepared for analysis. The following process was taken as recommended by Pallant (2005):

- Prepare a *codebook* that briefly provides the instructions used to convert the raw data into a form that Statistical Package for the Social Sciences (SPSS) can understand (see Appendix A3.6);
- Responses that did not continue past the demographic questions were removed from the dataset;
- Where respondents missed one or two questions, these were left blank;

3.3.5.2 Interviews

Recorded interviews were played-back for transcription using Audacity 2.06.

3.3.6 Data analysis

3.3.6.1 Phase one

Analysis techniques used during phase one involved data collected from both the Survey and the Semi-Structured Interviews.

1. **Quantitative data**

The Likert-scale responses of the survey were subjected to *descriptive statistics* and examined for overall opinions and observed differences of opinion between stakeholder groups. *General Linear Model* (GLM) *Multivariate post hoc* analyses were performed to identify any statistically significant variance of opinion between demographic groupings regarding technology adoption factors.

Factor Analysis was then performed to reduce the data into meaningful thematic clusters (factors) and to examine any correlations amongst variables that may relate to sensemaking. Principal component analysis (PCA) was the chosen extraction method. To determine the best solution possible, an exploratory analysis was first conducted to ascertain item and factor suitability, as recommended by Tabachnick and Fidell (2001). A number of different approaches were explored to find the best factor solution. After comparing both rotation techniques during the preparatory analysis (Appendix A4.1), the items were rotated using the Oblimin technique.Rotation helped the examination of factor loadings to determine whether there were any confounding items or factors with few loaded items.

Each anomaly was examined closely to govern whether to keep or remove the item from the study. Three techniques were used to determine the number of factors, namely: eigenvalues above one (Kaiser's criterion), the Cattell's scree test to only accept factors above the elbow (Cattell 1966), and Horn's parallel analysis (Horn 1965) that involves comparing eigenvalues from the study with a randomly generated data set of the same size, with the decision to retain factors being based on study eigenvalues being larger than the corresponding random values generated. All factor solutions were evaluated against underlying theory and research, as recommended by Pallant (2005) when deciding the number of factors to select.

To check that the data was suitable for factor analysis, the following assumptions were checked (Pallant 2005):

- *Sample size* – an overall sample size of 150+ and a case to the variable ratio of at least 5:1.
- *Factorability of the correlation matrix* – for the data to be considered suitable for factor analysis, correlations of r=0.3 or greater must appear in the correlation matrix. The Bartlett's test of sphericity should be statistically significant at $p<0.05$ and the Kaiser-Meyer-Olkin (KMO) value should be 0.6 or above.
- *Linearity* – the relationship between variables is assumed to be linear and is confirmed by spot checking scatterplots of a few variables, as recommended by Tabachnick and Fidell (2001).
- *Outliers among cases* – Outliers are very high or very low scores falling outside the standardised residual values of 3.3 and -3.3. Extreme scores can affect the analysis negatively. To ensure no obscure data impacts the results, boxplots and 5% mean values were checked for outliers. Outlying cases were subjected to further scrutiny by examining box plots and mean scores for potential removal.

Reliability of the analysis was checked in two ways. Firstly, internal consistency was examined to determine whether the items within each factor accurately measured the concept of study; and secondly, discriminant validity was checked to ensure that the factor groups were distinct from each other (Hair et al. 2006). The Cronbach alpha score and optimal average inter-item correlation scores were examined to determine internal consistency. The component correlation matrix was checked to ensure correlations between factors were low to establish discriminant validity. Correlations do not indicate whether a causal or functional relationship exists between variables and whether one variable can predict another (McKillup 2012). Therefore, regression analysis was conducted.

To explore if any of the emergent factors could predict or shape an individual's technology adoption state, *Standard Multiple Regression* analysis was undertaken. Regression techniques are used to explore relationships between a dependent variable, and a number of continuous dependent variables. Multiple regression is a technique that can measure how well a set of variables are able to predict a particular outcome (Pallant 2005). As is

conventional (Krawthol & Anderson 2001), the level of significance was set at $p < 0.05$, with significance levels of <0.01 reported when applicable. The coefficient of determination (R^2) was used in two ways: (1) to explain the proportion of the total variation that was explained by the regression line; and (2) to compute effect sizes in the G*Power calculator for the examination of relationship strength between the predictive factor variables and the dependent factor variable.

Multiple regression analysis is particularly sensitive to the data and makes a number of assumptions that were checked to ascertain model reliability as recommended by Pallant (2005). Explanations of the assumptions to check are as follows:

- *Sample size* – if sample sizes are too small, they lose generalisability. According to Tabachnick and Fidell (2001, p. 117), the minimum sample size for social science research can be calculated using the formula N = 50+8m, where m is the number of independent variables. Similarly, a three predictor variable model should achieve a sample size of 74 cases or above.

- *Multicollinearity and singularity* - Independent variables must not be perfectly nor highly correlated with each other, preferably below 0.7. However, they must show some relationship with the dependent variable, ideally above 0.3 (Pallant 2005; Tabachnick & Fidell 2001). Tolerance level and the variance inflation factor (VIF) values show the level of variability of a specified predictor variable that is not explained by the others in the model. A way to pick up problems with multicollinearity that may not be obvious in the correlation matrix is to examine these two values. Tolerance and VIF scores were only used as indicators that multicollinearity may exist, suggesting that further examination was necessary. Therefore, multicollinearity between predictor variables *may* exist if tolerance scores fall below 0.10 and VIF scores are above 10 (Pallant 2005). Scatter plots were created to examine relationship type to the dependent variable, and the curvilinear line of the histogram was examined to confirm continuous probability and normal distribution of the data.

- *Outliers* - Outliers should not exist unless the sample size is large. Outliers are very high or very low scores falling outside the standardised residual values of 3.3 and -3.3. Extreme scores can affect the analysis negatively. The Normal Probability plot (P-P) and Residual Scatter plots were used to check for outliers. Outlying residuals are not uncommon in studies with large sample sizes and rarely need any action was taken (Pallant 2005).

- *Normality, linearity, homoscedasticity and independence of residuals* **–** are distribution and variable relationship factors that must be present. *Normality* (normal distribution of predicted scores) was checked by examining the curvilinear line on the histogram that should reflect a typical bell curve; *linearity* (that is, residuals have a straight-line relationship with predicted variables) was checked by examining the Normal Probability Plot. No major deviations from linearity are indicated by points that align in a fairly straight diagonal line from the bottom left to top right; and *homoscedasticity* (that is, the variance of residuals are the same for all predicted scores) were checked by examining the Residual Scatterplot. Ideally, points will be concentrated in the centre, 0 points and distributed in a somewhat rectangular fashion (Pallant 2005).

Descriptive statistics, Factor Analysis and Regression techniques were conducted using IBM SPSS Statistics 20. G*Power was used to analyse predictive effect size to support pathway analysis (Faul et al. 2007). Monte Carlo PCA for Parallel Analysis 2.0.3 was used to help decide the number of factors to retain for rotation in factor analysis using randomly generated data (Shareware Junction 2013).

2. Qualitative data

Qualitative data collected from Section 3 of the survey were first subjected to content analysis by tabulating pertinent quotes against categories established as recommended by Miles and Huberman (1994). Due to the size of the data, the interview data was subjected to thematic analysis.To reduce the data in a meaningful way and to discover regularities and patterns, an interactive model was used as established by Miles and Huberman (1994) and illustrated in Figure 3:2. Interview transcripts were prepared and loaded into QRS NVivo 9, a

qualitative software analysis tool used to aid the identification of emerging themes through categorisation and coding techniques.

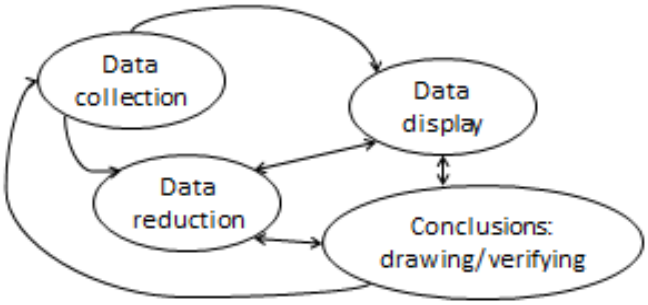

Figure 3:2 Interactive model of data components

Source: Miles and Huberman (1994, p. 12)

The initial themes used for analysis were based on topics identified in the literature and in particular, themes presented by the United Kingdom's Rail Safety and Standards Board (2008), namely: culture, conditions, design, training and staffing. New themes were added as they emerged during the analysis. This analytical process provides a formalised way to collect a body of knowledge that can be generated in the form of constructs or theories (Miles & Huberman 1994). Each transcript was coded by the same researcher with the aim of achieving consistency, and themes were sorted on cards to structure findings and to assist with reporting. With the help of NVivo, major themes and sub-themes were identified. Thematic iterations for analyses of interview data for this project can be found in Appendix A3.7.

Qualitative data from the survey was subjected to the 'Constant Comparative Method' suggested by Strauss and Corbin (1990) to analyse and interpret the findings. This method involves coding collected information, a process of attributing a code to utterances, sentences, paragraphs or sections. After initial coding, data was constantly revisited until such time that it was obvious that no new themes were emerging. Memo writing was undertaken during data coding stages, pertaining to the coding process, to capture pertinent quotes and /or to highlight issues raised. This is an inductive approach to data analysis for the purpose of understanding the challenges and means for improving the introduction of new technology.

Once the initial analysis of both data sources was conducted, the survey data was converted to quantitative counts to be able to visualise comparisons between items highlighted. Both qualitative data sources were embedded into the quantitative findings, providing of examples of acknowledged significance (pertinent quotes) to enhance the results showing statistical significance and to determine any additional factors. Comparisons were also made between stakeholder opinion and end-user experience data sets.

Figure 3:3 shows the analytic framework followed during phase one for this research project. The figure identifies the data sources used and the concurrent nature of this study, as illustrated by the parallel analyses. The dotted lines indicate where the mixing of data took place. Results from these analyses are presented in Chapter 4.

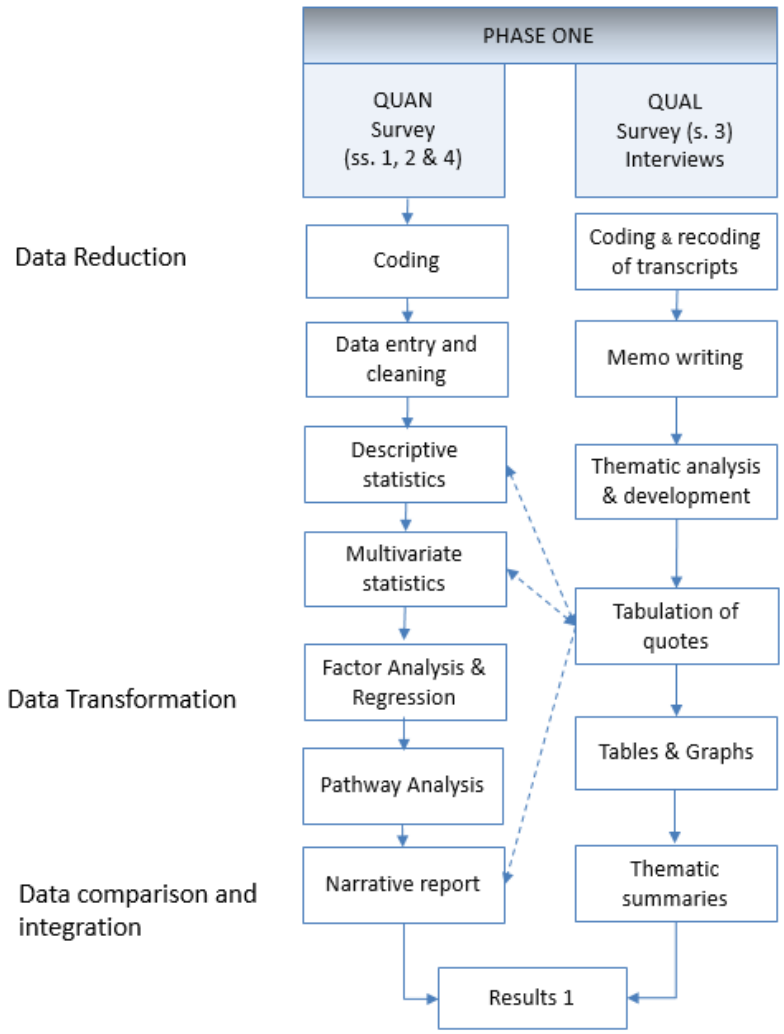

Figure 3:3 Phase one analytic flowchart

Adapted from: Li, Marquart and Zercher (2000, p. 122)

3.4 Phase Two

Q methodology was used to explore viewpoints on how to best approach new technology projects for control rooms. The purpose of this study was to find an explanation for why new technology continues to be designed will little regard for the needs of users. Thus, it is hoped that insights from the data might help to explain why the gap between the user and its design (design-user gap) continues to exist. Therefore, the investigation took an abductive approach as described by Thagard and Shelley (1997). Refer to Appendix A3.2 for a description of Q methodology.

Before undertaking the Q-study, the survey was piloted using Q-Assessor, an online survey platform (see http://q-assessor.com/). The pilot study was conducted to assess the study design and the online instrument. Q methodology is best approached following the recommended five-step process (van Exel & de Graaf 2005). Therefore, the five-step format is used to describe how the Q-study was undertaken.

3.4.1 Step 1 – Develop a concourse

The communication about a particular topic, known as a concourse of statements was gleaned from responses to open-ended questions and interviews from participants during the first phase of this study. The statements represent the breadth of discourse on the topic (van Exel & de Graff 2005). The communication on how to best introduce new technology into control rooms produced a concourse of 170 statements. The range of communication included the following topics:

- technology catalysts, innovation and selection;
- scope and achieving deliverables;
- consideration of constraints;
- product design, compatibility, usability and contextual concerns;
- the design process and practices;
- project management, leadership, practices and product validation;
- involvement of stakeholders and decision-making;
- regulation, safety, productivity and impact concerns; and

- user acceptance, technology adoption, training and implementation

The concourse contained variations of thought in nine areas as displayed in Table 3:5.

Table 3:5 Concourse topic themes

Topic Theme	Description
Innovation	Innovation and the impact new technology will have
Safety	Safety and risk management
Productivity	Benefits of increased productivity
User concerns	Concerns around change, adaptability and technology acceptance
Consultation	Opportunity to evaluate based on organisational culture, communication
Design process	Design process and who should be involved
Quality	Technology attributes, including quality and final outcome
Constraints	Impact of constraints
Support	Level and type of support to achieve success

3.4.2 Step 2a – Establish the Q-sample (Pilot study)

Not all statements in the concourse need to be included in the Q-study. Rather, the Q-sample (i.e. sample of statements) is a representation of the communication on the topic (Brown 1980; van Exel & de Graaf 2005). Therefore, 47 statements were drawn inductively from the qualitative data captured in the first research phase, to represent a broad sampling of matters where natural variations of thought (themes or dimensions) emerged from the concourse. The pilot study was also used to pick up any confusion over the intent of a statement, any other problems and to test instrument suitability. Findings from the pilot are discussed later in this section.

3.4.2.1 Research instrument

The ideal way to collect data for Q-studies is to conduct face-to-face Q-sorts (using cards) and interviews, to allow for observation and greater understanding and empathy (Brown 1980). However, many control-room technologies are designed by international companies and therefore international participation was deemed desirable and more reflective of general practice. To capture participation from countries in both the northern and southern hemispheres, an online Q-sorting/interview process was employed. Due to the limitation of not being present during the statement sorting process, interviews in the form of open-

ended questions included in the survey captured immediate feelings and thoughts about their statement ranking choices, while follow-up emails continued the interview process until final solutions were developed.

The online instrument used was Q-Assessor, an automated web-based application for Q data collection, management and analysis activities (Reber, Kaufman & Cropp 2000). Since Q-Assessor was in beta testing stage at the time of this study, technical concerns existed for the researcher. Therefore, a pilot study was conducted to examine aspects of technical reliability to ensure data would not be lost or corrupted and whether participants had any difficulty completing the survey. Aspects of interest included: (1) technical reliability – was Q-Assessor glitch free and could any data get lost?; (2) independence - can participants perform the task of sorting statements and complete the survey without the aid of the researcher?, as is the recommended practice (Brown 1980); (3) usability – did participants have trouble sorting and ranking statements using the 'select and move' technique?; and finally, (4) clarity - were all statements expressed in such a way to be clearly understood and considered applicable to the study?

After five demographic questions, two tasks were required of participants. Participants were asked to perform a statement sorting task (Q-sort) and to respond to an online interview in the form of open-ended questions. The process is described below:

1. **Demographic questions** – participants were asked to complete five demographic questions about their age, gender, experience, role and industry.
2. **The Q-sort**
    a. A short description of the study was used to set the context: 'this study explores the introduction of new technologies into cognitively complex environments, such as: air traffic control, railway network control, and electric power production and distribution centres, where safety is critical'.
    b. Participants were asked to rate their level of agreement to 47 statements according to the 'umbrella' question: 'What contributes to the best outcome when introducing new control room technologies?' This represented the condition of instruction.

c. To begin sorting, participants were instructed to divide all statements into three bins, namely: ‘agree’, ‘disagree’ and ‘neither agree nor disagree’.
d. The next stage of sorting involved ranking statements in accordance with a level of agreement according to the quasi-distribution bell-curve built into the system. The distribution spread was set at +/-5 at the following levels: (11, 11, 9, 7, 5, 3, 1) as illustrated in Figure 3:4.
e. Before progressing to the interview questions, participants were given an opportunity to change their responses.

3. **Interview** –Participants were asked to comment on the statement(s) they most agreed with, the statement(s) they least agreed with, and to add any additional comments if they so desired. Responses allowed for short 50 to 100-word responses.

Six participants (*n* = 6) were selected to represent the intended profile of stakeholders of control-room technology. Participants either worked with or were known by the researcher and convenience sampling was therefore used to gain participation in the pilot study. Convenience sampling is commonly practised when conducting pilot studies, as it allows the researcher to obtain basic data quickly (Explorable 2015). Five of the six participants held leading positions in their organisation or were independent consultants.

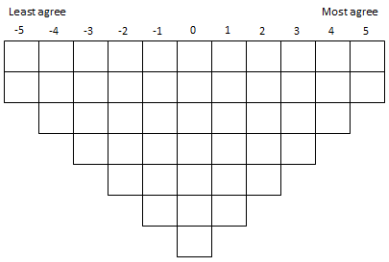

Figure 3:4 Pilot distribution grid

Communication with participants was managed within Q-Assessor. Three email messages were set up, including: an (1) *invitation message* containing an embedded link to the survey (sent on a predetermined date), a (2) *reminder message* containing an embedded link to the survey (automatically sent only if participant had not completed the survey within one week), and (3) *thank you message* (sent upon survey submission) explaining that this portion of the study was complete, but that they may be contacted at a later date to confirm a particular viewpoint.

3.4.2.2 Pilot results and discussion

The outcome of the pilot study resulted in making changes to the actual study. Two weeks following commencement, only two completed responses were received, both of which had been supervised to observe potential problems. This led to concerns over data transmission using Q-Assessor which needed to be investigated. However, after contacting the other four participants to find out what the problem was, they confessed that they had to exit after 30 minutes because the Q-sorting process was taking them too long. Similar results occurred in the pilot study by Jeffares and Skelcher (2011) where researchers presented participants with a Q-set of 64 statements, chosen from a concourse of over 300 statements. However, participants were not willing to sort this many statements. Q-sorting takes the time to properly consider each statement amongst the others and a further three or four minutes needs to be allowed for responses to additional questions to justify sorted choices. A Q-sort with 88 statements was found to take around 60 minutes to complete (Butler et al. 2014), while a 40 statement Q-sort took between 30 to 40 minutes (Kim & Lee 2015). Before choosing to randomly reduce the concourse, researchers advise to systematically reduce the Q-sample in a structured manner to ensure that the reduced Q-sample equally represents the key dimensions of the discourse, an idea developed by Dryzek and Berejikian (1993).

Piloted participants also commented that the statements themselves were fine, but in some cases repetitive. The recommendation to reduce the number of statements was thus accepted. While 30 to 60 have been described as a manageable Q-set (Jeffares & Skelcher 2011), studies with smaller Q-sets have been used such as the 20 statement Q-sort used by Spencer and Pisha (2015). However, small Q-sets are more difficult to interpret and analysis will, therefore, take longer (Jeffares 2015). In contemplating whether to have a Q-set less than 30, it is worth noting advice given by Brown (1993) who affirms that the Q-set is not the main focus since it only represents a miniature version of the larger concourse. Rather, more importantly, are the meanings (i.e. likes and dislikes and qualitative comments) that are attributed to these statements (Watts & Stenner 2005). Therefore, the piloted Q-set was reduced in a systematic and structured way for the 'actual' study.

Regarding the test for technical reliability, participants commented that they could complete the survey without difficulty due to helpful guidance built into Q-Assessor. One

participant commented that the 'select and move' technique for sorting was a little 'handraulic'. That is, the process was not as smooth as other applications that use a 'drag and drop' process. Nevertheless, all participants commented that the 'select and move' process for sorting was not difficult and did not require assistance from the researcher. A practice run on data analysis and report retrieval worked as anticipated. Therefore, the aspects being tested proved Q-Assessor to be a reliable and suitable online instrument for this research project. Furthermore, Q-Assessor offered the highest level of security amongst available online Q-technique options due to being password protected and given its automatic transfer of data from collection through to analysis, a feature that is not the case with other applications, such as Flash Q (for sorting) and PQMethod (for analysis).

3.4.3 Step 2b – Establish the Q-sample (Actual study)

The selection of the Q-sample has been described as a critical step in Q Methodology (Paige & Morin 2016). Results from the pilot study suggested that a smaller Q-sample would be better received by the desired participants. Therefore, to ensure that each of the dimensions that emerged from the concourse was represented in the Q-sample the statements were selected in a roughly structured manner. This is common practice for inductively established concourses to ensure even representation is captured of the themes or dimensions of the concourse (Hurd & Brown 2005). To reduce the number of statements without losing representation of the concourse, statements were selected by applying the Efficiency-Thoroughness Trade-Off (ETTO) principle. In relation to safety, the ETTO theory explains the common phenomenon whereby all business activity involves a trade-off between thoroughness and efficiency and, without the trade-off, total thoroughness would lead eventually to total loss of efficiency (Hollnagel 2009). Therefore, the ETTO theory was deemed useful to statement selection and thus used to achieve a balance between a number of statements (efficiency) and breadth of communication (thoroughness). Two statements for each of the nine dimensions within the concourse were selected, resulting in a Q-sample solution of 18 statements (N = (2)(9) = 18). Table 3:6 shows the nine topic dimensions with their associated statements used in this study.

Table 3:6 Q-set structure using the efficiency-thoroughness trade-off theory

No.	Dimension[a]	Efficiency	Thoroughness

No.	Dimension[a]	Efficiency	Thoroughness
1	Innovation	Businesses will benefit from technologies that anticipate future trends	The more job tasks change, due to new technology, the higher the level of risk
2	Safety	Business sustainability takes priority over safety concerns	Unless something can be done safely, it should not be done at all
3	Productivity	Standardising technologies across all sites will improve productivity	Greater productivity results when end-user preferences are incorporated into the design
4	User concerns	End users do not need to be consulted when Human Factors professionals are involved in the design	Safer outcomes result when Human Factors professionals are involved in new technology projects
5	Consultation	End users are not interested in participating in the design phase of new technologies	When introducing new technology, managers must consult with the intended users
6	Design process	End users make unreasonable demands when they are involved in the design of new technology	End users need to be involved at the initial design phase of the new technology
7	Quality	Fine tuning the technology is not necessary as people are very adaptable	To avoid problems, 'in-house' technical support must be consulted during the initial design phase
8	Constraints	Meeting deadlines can impact the design quality of new technologies	Newly created technologies are safer than modifying 'off the shelf' or existing technologies
9	Support	Online training is as effective as hands-on learning prior to implementation	During implementation, an 'expert' on the new technology must be available on site

[a]Note: Some topics are multidimensional and thus may seem to overlap

3.4.4 Step 3 - Select the participants (P-set)

Participants for phase two of this study were drawn from the participant organisations and delegates from conferences, as with phase one, although with one exception that recent members of a design project external to existing participant organisations were also invited to participate, interviewees excluded. This decision was made to achieve even representation across the various stakeholder groups and to capture participants who were actively involved in new control-room technology projects. Thus, sampling was purposive to achieve representation of each stakeholder group, namely: managers, designers, evaluators and end users of control-room technology. As with the first phase of the study, consent was assumed upon completion of the survey.

3.4.5 Step 4 – Perform the Q-sort

Research Instrument development

Q-Assessor was used to manage the Q-survey. Known email addresses of participants were loaded into the study's address book in Q-Assessor ready for the automated email messages. The Q-survey contained all the same features and questions as with the pilot, with one exception being the list of statements to be sorted, which were reduced to 18 (Q-set N = (2)(9) = 18; m = 1 replication each). The distribution for sorting statements was set at (+/-3) with levels set at 7, 5, 3, and 3, as illustrated in Figure 3:5. A relatively flat distribution was chosen because the participants were considered to be knowledgeable on the topic under investigation. The procedure for performing the Q-sort followed the same process as for the pilot study. However, this time, 18 statements were used and thus a smaller quasi-normal bell-curve distribution was established. Appendix A3:8 contains the list of 47 statements used in the pilot study and the 18 used in the study for phase two.

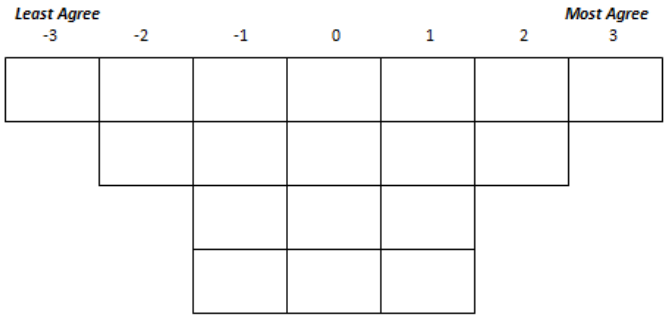

Figure 3:5 Q-sort grid for statement distribution

3.4.6 Step 5 – Analysis and interpretation

The analysis was primarily conducted within Q-Assessor. However, PQMethod was used to analyse the data to capture a scatterplot of the cluster groupings and to develop a correlation matrix of the Q-sorts, two items that Q-Assessor, at the time of this study, did not produce. Once factors emerged from participant Q-sorts, consensus and distinguishing statements together with interview (i.e. open-ended question) responses were examined to give meaning to the Q-sort. From this data, the viewpoint narratives were drafted. Drafted narratives were assigned a representative viewpoint name, and two participants who scored

closest to the factor viewpoint were sent an email and invited to comment on the viewpoint descriptor closest to their personal viewpoint.

Final interpretation of viewpoints (factors) was based on a number of factors, namely: (1) the normalised Q-sort assigned to each factor, (2) their distinguishing statements, (3) participant interview responses, and (4) feedback on viewpoint descriptors. Therefore, based on comments made by high-scoring participants, viewpoints were refined and research questions were visited for interpretation of the analysis. A summary of the Q-study elements is located in Appendix A3.9, while the results of this analysis are presented in Chapter 5. A summary of study elements for phase one and two can be found in Appendix A3.9.

3.5 Ethical Approval

The research conducted for this thesis was in accordance with the methods, instruments and recruitment strategies approved by the Human Research Ethics Committee (HREC) of Central Queensland University. The Project Number is H10/07-129.

Chapter 4: Results and Analyses – Phase One

4.1 Introduction

This chapter presents the results of the first research phase (Figure 4:1). Mixed methods were used to address the first research objective, *to explore the underlying factors that influence end-user technology adoption in a modern control-room environment.*

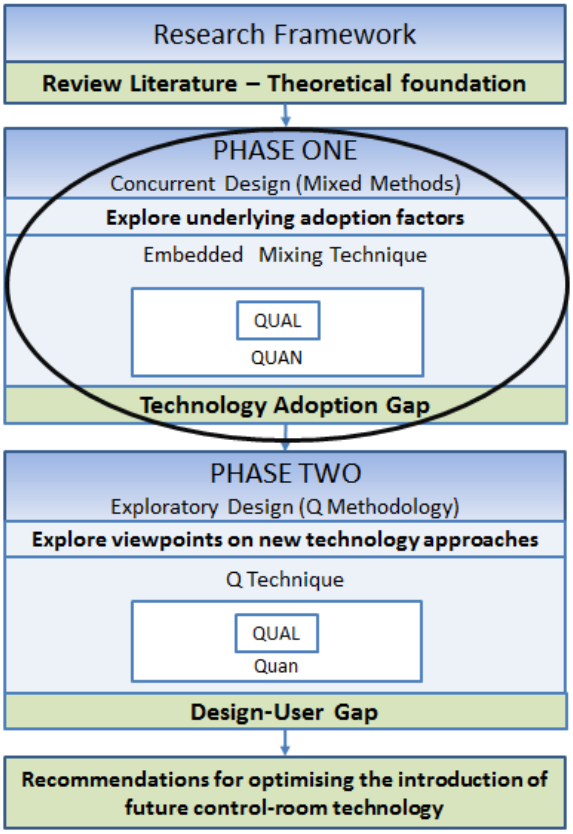

Figure 4:1 Research framework – phase one

The chapter commences with demographic results for both data collection sources (survey and interviews), followed by the results for each of the three associated research questions. Comments by participants have been cited where they clarify interpretation and indicated in-text or indented between the texts. Participant identification is bracketed to distinguish the source of the quote and for survey participants, stakeholder type. Since interviewees were all end users just the interview number is provided. Thus, interviewee number 27 will be expressed as [Interview 27], while survey respondent number 311 will be expressed as [Survey ID: 311 – Evaluator]. In this way, it is possible to distinguish the perspective in which

comments are made. To secure participant anonymity, all reference to information that will help to identify the individual has been removed. Similarly, all controllers regardless of sex will be referred to in the masculine gender. See Appendix A3.3 and Appendix A3.4 for a copy of the survey and interview questions.

4.2 Survey Demographics

4.2.1 Participant response levels

A total of 438 respondents participated in the survey questionnaire portion of the study. Since not all questions were applicable to all participants, completion levels varied. Therefore, 438 (100%) completed the demographic questions (Section 1) and rated their level of agreement to the importance of end-user input (Section 2). For Section 3 covering the risks associated with new technology and adoption, 315 (72%) participants completed the first open-ended question on actions to increase system success while 309 (71%) completed the second question requesting reasons for failed adoption. Finally, 402 (92%) participants completed Section 4 related to factors that impact the adoption of new technologies.

4.2.2 Geographical representation

Participants from forty-five countries were represented in the population sample for this study, as illustrated in Figure 4:2. Individuals from the Australia/New Zealand and Singapore region represented the highest percentage (40%) of respondents, while individuals from the developing world represented the smallest percentage (15%).

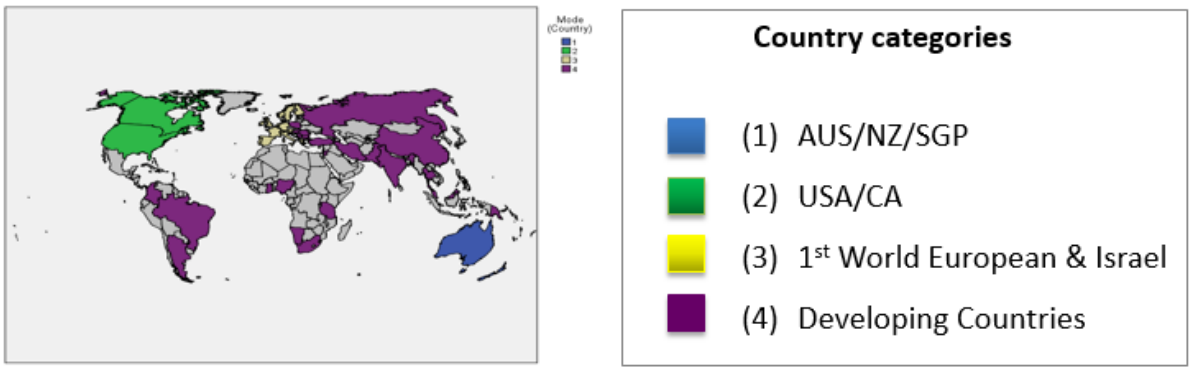

Figure 4:2 Population sample per country group

4.2.3 Industry representation

Transport companies (air, rail, road and maritime) represented the highest percentage (41%) per industry participation, followed by technology development and supply companies representing 21% of the population sample, as illustrated in Figure 4:3

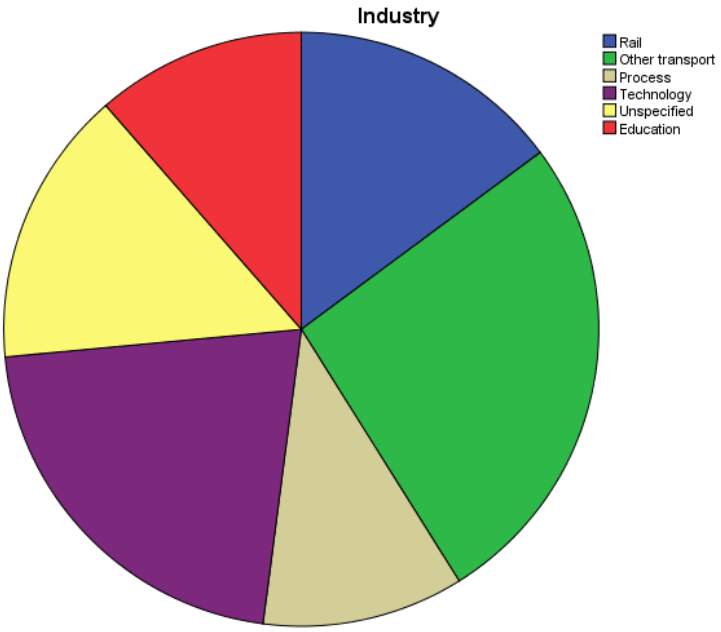

Figure 4:3 Industry representation

4.2.4 Business size representation

The population sample mainly comprised of workers from medium to large businesses (>150 employees) with 64 percent, and workers within hierarchical organisational structures at 57 percent. This outcome may reflect changes within organisations that recognise the benefits of networking and linear structures (Bryan & Joyce 2005). Additionally, differences in organisational structure may reflect that many stakeholders (project managers, engineers, safety and human factors professionals) freelance or consult from small businesses (Consult Australia 2015; Forbes 2013; Human Factors and Ergonomics Society 2015; Safety Institute of Australia 2015).

4.2.5 Stakeholder roles representation

Responses were categorised into stakeholder groups comprising of the following roles: *managers* (organisational, financial or project decision makers), *designers* (architects, IT developers, industrial engineers, technology suppliers and manufacturers), e*valuators*

(safety, quality, research and human factors specialists) and *end users* (staff who directly use technology to meet work tasks, such as: controllers, operators, control support staff, and those who train operational staff). Of the total respondents, 18% indicated that they had been a control room operator at some time. Representation percentages are as follows: Managers (14%), Designers (27%), Evaluators (42%), and End Users (18%), as displayed in Table 4:1.

Table 4:1 Stakeholder group representation

Stakeholder group		Frequency	Percent	Cumulative Percent
Valid	Manager	60	13.7	13.7
	Designer	117	26.7	40.4
	Evaluator	183	41.8	82.2
	End user	78	17.8	100.0
	Total	438	100.0	

4.2.6 Gender representation

Participants in this study were predominantly male (76%). This percentage generally reflects the transportation and technology industries. The findings are similar to current industry employment trends. An Australian study on the rail industry reported that 80% of total workers were men (Munro 2014). Similarly, recent figures in Australia for transport and logistics reported that men represented 76.7% of the total workforce in 2006 (Apelbaum Consulting Group 2008). Significant gender differences also exist in the technology industry, with few female students electing to study computer science. A study in the United Kingdom for 2012/13 found that few female students undertake engineering and technology courses (31.2%), and even less study computer science (21.1%) (Higher Education Statistics Agency 2014). Occupational health and safety student course enrolments in 2013 at Central Queensland University (2014) represented an almost even split, with females slightly higher (51%) than males (49%). Figures on gender differences amongst human factors professionals were not found. However, a gender bias may exist in this study, and amongst the professional roles chosen to be examined in this study.

4.2.7 Educational representation

The participants in this study were more highly qualified than averages across global populations, with three-quarters (75.4%) possessing a tertiary level qualification of an associate Degree or higher. General population percentages across participating countries are much lower as shown in Figure 4:4, with the highest national percentage of tertiary education being 54 percent for the Russian Federation in 2012 (The Organisation for Economic Co-operation and Development (OECD) 2014). Possible explanations for the high level of qualifications represented in this study group are that individuals who work with complex systems and/or for safety-critical organisations require higher levels of knowledge or that these challenging roles attract people with higher qualifications than do other types of work.

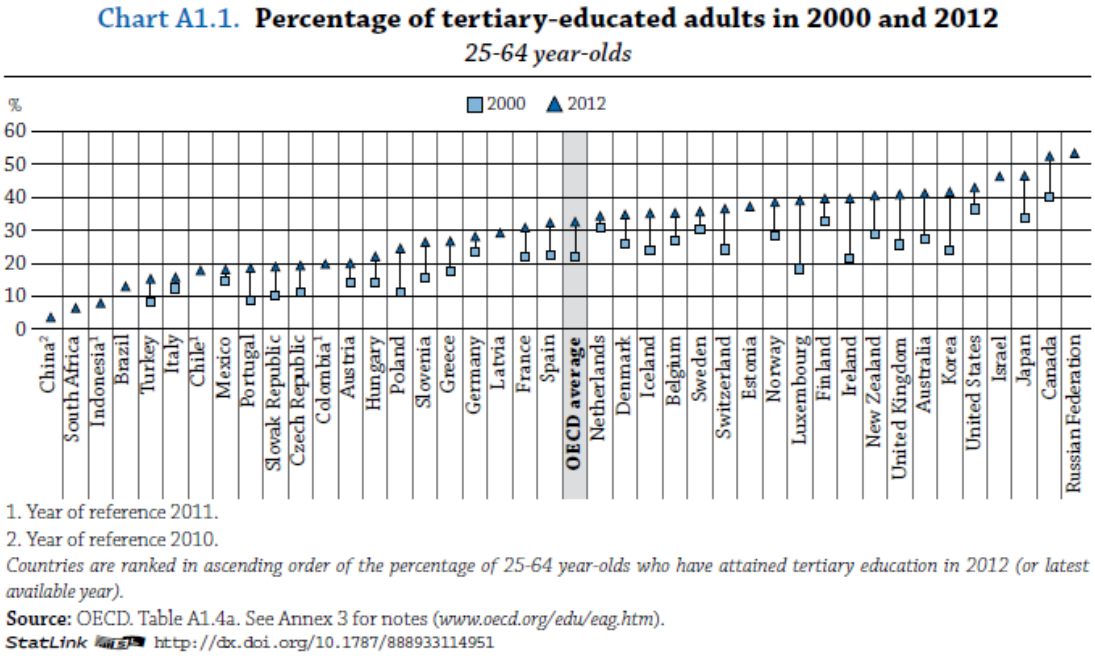

Figure 4:4 Global representation of tertiary education attainment 2012

Source: The Organisation for Economic Cooperation and Development (OECD) (2014, p. 30)

4.2.8 Organisational structure

Most participants (*N*=249, 57%) worked for an organisation with a hierarchical structure. Participants from organisations with linear (*N*=75, 17%) and matrix (*N*=76, 17%) type structures were considerably less, while few participants worked for organisations with a networking structure (*N*=38, 9%).

4.2.9 Age representation

Most participants (*N*=254, 58%) were aged 36 to 55 years. Few participants were younger than 25 years (*N*=10, 2%) and the remainder fell in the range between 25 and 35 (*N*=99, 23%) and those over 55 years of age (*N*=75, 17%).

4.3 Interview Demographics

A total of 36 controllers volunteered to participate in the semi-structured interviews. Interviews came to a natural end after 34 minutes on average, and thus the estimated 30-minute duration is considered appropriate for this study. Controllers as indicated in Plates 4: 1 to 4:6 came from five organisations and represented three industry groups: rail, aviation and power generation/distribution. Participant organisations were: Queensland Rail (QR) National, Rockhampton; Stanwell Power Station, Rockhampton; Ergon Energy, Rockhampton; AirServices, Rockhampton and Brisbane; and Metro Trains, Melbourne.

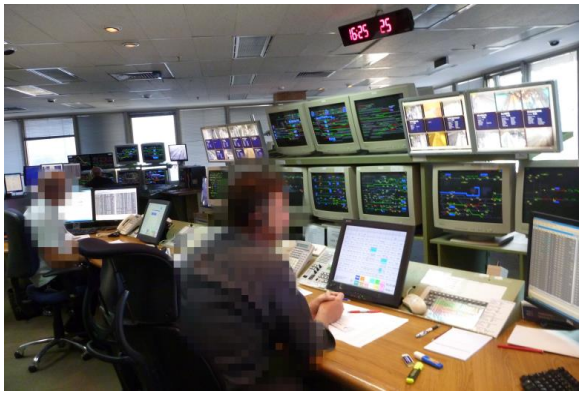

Plate 4:1 Network Control Desk

Plate 4:2 Signaller Control Desk

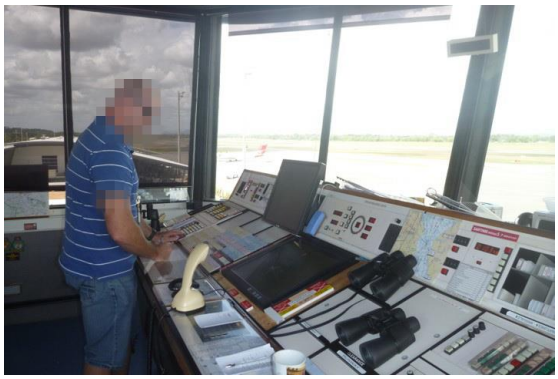

Plate 4:3 Air Traffic Control Tower Desk

Plate 4:4 Air Traffic Control Radar Desk

Plate 4:5 Power Generation Control Room

Source: Williams (2014)

Plate 4:6 Power Distribution Centre

Source: Power Stream (2015)

The participant work environments for the rail and aviation participants are shown in Plates 4:1 to 4:4. No pictures were allowed to be taken of the power control centres. Therefore, plates 4:5 and 4:6 have been sourced from the web and provide examples similar to those visited. The power generation control room was quiet, light and manned by two plant technicians. In contrast, the distribution centre was noisy, dark and crowded with many network operators that were frequently speaking on the telephone. These images show the variation and complexities within the control room environments of participating organisations.

The interviewed participants actively held positions within the control rooms. Depending on the organisation, the term 'controller' was expressed in a number of ways: Signalmen (*N*=3), Network Train Controllers (*N*=7), Electrical Train Operator (*N*=1), Plant Technicians (*N*=5), Network Operators (*N*=5), Air Traffic Controllers (*N*=14), and a relief Network Controller with 38 years' experience primarily working as the Control Board Trainer (*N*=1).

A fairly even representation of industries was achieved. Rail and Air traffic controllers equally represented the highest percentage of participants (36%, *N* = 13 each), while power plant technicians and network operators were slightly less (28%, *N* = 10). Across all participants, controllers were typically older in age, primarily 35 years plus (Rail = 92%, Air = 73%, Power = 80%) and male dominated (Male = 95%, Female = 5%). A significant (76%) number of participants were very experienced in their field (*N* = 27, *M* = 17.08, *SD* = 10.24,

min = 1, *max* = 38), having worked ten or more years in a control room setting. In total, the group represented 615 years of experience working in control room environments.

While experience is important, it was also critical to collect the experiences of new controllers as they are likely to have been through the technology adoption process fairly recently and may have different perspectives to their more seasoned colleagues. Table 4:2 shows the various levels of interviewee experience per industry.

Table 4:2 Level of experience of participants per industry represented

Level of experience represented in this study by industry			
	Very experienced [a]	Experienced [b]	Novice [c]
Network Rail	11	0	2
Air traffic	10	2	1
Power Processing & Distribution	6	4	0
Total	27	6	3

[a] 10 or more years' experience; [b] Between 3 and 9 years' experience; [c] Less than 3 years' experience

4.4 Research Question 1

- **Research Question 1:** *What technology adoption concerns do stakeholders of control-room technology have and do these opinions differ?*

To be able to answer the above question, quantitative responses from the survey were subjected to a number of statistical techniques. Descriptive statistics were undertaken to observe the data for any obvious differences of opinion (as reported in Sections 4.4.1 and 4.4.2). To explore any variance of opinion between stakeholder groups, General Linear Model (GLM) Multivariate and post hoc analyses were performed (as reported in Section 4.4.3). To provide greater meaning to these findings, qualitative data drawn from both the survey and the interviews was embedded into the results, as per the research design established in Chapter 3 (Figure 3:1).

4.4.1 Descriptive analysis

Participants were asked to rate their level of agreement to a list of statements using the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree. Observational examination of average levels of agreement (i.e. mean scores) per

stakeholder type across all survey items showed that most stakeholders agreed or highly agreed with all but one survey item.

4.4.1.1 Gender

The only variable that stakeholders as a group felt neutral about in regards to its influence on technology adoption was *Gender of the employee* (M = 2.84, SD = 1.05, Min. = 1, Max. = 5). Mean score comparisons between stakeholder groups revealed very similar opinions (Managers M = 2.93, Designers M = 2.78, Evaluators M = 2.87, End Users M = 2.78), indicating very slight disagreement that gender influences adoption. This finding aligns with scholars who found no gender differences toward prospective information communication technology use by teachers (Sang et al. 2010). Study findings also align with scholars who found no gender differences amongst air traffic controller trainees who were learning how to use traffic control technology (Nye & Collins 1991). However, these results are contrary to the vast majority of studies where authors found that gender differences did exist (Huang, Lu & Wong 2003; Padilla-Melendex, Aguila-Obra & Garrido-Morena 2013; Venkatesh et al. 2003). Mandatory technology adoption in control rooms may explain why gender is not an issue in a control-room environment. In support of quantitative findings, qualitative data showed that gender differences were not regarded as having an effect on a controller's ability to adopt. However, gender differences were noted in regards to making sense of maps for directions of travel, as expressed by this controller:

> So the ladies don't pick up as quickly on the maps and direction of travel as quickly as the men do. For instance, I can face south and the top of the page to me is north, even though that way is south, the top of the page is north, so I go up the page to be north. Whereas, I have noted that ladies have to turn the map upside down to make it run right. So that's a difference between men and ladies. So it's the way we're built. But I know that and I can help the ladies through with what they want to see… But the technology itself, once everyone is taught to use it, they seem to cope with it pretty well. [Interview 06]

4.4.1.2 Top five influential factors

Stakeholders agreed most strongly with five technology adoption variables, with the top influential factor for technology adoption success identified as: *It is important to consult and seek feedback from intended users when implementing new technology* (M = 4.7, SD =0.58, Min. = 1, Max. = 5). Second from the top was: *The new technology's ability to interact with existing systems* (M = 4.40, SD = .65, Min. = 2, Max. = 5), followed by *Employee openness to*

change (M = 4.39, SD = .64, Min. = 2, Max. = 5), *End user's need to understand why the new technology is introduced* (M = 4.31, SD = .77, Min. = 2, Max. = 5), and *Managerial support of additional resources (e.g. time, training).* (M = 4.31, SD = .65, Min. = 2, Max. = 5).

4.4.1.2.1 User input

Of all the variables selected for this study, end-user input via consultation and feedback processes possibly offers the greatest opportunity for users to make sense of the new technology and therefore to begin the adoption process. The knowledge and experience gained from exposure to the new technology would allow end users the chance to check plausible meanings as they develop, and thus develop a more realistic view of the developing technology.

Of the 438 who responded to this statement (Appendix A3.3, Question 10.1), four (0.9%) rated that they strongly disagreed, seven (1.6%) felt neutral, 88 (20%) agreed, while the vast majority (*N*=339, 77%) strongly agreed. Of the group who disagreed, only two participants had received feedback from end users and opinions were mixed. One Evaluator rated this feedback as not valuable, while a Designer rated the feedback as valuable. Observational examination of the average level of agreement (i.e. mean scores) per stakeholder type showed that most stakeholders agreed or highly agreed that it is important to obtain intended user inputs (N=427, 97.5%). Out of a possible score of 5 indicating highly agree, similar averages were found: Managers (M =4.62), Designers (M = 4.73), Evaluators (M = 4.77), and End Users (M = 4.74), as displayed in Table 4:3.

Table 4:3 Stakeholder opinion averages on the importance of intended user input

Importance of user input	Mean	Std. Error	Std. Deviation	Opinion
Evaluators	4.77	0.04	0.58	Very Important
End users	4.74	0.07	0.63	Very Important
Designers	4.73	0.05	0.57	Very Important
Managers	4.62	0.07	0.56	Very Important

The 355 (81%) participants who indicated that they obtained feedback from the end user rated the input received as valuable, 27 (6%) were neutral about input value, and four (1%) participants indicated that they did not find end-user input valuable, although they agreed to the concept. The stakeholders who did not find end-user input valuable included: Evaluators (N=2), a Designer (N = 1) and an End User (N=1). However, considering the number of participants these results seem negligible (i.e. 0.46% and 0.2% respectively).

To know whether these small percentages have any statistical significance further analysis was necessary. A one-way between-groups analysis of variance with posthoc tests was conducted. Stakeholders were divided into the four stakeholder groups according to their role (Group 1: Managers; Group 2: Designers; Group 3: Evaluators; and Group 4: End Users). Results found that there was no statistically significant variance between the four stakeholder groups at the $p<.05$ level regarding the *importance to consult and obtain feedback from intended users*: [$F(3,433)=0.975$, $p=.41$]; and regarding the *value of user feedback* [$F(3,382)=0.165$, $p=.92$]. While no statistical variance was found between the stakeholder groups, the results show that Managers rated the importance of user input on new technology projects slightly less than did other stakeholder groups, as displayed in Table 4:3. Averages across the two variables regarding the importance and value of end-user inputs related to new technology indicate that stakeholders view these activities to be highly relevant, as displayed in Table 4:4.

Table 4:4 Stakeholder opinion averages on the importance and value of user input

Variable	Scale	Mean	Std. Error	Std. Deviation	Opinion
It is important to consult and obtain feedback from intended users	1 - 5	4.73	0.03	.583	Very important
End-user input was valuable	1 - 3	2.91	0.02	.322	Highly valuable

Note: a score of 1 for each scale represents the lowest level of agreement

These findings show that the vast majority of participants (97%) consider end-user inputs in the form of consultation and feedback to be highly relevant to the successful introduction, and by extension, adoption of new technology. Furthermore, the value attributed to user input, based on past experience, indicates that most (81%) participants found their input had been valued. These stakeholder opinions on control-room technologies align with most

of the IT literature that reports user input to be critical for success (Abelein, Sharp & Paech 2013; Harris & Weistroffer 2009; Petter, DeLone & McLean 2013).

Not only are control-room technologies increasingly computer-based and thus information driven, they are also growing in complexity. As such, the high relevance of user input indicated by participants in this study also supports the literature that suggests that user input is particularly important for the design of more complex systems (Harris & Weistroffer 2009). Furthermore, these results are consistent with the vast majority of human factors experts who recommend utilisation of user input, and thus their involvement in new projects, to optimise system success (Booher 2005; Pew & Mavor 2007; Proctor & van Zandt 2008; Wilson & Sharples 2015; Wickens et al. 2004).

From these results and support from the literature, it is reasonable to suggest that the overall intent to involve end users in new control-room technology projects is high. It is also reasonable to infer that the small number of participants who indicated that they did not find user input valuable indicates that the way in which users are involved is also important to system success.

4.4.1.2.2 System compatibility

The new technology's ability to interact with existing systems was rated the second top concern for end users and stakeholders alike. This finding is in line with the current literature that recognises that system compatibility can influence system performance (Booher 2005; Ghobakhloo et al. 2012; Luecke 2003; Pew & Mavor 2007) and technology adoption success (Ghobakhloo et al. 2012; Premkumar 2003). The following quote shows the extent of the consequences when system compatibility has not been considered during the design process:

> It [past project] was supposed to be really smart but they couldn't get it to work with our equipment in the field. Because our equipment out in the field is old technology and there are so many different bits of equipment out in the field, old and new, that it just wouldn't work…so they had to scrap it and that cost them 80 to 90 million dollars. So ten years later, what they decided to do was to build another one based along the lines of what we have now. [Interview 33]

4.4.1.2.3 Openness to change

Employee openness to change has been recognised by stakeholders, including end users, as a psychographic trait that can influence the technology adoption process. This finding is

consistent with other studies that have found greater adoption success amongst individuals who fall higher on the openness continuum (Moore 2002; Rogers 2003). Some controllers embrace new technology as expressed here:

> But God I'd like to have new technology. I am so tired of working with 50 year old stuff. [Interview 28]

However, where technology adoption is mandatory and when controllers have had insufficient opportunity to make sense of the new system, they can feel that the change is forced on them and this can lead to resistance to new technology in the control room. Furthermore, new technology may not be utilised to its fullest potential, as these quotes imply:

> Because they [management] view that they conceptualised the idea themselves, they haven't had something imposed on them. [Interview 17]

> Oh yes we have people who resist change, who like to do it the old way or don't like accepting new technology. But I suppose here it is forced upon us because if we don't do it, it is sink or swim. We might not like it, but there are so many things this computer system can do. But some people just chose to operate it and get by that way, [while] some people like to do a few extra things, to make it work a little bit better. [Interview 33]

While the introduction of new technology can offer certain advantages for the organisation, controllers generally do not like change for change sake, as expressed by this controllers:

> I think change is a good thing, but I think change for change sake isn't necessarily a good thing, so you need to be able to distance yourself a bit, but at the same time embrace what is going on. [Interview 21]

4.4.1.2.4 Need to understand why

As part of developing trust in new technology controllers begin to make sense of the new technology by asking questions to grasp an understanding for the reason behind the change, as this controller puts it:

> Well because if something is working, why switch from it, why break it, why do anything to try and increase efficiencies? [Interview 17]

Therefore, safety uncertainty leads to a need for trust in the new system. The first step being*: the need for employees to understand the reason why a particular technology is being introduced*. This is consistent with advice provided by Luecke (2003) who found greater technology adoption success was experienced when intended users understood what was

required of them, and the benefits of that change (Nguyen 2009). In light of resolving doubts about meeting job responsibilities, it can be useful to help the controllers to come to make sense of the technology, and to help them understand the reasons for the change. Otherwise, the controllers cannot make an informed adoption decision. This is particularly so when the current system is perceived to be working well, as expressed by these controllers:

> One of the things that people don't realise is that, you may have heard in the news that we need to update our technologies out of the pre-war days to get [a certain technology] everywhere, but the procedural system we use is generally very, very safe and it works. In the right weather conditions it means it can be significantly less restrictive to industry, believe it or not. [Interview 20]

> I think if you can understand why things are happening then it is a lot easier to accept. And most of the people, the whole time I've been on the project, I don't tell people, 'this is what we are doing', it's 'the reason we are doing this is the system will do this", if they can see why then most people are happy to give it a go. [Interview 21]

> If you explain why! You know, if somebody says, 'we are going to do this, it's better,' you think, 'Alright okay I'll go with that.' But if they say, 'this has changed', you go 'why it's worked for 30 years this way, you think this is going to be better?' Maybe, maybe not! [Interview 04]

Controllers also acknowledge that experience with the new technology helps them get to know the technology better. Experience also helps them to become more accepting of it, as these controllers share:

> Some people thought it was great, while other people are just holding onto [the old way], "I've been doing it this way for so long" and they didn't want to leave the old system. We found that after about a month on this [new] system, people didn't want to go back. [Interview 12]

> Generally the technology might look a bit daunting at first, but then those that fought it generally end up using it to its best advantage anyway. [Interview 03]

Not all reasons for a change are difficult to grasp. For instance, technology that is no longer supported by manufacturers makes a very compelling case for seeking new technology, as explained by these controllers:

> Another one is you just can't get the bits for it anymore, it's redundant, they don't manufacture it anymore, they don't even make the spare parts for it anymore, so at some point in time you have to upgrade because it's either costing a lot of money to get parts sourced or made specifically because you can't buy them off the shelf anymore. This upgrade we did here was actually a bitzer. What we upgraded was just the front end just the

> interface. The old automation system that drives the plant is still the one that we started with 18 years ago. [Interview 04]

> Well, like the Europhone is a classic. It is an early 60's icon. It is just the ideal shape for using in the [control room]. It is interesting, they have plenty of the plastic carcasses; you can buy these things in antique shops these days, but the things like the cords, they can't buy, long flexible cords because nobody makes that stuff anymore, so they have difficulty with that. [Interview 32]

However, other reasons for new technology are less obvious. For instance, new technology may be introduced to help the company keep up with changes made to government regulations, as this controller explains:

> Or the existing technology has become old and is no longer meeting the needs. You know it's either not giving you the control you want, because you've got to remember that standards change too. So the system we work in now where we've got a market trading system, that's relatively new. We've been in this system for 10 or 15 years now but earlier than that it didn't exist. You know there was no such thing as a trading system, we didn't have trading screens and we didn't have traders. The regulations we have as to what we've got to provide and what standards we have to stick within get tighter and tighter. Emissions, for instance, the requirements there get tighter and tighter. [Interview 12]

4.4.1.2.5 Additional resources

Stakeholders recognise that *additional resources are required to successfully introduce new technologies* and that managers must allow for this. The recognition that successful technology transfer requires additional resourcing aligns with research conducted by Sawang and Unsworth (2011). The project as a whole requires sufficient funding, as expressed by these participants:

> Not correctly costed therefore implementation of new technology is not fully programmed and supported. [Survey ID: 332 – End User]

> [Need funds] for the technology and the training as well as the lost time in production to adapt. [Survey ID: 162 – Evaluator]

As indicated above, resource considerations include allowing for realistic timeframes that do not rush the project detrimentally (Love et al. 2005), and to allow for adequate training for users (Seyal & Pijpers 2004). Timeframes affect design outcomes and the degree of technology adoption achieved, as outlined by these participants when projects fail:

> There is no time to grapple with the novelty. [Survey ID: 53 – Evaluator]

> It is rushed through concept and scope creep. [Survey ID: 311 – Evaluator]

> Make sure time is available to 'play' with the system to become familiar with it prior to formal use. [Survey ID: 216 – Evaluator]

The above comments show that controllers need time to make sense and to appropriately learn and adopt the new technology before being expected to use it in real situations. Past research recognised that additional staff are also required and must be budgeted for if an optimal technology transfer outcome is to be possible (Huber et al. 2009), as also recognised by these participants:

> You need resources to allow groups of people to get away from the work-face to do this sort of thing [small group training] and so that tends not to happen. [Interview 26]

> We certainly need extra [staff], taking out leave and everything like that, you wouldn't need double. If you want to [allow] leave and everything going, then you are going to have to go close to double. Which is a bit of a juggling act because you can't, depending on how long you are going to ghost and that, in the environment we're in you come into OHS and everything like that if people are actually working longer periods and no-one has any leave. Then running a section you run into the actual problems of once it's ghosted everyone wants leave because no-one has had leave for 4 months, so depending on how long we ghost for depends on how many extra people. The biggest drain on resources is going to be when we have a whole bunch of people on the new [system] and a whole bunch of people on the old. Initially and at the end there's not going to be as many people on one, but when we are doubled up there may be a concentrated period for say a three week period where no-one is on leave, no-one is doing anything. So I think in a [control room] this size [8 employees] I think we need about three extra people to do it. But that doesn't really factor in any sickness or anything like that. [Interview 21]

Some of the reasons given for poorly funded projects include:

> Fixed fee basis development and not enough staff and the right staff with the right skills working on the project [Survey ID: 403 – Evaluator/Ergonomist]

> Allowing accountants to control technical decisions (Putt's Law): The choice of 'cheap' in preference to 'actually capable' [Survey ID: 413 – Evaluator/Safety]

> Decision was based primarily on cost saving and not what is best for user. [Survey ID: 432 – Designer/Engineering]

Finally on the topic of resourcing, a lack of appropriate budgeting, and thus inadequate viability studies, can lead to negative reactions particularly in cases where inadequate resourcing has become a common occurrence, as expressed by this controller:

> The things I would look for in a technology are that it's complete. One thing that's been frustrating working in this organisation over the years has been that they'll come up with a plan to do something, and it may be great what they want to do, but invariably it seems to get watered down and it seems to be too expensive and you end up with a bit of a half-

baked thing at the end if you get anything at all and it becomes a daily frustration to work with these systems that are not quite as good as they could have been. [Interview 26]

4.4.2 Top technology adoption factors

To identify the top ten technology adoption factors, the variable regarding 'user input' was included in this analysis. Thus, 22 variables were examined. This study found that control-room technology stakeholders are concerned about technology adoption in control rooms. Only one study variable, *gender of the employee*, was not considered to be an adoption concern. The top ten influential factors that influence technology adoption that concern stakeholders are itemised in Table 4:5.

Table 4:5 Top ten influential technology adoption factors according to end users

*Rank	Technology adoption variable
1	It is important to consult and seek feedback from intended users
2	Technology's ability to interact with existing systems
3	Piloting the new technology before implementation
4	Management support of additional resources (e.g. time, training)
5	Employee openness to change
6	End user's need to understand why the new technology is introduced
7	Employee attitude
8	Shared decision-making between employees and management
9	Unlearning old habits or procedures
10	Level of task/job demand changes to employee's role

*Where a rank of 1 represents the highest

4.4.3 Variance of opinion

A one-way between-groups analysis of variance was conducted for each technology adoption variable, to explore any statistically significant variance of opinion according to stakeholder group. Therefore, *General Linear Model (GLM) Multivariate* and *post hoc* analyses were performed. Results found that there was no statistically significant variance involving all four stakeholder groups at the $p<.05$ level regarding the *need to consult users*: [$F(3,433)=0.975$, $p=.41$]. However, six points of difference were identified across three stakeholder combinations, namely: (1) Designers and Evaluators, (2) Managers and Evaluators and (3) Designers and End Users. These differences were found to be statistically

significant according to Pillai's Trace test of statistical significance ($p<.05$) and Scheffe post hoc tests.

4.4.3.1 Designers and Evaluators

Evaluators agreed more strongly than Designers on three factors that influence end-user technology adoption (1) *Unlearning old habits or procedures* ($F(3, 327) = 4.56$, $p<.05$; M = 4.09, M = 3.98), (2) *The new technology's ability to interact with existing systems* ($F(3, 327) = 2.90$, $p<.05$; M = 4.47, M = 4.23) and (3) *Piloting the new technology before implementation* ($F(3, 327) = 4.51$, $p<.05$; M = 4.32, M = 4.05), which is also a higher priority for end users (M = 4.48). Each of these statements relates to contextual matters such as: user concerns associated with their ability to learn how to use the system, the technology's compatibility with existing systems, and application in situ.

1. Unlearning

New technology can introduce new work practices. These new ways of working require controllers to unlearn old ways and to adopt new. Designer contracts rarely go beyond user acceptance testing and therefore, although a priority, unlearning old practices is not as high a priority as it might be for Evaluators. Evaluators of systems are concerned about how the end user uses the system, as expressed by this safety professional who recognises that unlearning old ways can put successful technology adoption at risk:

> Non-openness to change and old work habits [Survey ID: 64 – Evaluator]

Controllers also recognise that unlearning old work practices can be problematic, as expressed by this controller:

> What you might find is, and this is all to do with still resisting and not accepting a fact that it's changed. Some people even though the new system might have a different way of doing something some people still try to do it the old way, using the new system. So they are not adopting the new process or new technology, they are still trying to do it the way they did it in the old system, but just using the new system to do it. [Interview 12]

The comment made by this controller, helps to shed more light on why unlearning old practices may be particularly difficult for controllers:

> People will tell you that traditionally, that [controllers] in particular are not receptive to change, and that is probably true for some of it. But what you have to remember is that we

> train long and hard to achieve a very, very particular aim and if we are going to use different methodologies, different technologies or whatever to achieve it, it is a lot more than just saying we'll do it electronically rather than on paper. There's a whole bunch of things to consider. The fact is that we primarily operate with data rather than with interpersonal type relationships so it [new technology] doesn't have the same impact that it would do in other environments, but you need to be cognisant of it. Training is the big thing you know. We just train all the time, we are forever training. [Interview 20]

The above experience shared illustrates that the role of the controller requires extensive and continuous learning that has been practiced for many years. Hence the difficulty of letting go of existing knowledge is consistent with the literature (Becker 2008; Becker, Newton & Sawang 2013; Brod 1984; Ennis 2005). Therefore, it is reasonable to propose that those on design teams need to be mindful and anticipate the impact of designs that cause significant changes to work practices and those that will require substantial levels of new knowledge.

2. System compatibility

As identified earlier, compatibility with existing systems was the top concern across all stakeholders, and as mentioned above, one might expect the assessment of compatibility between system elements would primarily be a concern for an Evaluator. However, the achievement of system compatibility is also a major concern for the design team. Consideration of existing systems is consistent with best practice project management, as a constraint within the enterprise environment (Project Management Institute 2013, p. 29). Thus, context of use and compatibility with existing systems should be taken into account during the planning process to avoid negative project outcomes, as expressed by this manager:

> The fact is the technology itself may not be fit for purpose. It may work perfectly well, but not in the environment / field in which it is introduced. [Survey ID: 307 – Manager]

Furthermore, controllers expressed concerns regarding designs that are incompatible with their existing mental model of how to achieve safe control, and thus stated that designers need to identify what does not need to be changed, as shared by this controller.

> We tried to limit the impacts of the change by in a lot of cases using similar graphics to what we'd had before. They didn't end up looking exactly the same but rather than rebuild the whole system and make all new graphics we tried to reutilise graphics. Because these are fairly simple, they're not overly cluttered, there's not too much information on the screen,

> they don't utilise any fancy novelty things, they are pretty basic and the information is distributed fairly well through them, so we tried to stick with those and not go down the path of creating whole new graphics just for the hell of it. [Interview 12]

The comments shared above illustrate how the design-user gap as expressed by Norman (2004) can be reduced by matching the designer's mental model to that of the users. The statistically significant difference between the Designer and Evaluator stakeholder groups is consistent with the role of an ergonomist. However, there can be serious implications to the design of new technology if ergonomists are not involved in new projects early enough to ensure contextual details are taken into design consideration.

3. Pilot programs

As with system compatibility, the interest in pilot testing of new systems is likely to be a high priority for Evaluators because pilot programs provide a means for them to evaluate how well the new system interacts with users and their needs before it is fully rolled out. Pilot programs are frequently used to test new technology on a small scale to find and resolve problems prior to full-scale deployment. They also offer an opportunity for the actual users to identify design flaws from their perspective (Bansler & Havn 2009). However, it must be noted that no technology is flawless due to the level of variability to be accounted for (Lee & See 2004). Therefore, in low-risk environments, pilot programs are relatively safe to conduct during normal business. However, this is not the case for safety-critical environments. Rather, pilot programs should be conducted 'off-line' and take on more of a real world scenario testing phase. This Designer offers the need to conduct pilot runs but for them to be completed before the product is implemented so that operational safety is not disturbed:

> No pilot runs to develop the technology to an optimum level before line/end-user implementation. [Survey ID: 82 - Designer]

Furthermore, controllers explained that their role in the design phase is quite often to find technical defects, particularly in software logic that they consider should have been resolved before they test it under scenarios. Therefore, pilot tests should be treated as pre-implementation exercises to test how well the product helps the controller to meet work goals, as explained by these participants:

> You've got to test it. No, you've got to test it in an environment that doesn't have a negative impact on what you are using now. [Interview 01]

> Training and pilot tests prior to implementation are to test, not the technology, but the user's perception. [Survey ID: 26 - End User]

Discovery of technical faults can be very disconcerting for controllers and has led to the rejection of past systems as highlighted by the Federal Aviation Administration experience in Chapter 1. When participants were asked about their experiences of how new technology was introduced, few had experienced pilot programs. Of the 36 controllers interviewed, only one could share a pilot experience and this experience was not a pilot program as outlined by Bansler and Havn (2009).

> We've had a... ah..., so we will come in here [new room], they'll turn it on, and they'll probably test it probably on night shift or on the weekends to see if it works. If it doesn't work we'll probably go straight back next door, turn it off, and go straight back next door. And how long that switching will take, it may take a couple of hours to get it over, but I'm sure they will do testing first. [Interview 33]

Rather than a pilot program per se, the transition from old to new system was accomplished with great care to ensure faults were found and fixed before the new system went live, as this controller explains:

> To transfer from the old system to the new system here back in 1999 there were 9 days classroom training, then simulator exercises, then a check and then you went across, and then they'd do what they call shadowing. We'd run the whole thing from the old centre, and then they shadowed (i.e. mimicked) it here [new centre]. Then they flicked the switch and then it would run from here [new centre] but still monitored from the old centre. And that would go for months until they knew there were no glitches they haven't seen; and then they cut across and just go live from here [the new centre]. [Interview 27]

However, all participants recognised that new technology needs to be tested, but the reality is that it is often left to the end user, as identified by this controller:

> And the same thing is for the operators, you have to tell them that everything is not going to be perfect when they first take it over and they're going to have to spend some time righting defects or problems. If they're willing to do that they should get a system that works quite well! And that's pretty much what we did here. [Interview 10]

While using end users to find faults can help to produce a useable system, fault finding can interfere with controller concentration and thus safety. For instance, fault finding has been found to be tedious, adds to workload and can be exhausting for the controller, particularly

if faults are not fixed or reasons for why they are not fixed are not given, and controllers can become very disillusioned and complacent, as these controllers shared:

> Oh, yeah they say they are going to have these reviews and updates and all the rest of it but you get worn down after a while. Some people like sending emails, I don't. If I send one and it doesn't get rectified with that one I just figure, they are not ever going to do it. Now you shouldn't have to continually say, 'this isn't working STILL'. And then, when something comes up about it later, someone will say, 'Ah, hasn't that been fixed yet?' No, I think they have worn me down over the years. I just ignore it, I know it's a problem, but you cope, you get around your problems. You know there is a problem and you say, 'yeah it's happening again', it's happened so many times before 'why put in another report, why put another email in? [Interview 05]

> Personally, I got sick of sending them my feedback. [Interview 14]

Controllers recognise the necessity to test technology before it is implemented, as expressed by this controller:

> You've got to test it. You've got to test it in an environment that doesn't have negative impact on what you are using now. [Interview 01]

However waiting until a pilot program to fix design faults was considered undesirable, as expressed by this controller:

> It's probably too late at that point. [Interview 14]

These results suggest that the role of an Evaluator and hence their priorities can influence End Users in a very direct manner, whereas, Designers have an indirect influence depending on the size of the design-user gap once the new technology is experienced by users in situ.

4.4.3.2 Managers and Evaluators

Managers agreed less strongly than *Evaluators* over two technology adoption factors: (1) the influence of workflow disruption ($F(3, 327) = 2.82$, $p<.05$; M = 4.12, M = 3.78) and regarding (2) shared decision-making between managers and employees ($F(3, 327) = 3.65$, $p<.05$; M = 4.14, M = 3.69).

1. **Workflow disruption**

Management does have concerns over indirect productivity losses as a result of workflow disruption (Love et al. 2005) as expressed by these Designers:

> Conduct a risk assessment and determine compliant risk controls which at least do not reduce productivity, at best improve it. Workers job made more difficult, and/or productivity is reduced. [Survey ID: 129 – Designer]

> When a new technology completely changes the workflow the effects will be a decreasing of performance and efficiency. [Survey ID: 33 – Designer]

However, where safety-critical systems are concerned, workflow disruption has the potential to undermine work quality (Cain & Haque 2008) and is, therefore, a safety concern for Evaluators. Since a large part of an Evaluator's role is concerned with improving how workers interact with their work environment, this would explain their higher priority. Controllers support the level of importance for consideration of workflow disruptions, explained by this controller:

> The moment that the system begins to change, that's when things become distracting to them. [Interview 28]

In a safety-critical work environment, even a small change can become a major source of distraction, as explained by this controller:

> But something as minor as that has actually had some very strong opposition...It's just amazing that something as minor as that actually did have a pretty high impact on my workload initially, making sure that I was keeping it up-to-date… requiring us to look down to update this instead of looking out the window. [Interview 28]

2. Shared decision-making

In regards to shared decision-making, this result may reflect the widely accepted belief that decision making is a key management process (Project Management Institute 2013). However, emergent safety thinking, particularly in safety-critical circumstances, recognises decision-making as a safety concern and argues for more flexible decision-making arrangements allowing decisions to migrate to expertise (Hayes 2006; Weick & Sutcliffe 2007; Woodcock & Au 2013).

Advocates offer that controllers of safety-critical organisations are the most sensitive to operations and should be frequently deferred to for operational decision-making. While deference to expertise in safety-critical environments is strongly recommended by the safety and human factors research communities, managing experts can be challenging (Dekker 2014). Furthermore, subject matter experts that gain informal power may explain why some managers are reluctant to defer to experts for fear of losing effective

collaboration (Girard 2005). Nevertheless, controllers like to be involved in decision-making on matters that impact them.

4.4.3.3 Designers and End Users

This study found that *Designers* are less concerned than *End Users* in regards to *additional resources needed to support end-user adoption of new technologies* ($F(3, 327) = 4.30$, $p<.05$; M = 4.14, M = 4.52). Resources for the successful adoption of new technology involve more than ensuring training needs are met (McLaughlin & Skinner 2000).

In safety-critical environments, it is not surprising that controllers would be concerned about their ability to adopt and to operate the new technology correctly, hence providing a higher priority for them than Designers. However, increasingly there is an expectation that the design team must integrate human factors so that the end user can relate to the technology. There is a great deal of literature that stresses the importance of human-centred or user-centred design approaches (Maguire 2001; Pew & Mavor 2007; Wickens et al. 2004; Wilson & Sharples 2015) and promotes designing in accordance with the user's rather than the designer's mental model (Norman 1983).

Furthermore, it is well established that better-designed technologies, those without a design-user gap, have been found to reduce training needs (Heeks 2006; Heeks, Mundy & Salazar 1999; Wickens et al. 2004). Designs that better suit end users can often be achieved by involving users in project development, and have been found to significantly expedite and increase likely technology adoption (Parker 2012). Additionally, involving users reduces not only the training needs but also the technical support required during implementation (Maguire 2014; Serco Usability Services 2002). Nevertheless, available resources for training can be a particular concern for large projects due to their higher risk of running over budget than small ones (The Standish Group 2013). Consequently, resources for training are often ignored in the project and left to local business units to resource after the new technology has been implemented. However, this practice can put training provision at risk, as explained by this controller:

> It's a budget thing. They spent $40 million on that over 6 [centres] and it's down to like a couple thousand dollars to spend and then [local management] just said 'that's not coming out of my budget you [controllers] find the time [to learn how to use it]. [Interview 27]

While there is a recognised risk to achieve adequate resourcing to support technology adoption of larger projects, larger organisations are often better equipped to ensure adoption occurs. For instance, the technology adoption literature has found that greater adoption success has been achieved in larger organisations (Faria, Fenn & Bruce 2003; Swamidass 2003). Larger organisations often have more resources than smaller organisations (Forman 2005) and can distribute costs associated with new systems more effectively (Astebro 2002; Mathieson, Peacock & Chin 2001). Nevertheless, findings from this study are consistent with the human factors literature, whereby the increased cognitive activity from learning processes increases user workload and hence the need for increased support during technology transfer (Berka et al. 2007).

4.4.4 Summary

This section summarises the answer to the first part of Research Question 1: *What technology adoption concerns do stakeholders of control-room technology have?* Of the list of technology adoption factors used in this study, all but one, the *gender of the employee*, was considered influential to the adoption of control-room technologies. Table 4:6 displays the strength of agreement that control-room technology stakeholders assigned to each factor, ordered from most to least influential.

Table 4:6 Stakeholder opinion of technology adoption factors for control-room environments

Level of Agreement	MEAN	Std. Error	SD	*Min.	*Max.	Survey item
Strongly Agree	4.73	.028	.583	1	5	User input
	4.40	.032	.648	2	5	Technology compatibility
	4.39	.031	.636	2	5	Openness to change
	4.31	.037	.766	2	5	Understand why change
	4.31	.033	.654	2	5	More resources
	4.28	.035	.695	2	5	Pilot test 1st
	4.26	.034	.707	2	5	User Attitude
	4.18	.035	.726	2	5	Unlearning
	4.13	.032	.655	2	5	Job changes
	4.10	.034	.696	2	5	Computer ability
	4.05	.034	.693	1	5	Workflow disruption
	4.05	.041	.826	1	5	Share decisions worker and Manager
Agree	4.00	.041	.817	1	5	Prior tech failure
	3.94	.036	.738	1	5	Influence from others

Level of Agreement	MEAN	Std. Error	SD	*Min.	*Max.	Survey item
	3.91	.040	.808	1	5	Physical environment
	3.81	.042	.871	1	5	Age of employee
	3.74	.047	.965	1	4	Fear job loss
	3.73	.043	.872	1	5	Fear lost control
	3.73	.035	.712	2	5	Support networks
	3.72	.043	.856	1	5	Management structure
	3.48	.045	.905	1	5	Fear of lost job satisfaction
Slightly Disagree	2.84	.056	1.053	1	4	Gender of employee

*where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree & 5 = strongly agree

This section summarises the answer to the second half of Research Question 1, *Do these opinions differ?* Various stakeholder groups varied statistically on some items. These variations are displayed in Table 4:7.

Table 4:7 Technology adoption factors where stakeholders statistically vary in opinion

Stakeholder Attribute	Factors that impact adoption of new technologies	Pillai's Trace test of Statistical sig.	Scheffe posthoc tests Average scores
Role	Unlearning old habits or procedures	F(3, 327) = 4.56, p<.05	Designers & Evaluators (M = 3.98, M = 4.32)
	Level of workflow disruption	F(3, 327) = 2.82, p<.05	Managers & Evaluators (M = 3.78, M = 4.12)
	Piloting the new technology before implementation	F(3, 327) = 4.51, p<.05	Designers & Evaluators and End Users (M = 4.05, M = 4.32, M = 4.48)
	Shared decision-making between employees and management	F(3, 327) = 3.65, p<.05	Manager & Evaluators (M = 3.69, M = 4.14)
	More resources	F(3, 327) = 4.30, p<.05	Designers & End Users (M = 4.14, M = 4.52)
	Technology interoperability	F(3, 327) = 2.90, p<.05	Designers & Evaluators (M = 4.23, M = 4.47)

While significant variance of opinion only related to 6 of the 22 technology adoption variables differences of opinion would nevertheless need to be identified in the planning stages of the design process to ensure all stakeholder perspectives were addressed to ensure associated requirements were taken into consideration (Project Management Institute 2013).

4.5 Research Question 2

- ***Research Question 2***: Does sensemaking play a role in technology adoption and in what way?

After conducting preparatory analysis (Appendix A4.1), 18 technology adoption variables were subjected to confirmatory factor analysis to determine whether sensemaking influences technology adoption. Factor analysis is a statistical technique used to reduce the data into factors containing closely related items. These factors were then examined for sensemaking representation. Once identified, sensemaking factors were subjected to standard multiple regression to determine whether factors could predict likely adoption of new technology. Finally, the strength of predictability was examined through pathway analysis. The preparatory analysis for factor analysis can be found in Appendix A4.1 and outlier test for original data set in Appendix A4.2.

4.5.1 Data ready for factor analysis

a) The analysis was repeated after outliers were removed. Principal component extraction with Direct Oblimin rotation produced a four-factor solution. The results show that technology adoption factors associated with sensemaking explained almost half (49.6%) of the total variance of opinion. The Bartlett's Test of Sphericity disproves the null hypothesis that there are no significant correlations and thereby indicates that the correlations amongst items are significant (KMO = .84, df = 153, $p<.01$).
b) To determine the number of factors to keep, the eigenvalues, scree plot and parallel analysis were considered against theoretical foundations.
c) Based on theory and research, the criteria that best suited the study was the Kaiser's criterion to keep all four factors above a score of 1.0. This decision was supported by the scree plot (Figure 4:5) but not by parallel analysis (Table 4:8).

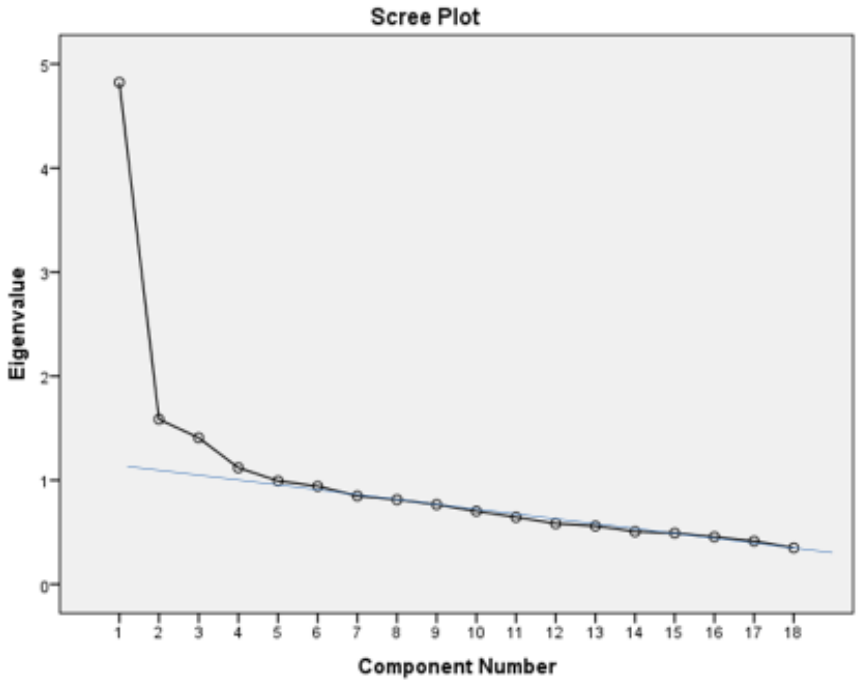

Figure 4:5 PCA Factor Analysis Scree Plot

Table 4:8 Parallel analysis eigenvalue comparisons

Component number	Actual eigenvalue from PCA	Criterion value from parallel analysis[a]	Decision
1	4.823	1.3876	Accept
2	1.585	1.3137	Accept
3	1.407	1.2553	Accept
4	1.119	1.2065	Reject

[a]Calculation according to 397 cases, 18 items and 100 replications

Before assigning names to each factor, items were examined against aspects of sensemaking. Four emergent factors were considered to represent aspects of sensemaking, namely: (1) the creation of plausible meanings, (2) opportunity to enact these plausible meanings to determine a moment of truth and thus reality, (3) the final state of adoption of the individual, and one further factor that represented the emotional response, (4) fear. While emotions, as a variable, are accepted in a number of theoretical areas as being able to influence technology adoption related to attitude (Barki & Harwick 1994; Davis 1986, 1989) and learning (Bandura 1989), to impose a subjective perspective on reality (Hofmann, Ellard & Siegle 2012), and potentially to inappropriately influence behaviour and decision making (Keltner & Horberg 2015), their effect has not, to date, been considered an aspect of

sensemaking. However, since scholars recommend that emotion has a place in sensemaking theory (Maitlis & Sonenshein 2010), this study retained the factor.

The factor analysis correlation matrix can be found in Appendix A4.3, and the factor analysis correlation tables that supported factor interpretation are in Appendix A4.4. The interpretation of the four factors was theory led. The factors are labelled as:

- Factor 1 = *Plausibility*: the plausible meanings an individual creates based on interpretation of new knowledge and understanding.
- Factor 2 = *Fears*: the negative emotional response when the plausible meanings created have either a high degree of uncertainty or are in conflict with personal values, needs or existing mental models.
- Factor 3 = *State*: the state of adoption an individual has achieved on the technology adoption continuum from initial awareness through to expert use (Figure 4:6).
- Factor 4 = *Reality*: the new knowledge and understanding gained from opportunities to conduct reality checks by enacting plausible meanings that develop a more accurate mental model of what the new technology means to the individual.

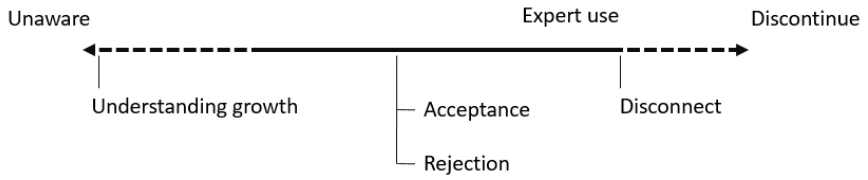

Figure 4:6 Technology adoption continuum when technology use is mandatory

Analysis showed that four distinct factors emerged from the data. The factors explain 49.6 percent of the total variance of stakeholder opinion, as indicated by the correlation matrix. This means that participants indicated that the variables selected for this analysis represent half the variance associated with technology adoption. Factor 1 (*Plausibility)* explains the largest contribution at 26.8 percent, Factor 2 (*Fears)* contributes 8.8 percent, Factor 3 (*State)* contributes to 7.8 percent, and Factor 4 (*Reality)* contributes to 6.2 percent. The items that loaded together represent the common opinion amongst participants.

4.5.2 Survey items analysed for reliability

The survey items were analysed to determine their internal reliability. The results found that internal consistency was considered acceptable for exploratory research purposes. Since technology adoption variables from a sensemaking perspective were being explored in this manner for the first time, the scores achieved in this study were considered suitable for exploratory study. Cronbach alpha values for this study ranged between 0.73 and 0.60. In factor order, they were: *Plausibility* ($\alpha = 0.70$), *Fears* ($\alpha = 0.73$), technology adoption *State* ($\alpha = 0.60$), and *Reality* ($\alpha = 0.70$). Of the 18 survey items analysed, 05 items measure *Plausibility*, 03 measure *Fears*, 04 measure *State* and 06 measure *Reality.* Thus it can be concluded that construct validity was supported. The analysis undertaken to test survey items for internal reliability can be found in Appendix A4.5.

4.5.3 Sensemaking for technology adoption

The factor loadings as displayed in Table A4:4.1 illustrate how sensemaking supports the technology adoption progress. Technology adoption variables that are grouped with the *plausibility* factor provide the individual with opportunities to create plausible meanings. For instance, being involved in decision-making enables the sharing of knowledge and thus greater understanding of the pending new technology. Opportunity to test the technology and consideration of the physical environment also helps to update the mental model to refine plausibility, as does involvement in knowledge sharing via facilitated networks, while the personal desire to understand helps to motivate knowledge seeking. All of these items thus help an individual to update their mental model (explanatory mental framework) of the technology, enhance their competence in use and thus clarify what the technology means to the individually personally (their plausible meaning).

As the plausible meaning develops, a more complete mental model is developed and is thus better able to influence the refinement of enactment activities. As sensemaking proceeds, the individual also progresses through the technology adoption process until competence in use is achieved. At this point, sensemaking lies relatively dormant as the plausible meaning is continually monitored and confirmed through competent use. Until such time that perturbances or deterioration of the interaction between the user and the technology begins to occur and sensemaking once again is triggered to become more active. Therefore,

the level of activity to create a plausible meaning depends on changes to this meaning through the continuance of enactment activities. Just as technology attributes may initially trigger sensemaking (Griffith 1999), changes to meaning may further trigger and reignite sensemaking associated with that particular technology. To help visualise activity levels of sensemaking throughout the system's lifecycle, a hypothetical process was developed by the author based on participant experiences, as shown in Figure 4:7.

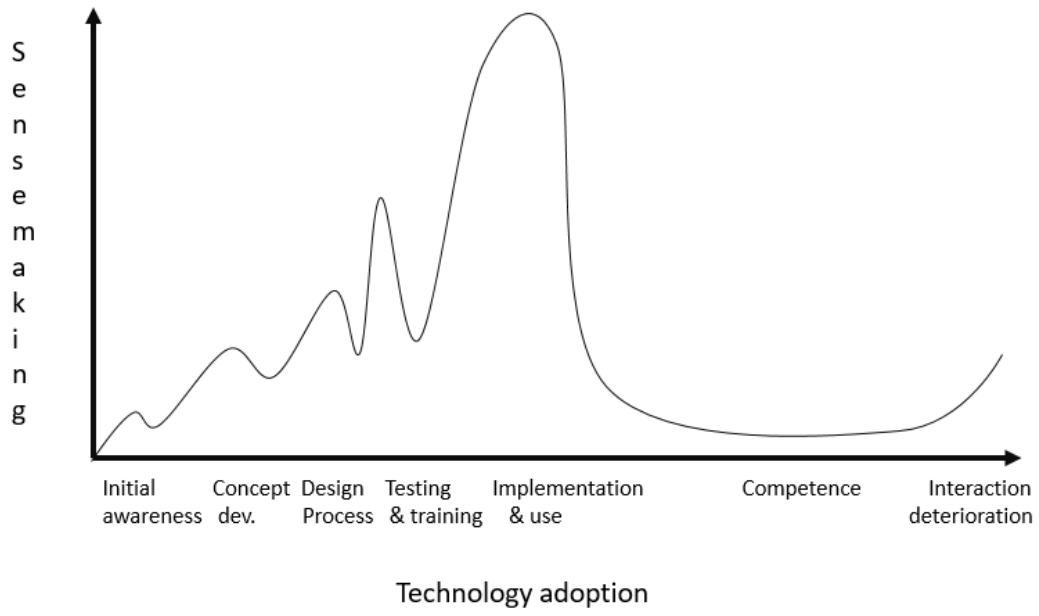

Figure 4:7 Hypothetical sensemaking-adoption correlation within a technology's lifecycle

The variables clustered with the *reality* factor, provide opportunities to enact plausible meanings. For instance, additional resources that allow for user involvement provides an opportunity for end users to test their plausible meanings, while experience with how the technology interacts with existing systems provides an opportunity to test past experience of failed technology adoption and to discard what is not true and thus create new knowledge from the new experience. To realise the extent to which the new technology disrupts workflow, changes to the nature of the job and how these realities fit with existing management structures, policies and practices all allow for that moment of truth as the plausible meaning is enacted and is therefore tested against the existing plausible reality.

Variables clustered with the *fear* factor are personal emotional responses to either a negative realisation of the truth or to a negative plausible meaning that was drawn from other mental explanatory frameworks to fill the void of uncertainty. For instance,

incomplete mental models can lead to unfounded fears that the individual will lose job satisfaction, experience a reduced ability to control operational safety and lose their job on account of the new technology. The truth of these fears cannot be confirmed until the plausible meaning created has been tested through enactment activities. Therefore, until a more accurate mental framework can be developed about these fears, they will remain and have been known to lead to inappropriate behaviour (Keltner & Horberg 2015). Sincesensemaking and technology adoption reside in a social setting, negative emotions can influence the plausible meanings developed by others, and thus may undermine the organisation's technology adoption efforts.

Variables clustered with the factor labelled *state* represent where the individual sits on the technology adoption continuum from awareness to expert skill or beyond. For instance, how open and receptive the individual is towards the change and their attitude toward the pending technology, will determine where they are at in the technology adoption process. This is also true when old practices and knowledge need to be unlearned. An individual's current computer ability can also be an indicator of how far along the technology adoption continuum they may be.

Therefore, while Cronbach alpha scores are modest in industry terms, they are acceptable for explorative research and thus provide a useful baseline against which to refine the variables to better reflect the sensemaking factors. To explore whether sensemaking can predict an individual's technology adoption state, further analysis was undertaken.

4.5.4 Sensemaking's role in technology adoption

To explore the role of sensemaking in regards to technology adoption, sensemaking factors were tested for predictability through *Standard Multiple Regression* analysis. A three-step process was used, as offered by Pallant (2005), to interpret the results. The assumptions were first checked for model integrity, the model was evaluated, followed by its predictability.

The results found that assumptions were not violated and thus the regression model possessed integrity. Examination of the model found sensemaking to be an important predictor of the degree to which an individual comes to adopt new technology, on a

technology adoption continuum from awareness to expert use. The results of the predictability evaluation were statistically significant according to the Analysis of variance (ANOVA) ($F(3,417) = 36.20$, $p<.01$). The results showed that all three variables, *Plausibility, Fears* and *Reality* explained 20.8 percent of an individual's technology Adoption *State.* The analyses performed to test for factor predictability can be found in Appendix A4.6.

The predictive score of 20.8% (R Squared) indicated in the model may seem moderate in comparison to the technology acceptance studies that report percentages around 40 percent (Legris, Ingham & Collerette 2003; Venkatesh & Bala 2008). However, it must be noted that this study did not focus on technology attributes because technology attributes as a predictive factor have been accepted and are thus not further tested in this study. Rather, this study explored the effect of sensemaking on an individual's technology adoption state and therefore breaks new ground for the better understanding of technology adoption in mandatory settings.

In consideration of other studies that explore less common topics, these results are comparable. A recent study explored user personality and resistance to the mandatory use of information systems and found that an individual's perceptions and reactions accounted for 23 percent of uptake (Laumer et al. 2015). While few studies have investigated user resistance, these results were considered good in comparison to other similar studies, such as the effect of personality on perceived usefulness that predicted only 11 percent (Junglas, Johnson & Spitzmuller 2008). Therefore considering the new focus on technology state, rather than on technology intentions, this study has shown some promising results that warrant further investigation. Table 4:9 provides a summary of the regression analyses.

Table 4:9 Summary of regression statistical analyses

[Pearson Correlations, Means, Standard Deviations and Cronbach Alphas for User State Variables]

User experiences	S	R	F	P
Technology Adoption State (S)	1.00			
Reality (R)	.41***	1.00		
Fears (F)	.31***	.36***	1.00	
Plausibility (P)	.34***	.55***	.37***	1.00

User experiences	S	R	F	P
Mean	4.25	4.10	3.66	4.06
Standard Deviation	0.45	0.45	0.74	0.52
Cronbach's Alpha	0.60	0.70	0.73	0.70
Number of variables	4	6	3	5
Sample Size	417	417	417	417

*p<.05, **p<.01, ***p<.001 (according to ANOVA)

To determine the strength of association between sensemaking dimensions, effect sizes are examined and were calculated using G*Power developed by Franz Faul (Faul et al. 2007). Path analysis was then conducted, based on strength of effect size and theoretical underpinnings to illustrate variable strength. The path analysis and effect sizes are illustrated in Figure 4:8.

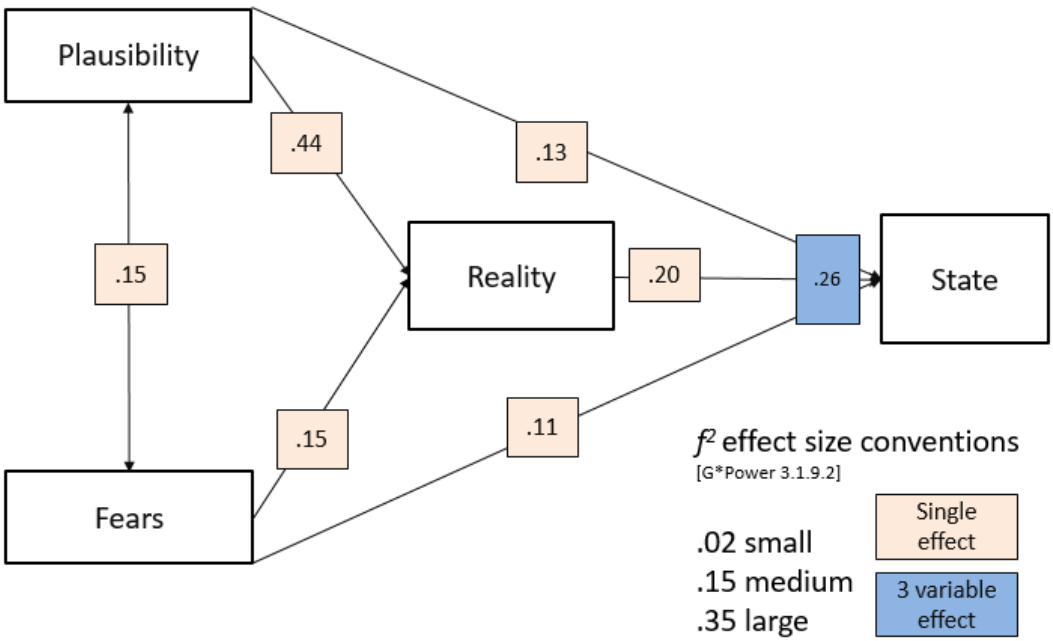

Figure 4:8 Path analysis and effect size

The opportunity to develop plausible meanings about the new technology has a large and positive effect on the end user's reality of tested plausibility (F(1,415)=180.28, p<.01). However, on its own, plausibility has only a medium effect on the end user's overall state of

technology adoption ($F(1,415)= 52.94$, $p<.01$). Furthermore, the opportunity to develop plausible meanings has a medium effect on fears and vice versa ($F(1,415)= 63.64$, $p<.01$).

Individually, each of the factors has a medium effect on an end user's state of technology adoption, while the total effect from *plausibility*, *fears* and *reality* of use in situ is slightly larger ($F(3,413)=36.20$, $p<.01$). The itemised path analysis statistics are located in Appendix A4.7.

Thus, while the multiple regression model showed that sensemaking dimensions of technology adoption, as represented by *Plausibility, Reality* and F*ears,* explained 20.8% of the total variance in an individual's technology adoption *State*, path analysis has shown that the strength of relationships between the variables, to range from large to small effects. Of the three dependent variables, *Reality* makes the largest unique contribution (Beta = .41, $p<.01$).The single largest effect size between any two predictor variables was between *Plausibility* and *Reality* ($f^2 = 0.55$)*,* indicating that *fears* on their own only have a small to medium influence on the technology adoption *state*.

The results from this study found that plausible meaning, opportunity to test plausible meaning and fears influence an individual's state of adoption. The connection between sensemaking and technology adoption can be expressed in the following way, as drawn from the data:

- Initial awareness that a new technology is being considered for introduction triggers the start of sensemaking.
- Information is gathered to make sense of what the new technology will mean to the individual personally. Thus, a mental model is formed and begins to develop with plausible meanings drawn from values, past experiences and other explanatory models. The individual questions 'what does this mean for me'?
- To increase the accuracy of the developing mental model (explanatory mental framework) about the new technology, plausible meanings are tested as they are enacted (i.e. observe others action, take personal action), thus providing truth or, in this regard, a reality check.

Based on the literature review, it is suggested that the rest of the sensemaking lifecycle would continue in the following way:

- Enacted experiences are interpreted and the findings update the individual's mental model creating new knowledge and thus new plausible meanings.
- As the mental model is updated, a greater understanding of the new technology develops.
- Resistance toward adopting the new technology can result in cases where accuracy or plausibility are contrary to the individual's needs or values. During this time, fears may surface that reduce motivation for continued sensemaking. Additionally, the level of dissonance between the reality of use and the design determines the size of the design-reality gap.
- Skill competence in using the new technology advances as a greater sense of the new technology grows. Once competence is reached, the design-reality gap is either non-existent or small.
- With continued use, the individual begins to monitor the design-reality gap for changes and disruptions to work performance to ensure and confirm continued connectedness. During this time, sensemaking may appear dormant.
- As the technology begins to no longer support work processes, either due to age, technical problems or changed work demands, a disconnect develops and a deterioration in work performance becomes apparent and changes and disturbances are noticed. These changes trigger the revitalisation of sensemaking in an attempt to make meaning of these deviations. At this point, a design-reality gap starts growing and the human-machine interacts less effectively.
- Once the design-reality gap widens and is deemed too difficult to manage or no longer suitable, the technology will be discontinued, bringing sensemaking of this technology to a close.
- However, the discontinuance of one technology often leads to the introduction of a new one and thus the discontinued technology provides the catalyst for new awareness and new sensemaking opportunities.

4.5.4.1 Sensemaking as expressed by controllers

This study supports the notion that an accurate sense of something cannot occur until plausible meanings have been tested (Weick 1995), as expressed by this controller:

> It is just interesting to see what it looks like and feels like, that sort of stuff. [Interview 32]

> We don't know, because we haven't seen anything yet. When they come up here and turn it on we will find out… 'If we don't like it, we won't operate it, we won't accept it. [Interview 33]

This study also found that technologies can be inappropriately designed unless consideration of the user's mental model (i.e. plausible meaning of what they need the technology to be), is considered. In cases, where enactment reveals a significant gap between its design and its reality of use, the technologies become at risk of user rejection, as this controller explained:

> [Technology organisation], said 'this is what it is going to do', and we said 'no that is not acceptable' because they had no user group involved in it. And then we said, okay unless you actually get the people who are actually using the equipment actually get involved in what we want out of it, otherwise we won't accept the system. [Interview 33]

Sensemaking can be impaired where social discourse amongst peers is restricted as this controller shared:

> Like when I was assessing things in Brisbane, we went down to look at three different companies, worldwide companies, and I wasn't allowed to talk to the guys about it, you know, so it was [just] me. It was just stupid. You need the ability to be able to converse with your mates. Well, I wrote a report to my superiors, but I could not give it to my work mates. I've still got it in there, now it's been there for a year now, I guess. [Interview 18]

Sharing of knowledge is a way to speed up the sensemaking process, because, sensemaking takes time to develop an accurate understanding. This is true, whether through personal experience, observation of others, or through training, as this controller expressed:

> Because it was basically, one day you got this, next day it's turned off and you got that. They give you a couple of days training, but the same with a lot of things, unless you actually sit down and start using it, you are not going to be able to do it in a hurry. [Interview 08]

Furthermore, controllers recognise that sensemaking does not occur in a vacuum, but must also be supported and appropriately resourced, as expressed by this controller:

> You've got to have time to get trained on how to use it, the new technology and the infrastructure to support that… [Interview 01]

Not all knowledge is easily transferred, some requires a social exchange for tacit knowledge to emerge. In this regard, sensemaking continues by learning from the experience of others, particularly in complex circumstance, as this controller explained:

> I've learnt all the rules and theory on everything but the difference from learning from somebody who's got experience, you can't beat it as…, they just know instantly, it's amazing… I think there are a lot of peripheral things to understand, that'd make you a better controller which only happens from seeing certain situations. Every day a situation will arise and I've got to ask someone who has got experience. Because that is not something, not essential for me to know to be a controller, but then when something is happening out in the field, you have to deal with it. You only know how to deal with it from experience. It's true, it's that experience, it's huge, it counts for so much. [Interview 02]

The above comments from controllers show that sensemaking does influence their ability to adopt and use new technology competently. While the term 'sensemaking' is not common language in the control room, aspects of sensemaking are understood and identified as necessary to appropriately adopt new technology. Terms used in the control room include: make sense of, grapple with, to learn, come to grips with, to know, to understand, to think, to find out, to experience, training, to learn from the experience of others, to share knowledge, if it's not right we won't accept it, don't know about it until it comes in, until we are told.

4.5.5 Summary

This section summarises the answer to Research Question 2: *Does sensemaking play a role in technology adoption and in what way?*

To summarise, regression and pathway analysis has provided an opportunity to test whether sensemaking influences technology adoption. Results found that those plausible meanings (plausibility), enactment of these meanings (reality), and the negative emotional response (fears) when conflict arises, in combination predict 20.8% of an individual's state of technology adoption. In this regard, this study offers a unique contribution to the body of knowledge on technology adoption and sensemaking.

The way in which sensemaking plays a role in technology adoption has been expressed in terms of end-user needs when new technology is being introduced. Such needs highlighted include: early awareness of the change to learn and understand the change, and that this takes time (to *create* meaning), the awareness of emotions that arise from their created plausible meanings (*affect*), and their desire to share and learn with and from others

through experience of doing and participation (*enact* to *interpret* created plausible meanings).

Finally, the results presented here have shown that prior to implementation sensemaking opportunities are not always made available or encouraged. In some cases, the sharing of knowledge is prohibited, in other cases, controllers are only given a few days to grasp the new technology before being expected to use it in situ. Additionally, controllers acknowledge that tacit knowledge on how to use the technology in less common situations only comes from experience, and thus the need to enact plausible meanings made. Furthermore, they acknowledge that, in safety-critical circumstances, this knowledge is most efficiently gleaned from the experience from others. These are matters that controllers have identified as barriers and potential ways forward to achieve more accurate and efficient sensemaking.

4.6 Research Question 3

- ***Research Question 3*:** What factors help or hinder end user adoption of control-room technology?

Technology adoption is an observable symptom of system success and is often viewed as a success indicator. Therefore, to explore the factors that help or hinder the positive progression of technology adoption, it can be helpful to adopt a systems thinking approach. Systems thinking requires deeper level thinking and learning to enable examination of the underlying structures within a reality (Richmond 1994), end-user adoption of new control-room technology in this case. Systems thinking requires an ability to take a worldview of a reality and the relationships that exist within the reality (Maani & Cavana 2007). In an attempt to disclose these underlying conditions, analysis of the data attempted to capture a worldview of technology adoption as it exists within a control-room context.

4.6.1 A worldview

Since system success and technology adoption seem to go hand in hand, questions were directed at both topics to first determine whether there were any differences in how control-room technology stakeholders viewed them, and then to identify areas of greatest concern. Therefore, survey participants were asked to identify (1) the most important thing

to do to minimise the risk of system failure, and (2) the most significant reason why adoption of new technology fails. While these questions focus on ways to prevent failure, responses to these questions can thus be used to achieve success.

Thematic analysis of the data revealed that according to stakeholders, factors that influence system success and technology adoption fall into six thematic areas, namely: organisational factors, viability, design process, product outcome, implementation, and issues concerning end-user adoption. To visually see the strength of variance between opinions on the two topics, the data was transformed into quantitative data and subjected to *multiple response* analysis which produced frequency rates on each area of concern. Table 4:10 shows the number of comments made in each category, and response percentage, in regard to achieving system success and technology adoption.

Table 4:10 Frequency of themes

Focus: System success	Freq.	%	Focus: Technology adoption	Freq.	%
1 End-user technology adoption	142	25%	1 Design process	224	33%
2 Product outcome	109	19%	2 Implementation	170	25%
3 Implementation	96	17%	3 Organisational factors	114	17%
4 Design process	92	16%	4 Viability	61	9%
5 Organisational factors	83	15%	5 Product outcome	55	8%
6 Viability	43	8%	6 End-user technology adoption	51	8%

The first observation is that the number of comments for each theme revealed that stakeholders think differently when focused on system success, than when they are focused on technology adoption. The differences revealed different areas of priority. This finding is pertinent because while issues associated with end-user technology adoption was found to be the top area of concern for system success, a focus on system success does not produce the level of detail required to know what helps or hinders the technology adoption process.

The second observation is that when focused on system success, participant comments concentrated on issues associated with *end-user technology adoption*. However, when

focused on technology adoption, *product outcome* was of least concern. Rather, comments focused primarily on how the technology was designed, how it is introduced, how organisations conduct themselves, and how viability studies have been conducted. This finding is important because technology adoption is not an explicit area of focus for human factors integration (HFI) efforts or human factors engineering, suggesting that it possibly should be.

Closer examination of the thematic areas to determine possible priorities for the achievement of system success ranked the most critically important concern as the need to ensure that the product outcome was 'fit' for humans. This advice was followed closely by the need for learning support for users, the achievement of user acceptance, and the need for effective communication. Robust and reliable technology came in fifth, followed by sufficient resourcing, ensuring the technology offers benefits to users, that it is the right idea, and context compatible. In line with user support, the comment that rated tenth was expressed concerns over the user's ability to use the new technology. This concern may reflect the general trend towards more sophisticated technology including the replacement of paper-based, manual lever and button operated systems with new paperless computer-based mouse driven control systems. These changes require controllers to learn how to achieve the same goal in a vastly different way.

Top concerns when focused on achieving end-user adoption of technology, included: provision of appropriate learning support, delivery of effective communication, application of a user-centred design approach, and the achievement of safety assurance. These comments were followed by examples of user involvement, namely: user participation, user acceptance testing, user requirements gathering, user consultation, and user pilot testing. The achievement of a design 'fit' for humans followed these concerns and came in tenth. As offered by participants, the ten top factors that support the achievement of system success and end-user adoption of new technology are listed in Table 4:11.

Table 4:11 Ten top factors that help and hinder system success and end-user adoption of new technology[a]

System success	Category	Sum	Technology adoption	Category	Sum
Technology 'fit' for humans	Product	62	Appropriate learning support for users	Implementation	114
Learning support for users	Implementation	57	Effective communication	Org behaviour	77
User acceptance	User issues	49	User-centred Approach	Design process	36
Effective communication	Org behaviour	44	Safety assurance	Viability	34
Robust/ reliable technology	Product	33	User participation	Design process	32
Sufficient resources	Viability	31	User acceptance testing	Design process	25
Technology benefits users	Product	26	User requirements validation	Design process	24
Technology is the right Idea	Product	24	User consultation	Design process	24
Technology is context compatible	Product	20	Pilot to trial	Design process	22
User ability	User issues	19	Technology 'fit' for humans	Product	22

[a]Sum of stakeholder responses reported

Differences in focus were also noted between stakeholder groups. In consideration of areas found to influence system success, managers were found to be mostly concerned about the implementation process, followed by general concerns about end-user technology adoption. Scholars noted some years ago that problems identified during implementation can be the most difficult to resolve, primarily due to the costs involved to make changes to the design (Damodaran 1996). This may explain why management may be more heavily focused on this area.

Results also show that end users are concerned with implementation as well, as this is often the moment of truth when their ability to successfully adopt the new technology is, or is not, realised. The finding that designers were most concerned about the product outcome and the design process was not surprising since these topics were anticipated priorities for designer concerns. Visually, a comparison across stakeholder groups can be grasped in Figure 4:9 where the graph shows the emphasis of influence on system success according to stakeholders. To achieve a fair comparison across uneven participation within stakeholder

groups, the percentage of total response was used to enable comparisons across stakeholder groups.

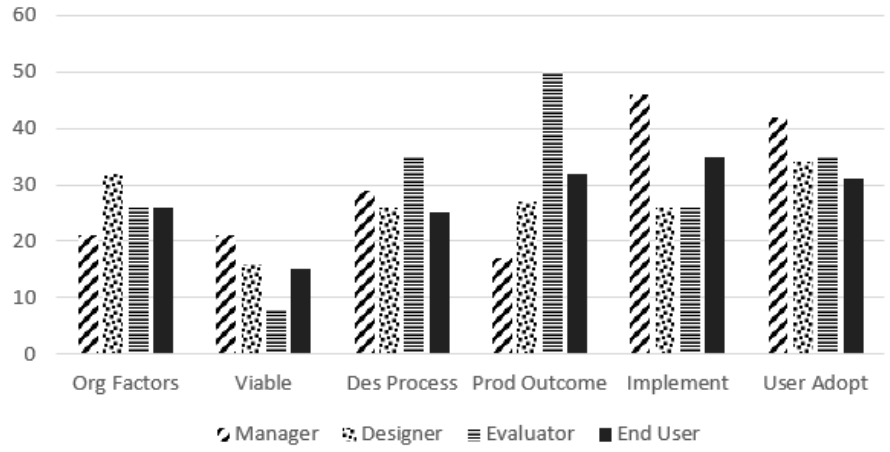

Figure 4:9 Areas to Attend to for System Success

The percent of total response for each category related to the end-user adoption of new technology are displayed in Figure 4:10. The graph shows that the dominant areas of concern involved the design and implementation processes. These findings are consistent with current trends in the human factors literature where the interest of enquiry is moving into areas of understanding process effectiveness (Imada & Carayon 2008; Lewis 2014).The design process has received a lot of attention, especially for the mitigation of usability problems (Burgess-Limerick 2010; Lewis 2014; Rail Safety and Standards Board 2008). As opposed to changes made post-implementation, to catering for usability during the design process has been found to save one-quarter of the total costs incurred for information systems projects (Hendrick 2008).

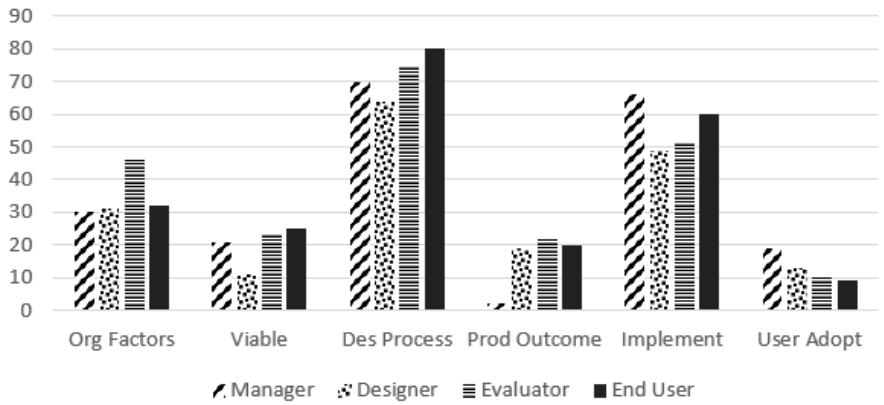

Figure 4:10 Areas that need attention to achieve end-user adoption of new technology

Observationally, the results show that priority areas of concern for system success do not always match concerns associated with end-user adoption of technology. The differences between stakeholder groups may reflect differences in the criteria they use to determine success. For instance, the criteria for success by IT project managers is: (1) the project is completed on-time, (2) on-budget, and (3) with all features and functions as initially specified (The Standish Group 1995, p. 2). However, these concerns do not seem high on the agenda for end users. End users have expressed a desire for: (1) assurance of safety, (2) the right idea for the job, and (3) adequate learning support; whereas, managers are likely to have alternative priorities that may include the achievement of business strategic goals, as well as budget and timeframe goals.

According to stakeholders as an overall group, the data suggests that the criteria for system success and the achievement of: (1) technology adoption by end users, (2) a well-designed product, and (3) system introduced without undermining safety. Meanwhile, the processes that lead to end-user adoption of technology involves: (1) a design process that incorporates user inputs throughout the process, (2) a technology that is implemented and deployed mindfully, and only when both the technology and end users are ready and (3) organisational values that lead to management demonstrating genuine commitment to the achievement of optimal solutions.

To delve deeper to identify factors that either help or hinder end-user technology adoption, each of the five areas of concern were addressed with supporting quotes from the survey and interviewed participants.

4.6.2 Organisational factors

4.6.2.1 Organisational integrity

Organisational values are addressed first, because everything else that happens within an organisation is likely to be led by how the organisation conducts business, their values, goals and drivers. Organisational values such as trustworthiness, honesty, accountability and transparency were offered as helpful toward end-user adoption of new technology, as shared by these participants.

> Discuss with the employee by clearly explaining the pros and cons and what benefits can be attained. It is also important to be transparent and honest. [Survey ID: 56 End User]

> Establish trust between employer and employee. Avoid suspicion of hidden agenda. Be honest about why you are making changes. Be honest about the plusses and minuses of change. [Survey ID: 93 – Evaluator]

Furthermore, participants identified that honest and transparent practices can help to avoid unwarranted suspicion of hidden agendas, as suggested by these controllers:

> The problem is, I don't know if Management is telling us anything, or are they just as ignorant as we are? [Interview 33]

> Even this little thing that you are doing [i.e. interviews], a lot of guys are in the room at the moment going around with this perception that it has got something to do with [the name of the company they work for] and that there's a secret hidden agenda somewhere along the line. [Interview 14]

> But we're talking high-end sort of tendering processes for this sort of equipment. Hey. Like I don't know who pulls strings, where and whatever. They don't seem to have any accountability. [Interview 16]

In the hope for the achievement of an optimal technology solution to current problems, controllers expressed that they want management to have some accountability for their actions. As alluded to earlier, this accountability can only be recognised when processes are transparent. Sometimes, only part of the information is shared in an effort to guard against resistance to the new technology, as expressed by this controller:

> So not everyone has or is privy to that information, but we can share it with them, but they don't [want us to share anything negative]… But it is amazing when you go to meetings and it's off the record, all of a sudden everyone starts opening up, 'oh this isn't going to happen, the systems not going to do that, and it's always crashing all the time. And you think, why can't they just say that at the meeting in front of everybody? But it is still like a secret society going on of what the company is trying to get out of it and what they are trying to get for nothing. That is what I am hoping doesn't happen with the [new system] because it's been quite, well I think, quite secretive. So either they are still struggling to get it working, or... [Interview 33]

However, the practice of telling only half truths does not promote accurate sensemaking for all those who will be expected to adopt the new technology, nor does it instil trust in management practices. Studies have found that, in general, people cope better with knowing the bad news than to be left with uncertainty (Lazarus 1966; Sweeny & Cavanaugh 2012). Furthermore, upon implementation, the truth about the technology will be revealed, and where reality and expectations don't match, user resistance is high. At the end of the

day, end users will come to know the technology for what it is regardless of what communication they have received. At which point the truth will be revealed, as expressed by these comments:

> It doesn't work as it was promised. [Survey ID: 7 – Evaluator/ Safety]
>
> They lied to us. [Survey ID: 283 – End User]

How well the new technology will be received will be based on judgments made at the point of confirmation, where plausible meaning is enacted and when new understandings are created about not only the technology, but also about management integrity. In the end, a deceptive approach does not help to prepare end users and puts future trust in management decision-making at risk, as explained by this controller:

> I've never liked how this organisation sets up projects…they'll set a big project and they have project sponsors and project managers and all these lackeys to run around to do next to nothing for a few years, costs millions of dollars and they are seen to be always after the quick win, or the project time frame is that tight that all they are after is a tick in the box, yep, yep. We roll this out on this day, you know, this is what you've [controllers] asked for, but is wasn't really, tick in the box, project manager has moved on, he moves onto another project. They had no accountability at all we were left with shit… I come across pretty cynical, but I've been here long enough. [Interview 16]

Therefore, trust in management decision-making can be undermined when workers are not kept informed about matters that ultimately impact them.

4.6.2.2 Management practices

Sound management practices offered included a strong yet flexible leadership style and a genuine commitment demonstrated through resource provision, shared by participants:

> Flexibility of directors and line managers [Survey ID: 7 – Evaluator/ Safety]
>
> Visibly consistent senior leadership commitment and support [Survey ID: 43 - Manager]
>
> Clearly stated goal by management [Survey ID: 250 – Designer]
>
> Demonstrated managerial support at all levels extending from the top of the organisation is crucial. [Survey ID: 422 – End User]

Low interest by management, lack of consistent senior leadership and lack of concern were identified to contribute to poor end-user technology adoption outcomes, as expressed by these participants:

> ‘Management imposition’ [Survey ID: 25 – Evaluator/ Safety]
>
> ‘Disturbing the hierarchic done level’ [Survey ID: 254 – Evaluator]

Furthermore, insufficient support from top management can lead to project failure, as expressed by this ergonomist:

> Ensure you have senior management commitment and that the employees witness this - have them walk the walk. Support has to come from the top down. (my last experience failed in this area and I pursued a role for 14 months before giving up due to the lack of support from middle management which stemmed from senior management not demonstrating/displaying their support) [Survey ID: 13 – Evaluator/Ergonomist]

These above findings are consistent with the literature that has also found that the manner in which the new technology project is managed can influence trust in management and their adoption of the new product (Bruque & Moyano 2007; Sarosa & Zowghi 2003). Scholars have found that management can gain trust from workers when they convey information clearly, accurately and in a transparent manner. However, it was also noted that these practices are less common in organisations with hierarchical structures (Griffith & Arenas 2014).

A further concern is that hierarchical structures can be quite rigid in nature and thus vulnerable to error. For instance, decision-making errors made by management at the top end of an organisation filter down and influence those who work at the bottom end. Thus, errors from both ends have an accumulative effect and thus create a far worse situation with greater complexity (Weick & Sutcliffe 2007). Hence, the achievement of worker trust is an important factor for successful user adoption, since most participants (*N*=254, 58%) in this study worked for hierarchically structured organisations. The following participant illustrates the inconsistencies that can take place in hierarchical organisations:

> The majority of the time when we’ve raised anything that we can see will increase our efficiencies they have been welcomed and met with a curiosity to engage and that to allow ourselves to be involved in that. I’ve experienced that numerous times, personally.
>
> Other times, there are things that you would have felt that the end users, those controllers, would have been consulted in and no we don’t get consulted in things like that which is leaving us wondering. We’ve got managers that go away to controller’s conferences and things like that for Australia wide and we don’t actually have a representation from a control room. And our managers feel that they know our roles well enough, whereas we know that there is so much distance between the two, it just doesn’t happen and unfortunately, that’s the way the relationships end up going. [Interview 17]

These findings on organisational behaviour are consistent with the research conducted by Choi (2009) and Johnson, Gatz and Hicks (1997) who found that organisational culture can either support or undermine successful technology transfer and user adoption. Therefore, management practices strongly influence the general management of change, and thus successful technology transfer, which includes technology adoption by end users.

4.6.2.3 Communication

Effective communication is one of the three criteria for successful project management (The Standish Group 1999; 2013). One way to be effective is to be honest. Controllers want honest communication about the technology, the design trade-offs, the benefits as well as the disadvantages, and this results in greater willingness to collaborate, as expressed by this ergonomist:

> Communicate the change, timeframe, cost (personal etc). This helps to develop a collaborative approach. Recognising and acting on feedback to reinforce opinions matters, you will be listened to, all this to reinforce a positive degree of mindfulness in addressing the change. Otherwise, the degree of change required provides a good indication of the potential areas of risk, and what is needed to minimise any negative impact of the change. [Survey ID: 261 – Evaluator/ Ergonomist]

Furthermore, effective communication is paramount for the success of teamwork and project collaboration (The Standish Group 2013). Examples of and reasons for effective communication provided by participants, included:

> Good communication of the reason for its introduction. This leads to workforce understanding and ultimately acceptance. [Survey ID: 180 – End User]

> Exceptional communication at all levels, full interaction at and between all levels of user… [Survey ID: 05 – Evaluator/ Safety]

> Communicate the change, timeframe, cost (personal etc). This helps to develop a collaborative approach. Recognising and acting on feedback, to reinforce opinions matter, you will be listened to, all this to reinforce a positive degree of mindfulness in addressing the change. [Survey ID: 261 – Evaluator/ Ergonomist]

The above contributions indicate that effective communication that helps users come to accept and adopt new technology is characterised by the following attributes: it is transmitted at all levels of users; approached from the end-users perspective; encourages collaboration; and helps end users understand why the new technology is being introduced,

what the change will entail, the pros and cons associated with the new technology, and how the change will impact them personally.

Effective communication was also identified as a two-way process involving listening and information provision for the resolution of fears and uncertainty [Survey ID: 40 - Designer], as explained by this participant:

> The risk of adoption of new technology will be minimised considerably once everyone is on the same page and understand the positive aspect of the new technology. [Survey ID: 97 – Designer]

To encourage users to listen to management, an ergonomist advised that communication is to be a two-way process of listening to user concerns and acting on feedback. Other benefits of two-way communication noted were: greater collaboration and reinforced user mindfulness regarding the change [Survey ID: 261 – Evaluator/ Ergonomist]. Finally, management was advised to avoid information overload and to give users the information they require [Survey ID: 47 – Evaluator/ Ergonomist].

These findings are consistent with past studies that found the technology adoption process involves the reduction of uncertainty, by seeking/receiving information, processing this information and learning (Rogers 2003; Tenkasi & Mohrman 1995). Furthermore, findings are consistent with the concept of sensemaking as being uniquely personal and a social activity (Weick 1995), and with Social Cognition Theory whereby learning occurs within a social context (Bandura 1989).

Controllers expressed that they do not like being left in the dark about matters that will ultimately impact them. Rather, they prefer to be prepared, as expressed by thus controller:

> I wrote my analysis and my recommendations [on the various technology choices] and sent it up the line, so the people up there, making the decision could go ahead and do it. But I still couldn't tell the guys here. I could not give it [the report] to my work mates. They [management] were quite strong on that. I've still got it in there, now it's been there for a year now. [Interview 18]

There may be good reasons why managers do not disclose all the information available or allow end users to be involved in decision-making. Sometimes it is company policy for workers to keep certain things confidential to protect the company's competitiveness, as

disclosed by this controller when asked for advice on how he would like technology to be introduced:

> Firstly, I'd have to consider what you are asking and whether it is 'ring fenced within our company'. Ring fencing is a system where you can't divulge any information which may allow you to give it to a competitive operator. [Interview 06]

While there may be confidentiality agreements made to protect organisations' competitiveness, or the intellectual property of technology companies, secrecy regarding general information about various products seems to be unwarranted and thus exactly what might be shared needs careful consideration, as this controller explains:

> Well most of the information is available on the web. You know like I downloaded, these three companies, I downloaded all of their information before I went to the meeting in [particular city] for a month. Each one [technology company] had a week to present their program. So, I was up to speed with it all before I went. You know, and I was just looking for the fine details between them, but I understood them all before I went, but you know, I couldn't tell my mates. [Interview 18]

However, general information about the different products and information regarding why and when new technology is being introduced can help to develop general awareness about the pending new technology, to support accurate sensemaking, and was found to progress the adoption process (Rogers 2003). However, information is commonly communicated in an ad hoc manner, and thus sensemaking is not always supported, as these controllers explain:

> We knew a coded block was coming through the grapevine, and then suddenly there was a Powerpoint show given to me, had to teach it by a particular date, but I didn't have any software enhancements that I could run a simulation inside. So everyone had to take my say so, on what was on the Powerpoint slide and they [management] didn't actually tell us what it was for and we thought that it would be used for a certain procedure in one of the standards. We guessed more or less right but we weren't officially told that and then, come roll out day, they said, 'it'll be rolled out, you have to do it, and it'll be introduced on a particular day.' [Interview 06]

> We tend to get told a bit that this change is coming. But you don't always get told about all the changes that have come in. Yeah, you get told we're trying to improve the system to get this sort of information but then, when it comes in, you find out that someone else has said, 'if it can do that, it can do this, and this,' and all of a sudden it is a bigger job that it was before. So, yeah, I think it is just a lack of communication sometimes between management and staff. And, then not being told exactly what changes are coming in. [Interview 07]

Uncertainty has been found to breed fears that can amplify expectation of negative life outcomes (Lerner et al. 2003). As a consequence, user resistance towards the new technology

can result (Lapointe & Rivard 2005). Therefore, to avoid heightened emotional responses, scholars recommend to address and resolve industrial doubts and uncertainty as quickly as possible (Dekker 2014; Project Management Institute 2013). Some suggestions for expediting information dissemination offered include:

> Engage technology evangelists (if present) in the organisation. Have the TEs internally start describing the changes and spread the word throughout the community at large. Use water cooler and social media to describe the benefits of the change, newsletters and blogs to support the benefits of the change, informal discussions for older workers and groups less likely to communicate online. [Survey ID: 402 – Manager]

The recommendations made above are consistent with studies conducted by Rogers (2003) and Johnson, Gatz and Hicks (1997) who found that technology diffusion cannot occur without effective communication channels. Successfully communicated technologies were those that encouraged accurate sensemaking. This can be achieved through effective consultation, as explained by this controller:

> So I guess having that consultative process allowed everyone to feed in what they've seen at other places and you reach a conscientious choice I guess on what you want to see. I guess in the end product there were no surprises, put it that way. It was as everyone thought it would be. They were aware of what's going to happen, when the changes were going to happen, so when it does happen there are no surprises there, so people are ready to take it on, they are well aware that it is going to happen. I think that is the biggest thing the consultative process, and that way when you do come to bring it in everyone knows what's happening are ready for the challenge. [Interview 09]

Communication between controllers helps to create new understanding that is often concealed in tacit knowledge, and this often requires a social exchange to draw out applicable knowledge which can and then facilitate the creation of new knowledge, as expressed by this participant.

> Sometimes you just need that someone to talk through a problem with, and a lot of times you work the solution out yourself, but just by talking to someone with similar knowledge just to get your head around a problem, that's where 2 [operators] would be helpful. [Interview 13]

These findings on communication are consistent with technology adoption research (Al-Gahtani & King 1999). Furthermore, most problems associated with the introduction of IT systems have been related to the social context (Korpelainen & Kira 2013). Therefore, as described by study participants, communication with end users, that approaches the change from their perspective has been identified to support sensemaking, acceptance, and adoption of new

technology. To a certain degree, the success of the communication reflects the organisation's social context, and thus the effectiveness of management practices.

4.6.2.4 Change management

The advice on change management practices shared by participants reflects points noted in the above sections. They relate to decision-making, time, reasons for the change, benefits of the new technology, and to ensure a realistic picture of what the change will entail ensuring appropriate planning and implementation can occur, as shared by these participants:

> Ideally, the decision would be participative, if not, management must communicate why there is a need for change. [Survey ID: 40 - Designer]
>
> Spend the time to give a good explanation of why the change is happening, and why it is important for the employee to utilise the new technology. [Survey ID: 229 - Designer]
>
> Ensure the full scope and impact of the change related to the technology has been identified, evaluated, communicated, and contingency planned, implemented AND RESOURCED. [Survey ID: 110 – Evaluator]

Sometimes the above advice is overlooked. However, controllers take great pride in their work, as shared by interviewed participant 07. Hence, when something is still working, they need to know why they need to do something else, as put this way:

> Well because if something is working, why switch from it, why break it, why do anything to try and increase efficiencies? In other ways, because they [management] view that they [management] conceptualised the idea themselves and they [management] haven't had something imposed on them. [Interview 17]

Furthermore, the impact of the change needs to be assessed as accurately as possible. End users identified that some managers find it difficult to understand the full implications of the change for the end users. Poorly envisaged impact has been found to negatively influence acceptance of the new technology (Ives & Olson 1984). Furthermore, user dissatisfaction was exacerbated by poor change management practices (Butler & Fitzgerald 1997).

4.6.2.5 Change management of technology transfer

The following outlines how a major change in technology was undertaken by one participant organisation that controllers [Interviews 20 and 21] felt was done particularly well, that helped them to achieve an optimal technological solution that they had no trouble

adopting. It was described as a process that could ensure that a major change could be done with minimal adverse impact on the controllers and on safety. It was also described as a long process, but an effective one. The change management process is outlined below.

1. **Identify your stakeholders**

The first stage is to ensure the project management team have identified all necessary stakeholders, particularly those who will be using the new technology.

2. **Conduct a safety analysis**

The second step involves identifying any hazards or risks to safety as a result of implementing a new technology. Issues to be clarified before a decision is to go ahead with the change might include:

- Conduct a safety analysis
- Can it be done?
- Can it be done safely?
- Can the hazards identified be appropriately mitigated to a safe level?

3. **Participate in the design process**

The third step involves end users in the design process. At least one representative from each control room is to be involved in project matters. They are to commence from the start of the project to ensure essential needs are identified. Similarly, maintenance staff are to be involved in the same manner from day one (to identify practicalities – local problems & possibilities). The representative controller/s listens to and liaises with co-workers, on all matters, such as: needs, suggestions, changes, etc. This input is to be put forward at project team meetings for design decision making. Items to be considered include:

- What do controllers need the technology to do?
- What tasks need to be kept doing?
- What new tasks need not be done due to new technology?
- What do controllers want to be displayed?

- How do controllers want it displayed?
- Can the current display be improved?
- Does the display need to stay as it is now?

As the project progresses, design trade-offs and safety matters are continually reassessed and certain tasks and design attributes that need to remain or go must be justified at each iteration. Ideally, a core group of people would be involved in designing the new technology, including the controller representatives. A flexible budget and timeframes also help to ensure that safety critical issues identified can be resolved. During the design process communication is high between the project team and the representative controller and between controllers. Regularly, all controllers are to be informed of progress and shown samples or demonstrations of prototyped work. All controllers must come to understand the reason for the changes and have any uncertainties addressed. As many faults as possible are identified before the end users are trained on the new technology.

4. Implementing the change

The change process must be fully planned. Staffing numbers must be considered and resourced at various stages of the implementation process. By this time, the controllers should be quite familiar with the technology that they are about to use. Before formal training commences on the new technology, the representative controller first becomes proficient on the new technology and is trained to train the other controllers in his control room. This way language, terminology, tasks, scenarios, etc. are site specific and better understood by the student controllers. Throughout the training process, any issues are to be identified and addressed before the new technology is used live.

Next was hands-on familiarisation which allows all controllers to play with the equipment and to know what it does until they are very familiar with how to operate it. Ideally, training can be delivered to groups of people to allow for questions and discussions. Once end users are quite comfortable with the equipment, ghosting commences. The process of ghosting can take two to three months to complete and involves the following steps:

- The student controller sits in the background and observes the proficient controller who is now controlling live with the new technology and in the new location if applicable.
- Next, the student mimics the work of the proficient controller while operating a dummy system.
- This progresses until the student controller can mimic every action and input every bit of data just as the proficient controller is doing live. At no time during the ghosting period does the student operate live on the new technology.
- Once comfortable with ghosting and certain that all functions can be completed competently, they go live and never return to the old system. This is to prevent doubling up and potential for errors.
- Gradually, as more controllers go live on the new system, the new system takes on the main functioning and the old system becomes the backup system in case anything unforeseen occurs and it is needed to regain control.
- Each controller goes through the same process until they have all been ticked off on the various functions and all are controlling live from the new system.
- While this is occurring, training continues in the background to ensure that everyone can successfully progress to the new system.
- Eventually, the last person on the old system makes the switch to the new and the old system is turned off.

5. **Conduct post implementation review**

After a few months, a review is conducted to assess technology acceptance, adoption, error provocation, the level of satisfaction, aspects that need to be changed or adjusted, and any new hazards and controls for these. Reviews are regularly conducted to ensure necessary changes are made and to ensure the systems operates safely.

Of particular note in the above example shared, is that the design process is included as part of managing the change and that controller familiarisation occurs throughout the entire process. Furthermore, this process proactively supports sensemaking and technology adoption by ensuring that all controllers undergo regular familiarisation sessions and have

an opportunity for hands-on experience. Thus, once deployed, there are no surprises and controllers are ready to further develop and refine their operational skills on the new technology. Thus sensemaking and technology adoption progresses, as explained by this controller:

> We actually get in and actually play with it and I'm a visual learner. I can learn by just having a fiddle with it and playing with it. But if you give me a textbook and say now read the instruction manual, straight over my head. It obviously makes a lot more sense when you are reading it, you think 'oh that's what they are talking about. [Interview 27]

The need to experience new technology to confirm the plausible reality achieved through reading the instruction manual is supported by scholars who offer that sensemaking is not merely a cognitive process of interpretation (Sandberg & Tsoukas 2015). Table 4:12, provides a list of descriptors provided by participants on various organisational factors found to help or hinder end-user adoption of new technology.

Table 4:12 Organisational descriptors that help or hinder technology adoption

Attribute	Help	Hinder
Values	Trustworthy; honest; open; accountable; and inclusiveness.	Secretive; accountable to self; dishonest; distanced; and exclusiveness.
Leadership styles	Mindful; considerate; collaborative; take another's perspective; strong yet flexible; consistent; committed to optimal outcomes; open-minded; and connected with staff.	Self-centred; hidden agendas; ulterior motives; rigid; weak and inconsistent; incapable of seeing another's perspective; inconsiderate; judgmental; and aloof.
Management Practices	Delivers on expectations; visible commitment through resourcing; follows clearly set goals; Provides top managerial support; resolves conflicts and uncertainty; has transparent actions; and defers to domain experts.	Low interest in the project; makes promises that cannot be met; looks for a quick win; lack of concern for staff; does not walk the talk; commitment uncertainty; conflict avoidance; and keeps to organisational structures.
Communication style	Clear; accurate; honest; frequent; listening; two-way process; mindful of another person's perspective; transmission at all levels; and aids understanding.	Does not communicate with staff at lower levels; infrequent; does not listen; one-way process; leave staff in the dark; ad hoc; unclear; inaccurate; incomplete; and prevents peer communication.
Items communicated	Reasons for change; to aid end-user understanding; design trade-offs, pros and cons; new procedures; timeframes; changes; impacts; and information.	This is what you are getting; orders; change from a management perspective; information overload; and half-truths.
Purpose for	To alleviate fears and uncertainty	To give information

Attribute	Help	Hinder
communication	To help prepare for the change To encourage questions and collaborative	To impose changes To direct action
Change management	The decision is participative; realistic timeframes; mindful of impact; time is given for good explanations; uncertainty is addressed; benefits of the new technology are communicated; the full scope of the project and its impacts have been identified, evaluated, communicated and contingency plans developed and adequately resourced.	The whole idea of the change has been conceptualised by management alone; change is imposed on staff; ad hoc changes made; change for change sake; not well planned; no contingency plan; impact not assessed; inadequately resourced; rushed; poorly envisaged impact; unrealistic expectations; change requirements unclear; high level of uncertainty from staff.

4.6.3 Viability

While concerns over technical feasibility may be the role of engineers and IT developers, concerns over the viability of the desired product are a major concern of users. Viability concerns relate to: safety, resourcing, staffing adequacy, time for product development, time for user adoption, and future proofing, to achieve a sustainable product. Practices noted as necessary to address viability issues included risk assessments on safety, impact of change studies, impact on productivity analyses, environmental and economic risk assessments, and comprehensive research and development activities of the proposed system and how it might fail prior to implementation. Safety is the controller's primary concern, as expressed here:

> First off, is a safety analysis, of 'can we introduce it and introduce it safely?' and hazard identification, 'are there any hazards to the introduction of this technology?', and if there are, 'can we mitigate them to the point where it is an acceptable risk?' So unless you do that step first, there is no point in even bothering. So that is the most important step first (1) can we do it, (2) can do it safely, and (3) is the risk is acceptable? Okay then we can go and properly look at ways in which we can introduce it. There is a long, long, long process. [Interview 20]

When the viability to maintain safety has not been considered, controllers struggle to cope knowing that limitations exist, as this controller shares:

> So it is limited in what it allows us to do which causes safety concerns to us as controllers. [Interview 14]

To select an inappropriate solution that neither ensures safety nor delivers on expectations was seen as a clear indication of inadequate viability studies, as expressed by these participants:

> The choice of 'cheap' in preference to 'actually capable' [Survey ID: 413 – Designer/Engineer]
>
> Being seduced by marketing and hence not thoroughly checking reality of the new technology [Survey ID: 116 – Evaluator/Safety]
>
> I'd be definitely saying, 'don't look for that quick win that just solves a solution now and then. Make sure it can be developed or upgraded. You know, as technology improves… That's what we've noticed with this stuff. You know, I had no idea that we were running with a computer, 5 year old computer running our phones. Like, that's our lifeblood, our communication. So that was a bit shocking to hear that. [Interview 16]

The viability of taking end users off their normal duties to participate in or be trained on the new technology needs to be considered, as this controller expressed:

> You need resources to allow groups of people to get away from the work-face to do this sort of thing [small group training] and so that tends not to happen. [Interview: 26]

Problems with short or unreasonable deadlines were identified to impact project outcomes, including the ability for end users to make sense of, test, and use the new technology, as these participants state:

> There is not time to grapple with the novelty. [Survey ID: 53 – Evaluator/Researcher]
>
> Lack of sufficient training while everyone has to do their day job, lack of support post implementation [Response 209 – Manner/Planner]
>
> It was rushed through concept [resulting in] scope creep. [Survey ID: 311 – Evaluator/Ergonomist]
>
> New technology that has not been assessed and tested (e.g. trialled) will lead to failure. [Survey ID: 121 – Evaluator/Safety]

Participants also advised that feasibility studies and resources should go beyond the immediate development of the new system, and must anticipate and assign resources to ensure the project can be completed appropriately, and thus avoid viability concerns, as identified by this participant:

> Ensuring service providers/suppliers deliver and provide efficient future backup services on expected features. [Survey ID: 292 – Designer]

Finally, controllers have expressed that management need to be realistic in deciding whether a project is viable, to not expect a perfect solution from manufacturers, to ensure there is either allocation in service delivery, or room in the budget to pay for the problems to be fixed, and time for controllers to support the fine-tuning process, as suggested by this controller:

> Be prepared to spend time fixing problems. That is the biggest thing I can say. The manufacturer will not deliver a completely finished system ever. There are always problems with it. Management has to spend time resolving those issues, especially the major ones, otherwise they [operators] will hate it. Realistically you are to expect, well okay I'm going to have to spend an extra few $1000s to be able to fix all these issues. We have to budget for some extra amount and do it. If you are willing to do that, you will get a much better outcome and avoid discontent from the people in the [control room]. [Interview 10]

Table 4:13, provides a list of descriptors provided by participants concerning viability factors found to help or hinder end-user adoption of new technology.

Table 4:13 Viability descriptors that help and hinder technology adoption

Attribute	Help	Hinder
Analysis	All stakeholders have input; thorough analysis of impact, constraints, needs, and provisions.	Poorly analysed and planned; analysis incomplete.
Safety	Safety analysed, hazards identified, risks evaluated, and safety assured.	New technology not assessed or tested; inadequate consideration of impact to safety; rushed without concern for safety.
Resourcing	Adequate; provision for unexpected costs; provision for time off the desk for end users; resources assigned to resolve problems;	Poor financial decisions; no provision for to allow for staff involvement and training away from their desk; lack of sufficient training;
Staff adequacy	Staff adequacy has been assessed and assured.	Insufficient staff number to accomplish the task; Insufficient staff expertise
Time	Suitable deadlines; the project is not rushed to completion; time is given to ensure end users can be suitably prepared for implementation; no time allowed to fix issues before going live.	Unrealistic timeframes; rushed through concept; no time allowed to grapple with the novelty;
Future proofing	Provision for unexpected training and support needs; backup services assured; how it might fail is assessed and planned for.	Seduced by marketing tricks; tendency to choose the cheapest solution without adequate consideration of suitability; solution does not deliver on expectations.
Expectations	Realistic	Unrealistic

4.6.4 The design process

4.6.4.1 Approach

The approaches to systems design identified by participants were those that were more flexible in nature by allowing for design iterations, were agile and adaptive, encouraged stakeholder participation, and were focused on achieving human/user needs. These descriptions suggest that more flexible agile systems design processes may be more suitable than the traditional well-structured forms that typically aim to visualise the end product before construction commences (Optimus Information 2016). Agile design processes, have been credited with the achievement of more customer acceptability, greater usability, and lower defect rates, and are therefore considered appropriate for the design of safety-critical systems (Douglass & Ekas 2012). Since activities in a control-room setting are sociotechnical and safety-critical in nature, ensuring technologies are suited to user needs is well founded and supported in the literature (Walker et al. 2008).

Traditional forms of systems design tend to follow a fairly well-defined structure that has a detailed visualisation of the finished product before construction begins, while iterations can occur between step loops. Conversely, agile systems design is less structured and revisits aspects of design multiple times. Agile design approaches allow for greater flexibility and focus on incremental and iterative development, and thus are more organic and adaptable in nature. They also rely on user input throughout the development process gathered from frequent evaluations and suggestions for improvement (Optimus Information 2016).

Iterative design has been described as a user-centred design principle, with an early focus on users and tasks, and involving empirical measurement and testing of product usage (Maguire 2001; Wide Web Consortium (W3C) 2004). Iterative design allows for a complete rethinking of design by continually testing ideas and conceptual models. The process involves repeated testing and modification to the design using actual users to test the iterative prototypes (Maguire 2001). Iterative design has been found useful for the design of information systems and for catering for usability needs (Lewis 2014). Furthermore, as explained in the opening chapter, human factors engineers frequently use iterative and trial and error design methods to ensure that interactions with the system are appropriate for

the user. It was also noted that these iterations can be in conflict with other design perspectives within the design team.

The intent of human-centred, user-centred, people-centred and even activity-centred design is to ensure the original intent of human-centred design is reflected in the development of products and services so that they genuinely fit the needs of humans (Norman 2012a). Activity-centred design came into being, to bring the focus back to the needs of the user and the real-life use of the product (Norman 2012a). Some distinguish human-centred design as keeping humans in mind during the design of new systems, while user-centred is a sub-group representing the conscious effort to understand the actual users and their context (Bhaskar 2013); however, the two terms are often used interchangeably.

4.6.4.2 Stakeholder participation

One of the main themes that emerged from the data was the importance of achieving stakeholder participation in the design process as early as possible to ensure all perspectives are tabled, as indicated by these participants:

> Involve the developers, implementers, management, users, and human factors people early on. [Survey ID: 208 – Designer/IT Developer]

> Get human factors involvement as early as possible in the project. Get the operator or their representative involved in the project as early as possible. [Survey ID: 212 – Evaluator/Ergonomist]

The involvement of multiple stakeholders is consistent with the sociotechnical philosophy of design (Walker et al. 2008). Furthermore, participants recognise that when ergonomists are involved in technology development projects, end-user involvement becomes more likely.

4.6.4.3 Involving users

Controllers understand that the idea to introduce new technology may not come from them, and participants in this study are fine with this. However, once the notion gains momentum, controllers stress the importance of their involvement, as expressed by this controller:

> It's alright to come along with a suggestion and everything else, but they've got to make those… To make those changes, they've got to have some sort of consultation prior to it, instead of bringing it along and dropping it on your lap. [Interview 05]

A major reason why controllers feel end users should be involved is because they are the ones who will ultimately need to use it and make it work, as these controllers explain:

> I think it is really important that you end up taking the stakeholders into account, you know the end user, they are the one who has to interface with it, they're the one who has to use it, and they're the one who has to be happy with it. So I think it is really important that you have them as much as possible involved in the process. [Interview 12]

> Because they are the one using the product. They have to be able to fix the product if it goes pear shaped. [Interview 01]

The desire expressed by participants, to ensure their needs are met in the design of new products, is consistent with studies that have found that technology adoption can be compromised when designers have not been sensitive to their needs (Choi 2009). Suitable end-user design participants are usually experienced and well respected peers who will faithfully represent their co-workers, as indicated by this controller:

> Senior controllers in the room, rather than management, given that opportunity to say, to be shown exactly how it works, how good it is. I think it needs to go to the next level, because those guys [managers] aren't the fellows that are using it. It is the controllers who are using it.' [Interview 15]

The above quote shows that the people who are involved in the design of new technologies need to be intimate with how control tasks are performed. Furthermore, the quote suggests that the user representative must be trusted to represent controllers' needs faithfully.

Additionally, the utilisation of actual controllers can help to progress the technology adoption process, not only for the controllers who participate but also for those who trust their opinions and expertise (Section 4.5). The need to spread the word, as expressed by this controller reinforces the need for all controllers to begin the technology adoption process early, rather than later:

> So, senior controllers within the room because obviously there are guys in there that are looked up to by fellows below them, and if they [senior controllers] are given a good experience and knowledge of how to use it and what the benefits are of it, then… I believe that needs to be done along… a lot earlier than say a couple of months out. If they know it's coming in 12 months, start getting a few of the guys clued up on exactly how it works and what the benefits are going to be of it, so that they can start spreading the word, so that everyone can start getting an idea as to how it works. Not a management side of it, so that, if it's what's coming, then managers have obviously got to say, 'this is great here and this is how it's going to work'. So I think the positive input needs to come from senior controllers in the room that are given the opportunity to go away and learn about the new stuff that is coming in. [Interview 15]

The desire to learn from trusted peers supports the research conducted by Rogers (2003) and that of social cognition theory (Bandura 1977), where technology adoption is enhanced through social learning (Rogers 2003; Maloney 2010).

In conclusion, a strong notion that came from study participants is that end users need to be involved during the design process. This finding is consistent with other studies (Day 2012; Sanders 2002; Stewart et al. 2000). The results from this study are also consistent with past research that has found that managers do not fully understand the needs of end users (Day 2012).

4.6.4.4 Benefits of end-user involvement

There are a number of reasons why controllers want to be involved**.** According to end users, the most important reason to be involved is to get the 'right' ideas into the design or selection of new technology. Of the surveyed participants who commented on product outcomes, almost half (49%) stressed the importance of achieving the right concept idea as an important factor to influence system success. Comments made by controllers also reflect these sentiments:

> It's no use giving me a screwdriver if I need a spanner. [Interview 04]

Controllers understand the intricacies of their work and are thus more sensitive to their priorities. Therefore, their involvement can help the design team to meet a pressing need that may be less obvious to others not so intimate with the control room.

Another benefit for involving end users early is because they often have good ideas that are sometimes easier to implement, as expressed by these participants:

> When talking with users, it appears that they already have the answers to the problems that the 'middle management' layer doesn't even realise exist.' [Response 413 – Designer Engineer]

> But they've also got to consult us. 'Okay [voice of manager], I'm going to buy this package because it's going to do this you beaut.' 'Well [voice of controller], we can do that already if we just add this, why waste all of this?' With certain people who know, or try to prove, who have no background knowledge and they give us to run control from, you've got to understand the fundamentals before you can actually just grab something off the shelf. [Interview 01]

Early involvement of end users also has benefits for the organisation they work for, such as the avoidance of potential problems, delays to the project, increased costs, and most critically the avoidance of end-user rejection, as this controller shared:

> They finally got a user group involved, and that has made it drag on a bit longer because now it is going backwards and forwards, while, that is not what you asked for, that's going to be extra money, there is no money for that, so now they have to decide what they want because otherwise if we don't like it, we won't operate it, we won't accept it. [Interview 33]

The desire from end users to be involved early in technology projects and the benefits that can be derived from this supports recommendations found in the literature that encourages early end-user involvement for positive technology adoption outcomes (Maguire 2014; Pew & Mavor 2007; Stewart et al. 2000; Wilson & Sharples 2015).

Controllers have expressed a desire to be involved, or at least to have a representative from their control room involved early and throughout the design process, particularly before the concept is finalised, as is also recommended by this engineer:

> Get user involvement as early as possible; preferably as part of defining the specification of what is required BEFORE buying something! [Survey ID: 163 – Designer]

However, the achievement of early user involvement has been problematic for many years (Woods 2002), leading engineers to rely on intelligent guesswork when it comes to catering for the needs of users (Chapanis 2015), as this engineer shares when asked how to integrate human factors:

> I use my own intuition in this area. [Survey ID: 413 – Designer]

It has been found that the lack of user input during concept development leaves the engineering/systems design process unsupported for HFI (Ferreira & Balfe 2014; Norman 2010; Woods 2002), and hence at risk of user rejection. As controllers in this study have indicated, and in line with past studies, problems in design are all too often not discovered until the system is field tested (Stoop 2011).

Past research has found that technology adoption can be compromised when designers have not been sensitive to end user needs (Choi 2009). One way to counteract this problem is to involve users to help establish the problem definition throughout the design process through to implementation (Stewart et al. 2000). Furthermore, utilising actual controllers

helps to progress the technology adoption process for not only the controllers who participate but also for those who trust their opinions and expertise. Thus the need to spread the word to help controllers to begin the technology adoption process early, rather than later.

These results show that many of the benefits of involving end users early and throughout the design lifecycle also align with the characteristics of innovations that expedite technology adoption, as highlighted in Section 2.4.2.1. For instance, the achievement of the 'right' idea achieves both a *relative advantage* where the innovation offers an improvement to the work system that is also *compatibility* with the end users' values and needs. The involvement of end users early in the design stages allows users to offer improvements that are often less *complex* and thus simpler to implement. Opportunity to involve end users also enables users to *observe* and *trial* the developing product so that potential problems might be averted. Thus, the innovation characteristics outlined by Rogers (2003) as a means for increasing the rate of technology adoption also apply in mandatory situations. Additionally, the importance of *communication channels* to the technology adoption process (Johnson, Gatz & Hicks 1997; Rogers 2003) and learning from others in a social environment (Bandura 1977; 1986) were also found to support more accurate sensemaking. Thus, the notion that employees will adopt new technology because it is part of their job, as many controllers shared, has been found to be flawed. User involvement that hinders technology adoption

In searching for examples of involvement, examples of poor user involvement emerged and are thus shared to ensure the identified bad practices can be avoided in the future.

1. **Wrong representation**

Section 4.6.4 on involving users stressed the importance of involving end users. However, in cases where funds have not been allocated for this to occur, such as allowing controllers time off the desk to be involved in new projects, organisations look for alternative solutions. A common practice is to use 'representative' users in the absence of actual users. This designer implies that managers are not suitable representatives because they do not fully know what the controllers need:

> Fully understand the client's requirements. Often the client themselves do not fully know. Continuous communication with the client and all stakeholders within the client's organisation [Survey ID: 434 – Designer]

In organisational settings, the individual who commissions and pays for the development of new technology, the client, is typically the manager (Day 2012). As the quote above suggests, managers are not usually intimate enough with the intricacies of end-user work and thus other stakeholders need to be consulted. Problems with poor representation in the past have magnified controller concerns over 'representative' users who make decisions on their behalf. Therefore, it is important not to assume that managers or past controllers are suitable representatives, as shared by this controller:

> Well, the people who did the tender used to work in here, and you would think they know better but they obviously think they are way smarter than the operators and asked for what they thought was needed and that wasn't adequate. [Interview 33]

Hence, the only people who fully know what controllers do are the controllers themselves. Consequently, controllers are very dubious of the term 'user', as is explicitly expressed by these controllers:

> Not the user! You want the people who will have the direct impact, e.g. controllers, ECOs… not someone who is up there [management] who's not here [in the control room]. You've got to have ground roots. [Interview 01]

> I made sure I got someone from here onto the project to have input to it, because people who don't do what we've got to do, simply do not understand it. [Interview 21]

These sentiments are shared by other stakeholders, as this safety professional indicated regarding the selection of new technology:

> To undertake a very thorough evaluation of the technology including hands-on evaluation of the technology at the supplier's premises or another worksite BEFORE you even decide to introduce the technology. The operators ALWAYS know much more about the actual use than management or technologists. [Survey ID: 116 – Evaluator]

However, an unsuitable manager in one location may be perfectly suited in another, so long as he continues to be an active controller, as was the case for this manager/controller:

> No, there is a big enough role, but the role of a manager here still requires that you be proficient in the [vehicle] traffic control side of it. [Interview 23]

2. **Powerless to influence**

End-user recommendations can be easily overruled during the design process due to the various levels of authority and power within the organisation, as this controller explains:

> We asked for a lot of the good stuff, but it just didn't happen for different reasons, different people had different opinions, most of them came from outside the [control] room who don't operate it. [Interview 14]

In some cases, ergonomists or other specialists are employed to help capture end-user needs in the form of design specifications. However, unless there is continued involvement of the specialist, user requirements run the risk of being negotiated out as the project progresses. For instance, scholars have found that when specifications do not seem to make sense to other stakeholders and when members of the design team do not feel they need to clarify reasons for their inclusion, user needs are easily negotiated out (Hall-Andersen & Broberg 2014).

3. **Too late to influence**

User involvement can be too late in the design process to have any real impact in the design or philosophy of the new technology. Late involvement of end users can lead to significant delays, renegotiations and additional costs. In certain cases, recommendations to improve the design cannot be made, as this controller shares:

> [Technology company], said 'this is what it is going to do', and we said 'no that is not acceptable' So we went to these user group meetings. We were finding out how inadequate the system was, but because the original tender... we never saw the original concept document of what we [the company] actually asked for, so when we were asking for the other things, they were saying, hang on that wasn't part of the original contract. So now… if you want any more than that then they'll [commissioning company] have to pay for it. [Interview 33]

The above quote, also illustrates how managers cannot replace end users during concept development. However, and as identified in the opening chapter, modern controllers are insisting that their new technologies are appropriate for use and will take a stand to reject an inadequate system, as the previous controller adds:

> So, they finally got a user group involved, and that has made it drag on a bit longer because now it is going backwards and forwards, while, 'that is not what you [the company] asked for, that's going to be extra money [voice of designer]', 'there is no money for that [voice of

> managers]', so now they have to decide what they want because otherwise if we don't like it, we won't operate it, we won't accept it. [Interview 33]

The frustration expressed above illustrates the disappointment expressed by controllers when their input is limited to aspects of the interface design when the really had far wider needs.

4. Relaying half truths

Involvement that requires controllers to keep all the negative information about a new technology to themselves is quite frustrating as they know a more accurate portrayal is better than one that slants the truth, as this controller expressed:

> But it is amazing when you go to meetings and it's off the record, all of a sudden everyone starts opening up, "oh this isn't going to happen, the systems not going to do that, and it's always crashing all the time." And you think, why can't they just say that at the meeting in front of everybody? But it is still like a secret society going on of what the company is trying to get out of it and what they are trying to get for nothing. [Interview 33]

This notion is also supported in the literature, where people have been found to generally deal better with bad knowledge of something, rather than when there is uncertainty (Sweeny & Cavanaugh 2012; Tversky & Kahneman 1974; Lazarus 1966).

5. Token involvement

Involvement that has no impact breeds disillusionment, as expressed by this controller:

> I know in the past there have been controllers involved in that sort of decision making. Well, when this new control room was getting set up, there was a selection of controllers on there to have their input on. But I don't think, in the end, it really mattered what they thought, hey… I don't know the tendering process. And this is what I'm worried about all along. I mean, who takes notice of the end user anyway. We haven't really made an impact, ever! Regardless of all the bitching and screaming we do at operational meetings, to get stuff implemented or fixed up. It's not working. [Interview 16]

Involvement that is perceived as a token gesture can lead to a perception that the participants' involvement was a waste of time, their contribution was of no value to decision-makers, and that their involvement was only a management's tick flicking exercise, as expressed by this controller:

> They [management] don't seem to give a rat's arse. They [controllers] were there [concept development meetings] because they probably had to have a representative from the

> control room. Oh, it's got to be something like that. Yeah, I don't know. But we're talking high-end sort of tendering processes for this sort of equipment hey. Like I don't know who pulls strings, where and whatever but ah… they [management] had no accountability at all… we were left with shit.' [Interview 16]

Token gestures, can therefore develop negative attitudes toward the adoption of that particular new technology. Some controllers have been involved in projects, but not to the extent that they desire, as expressed by this controller:

> They do negotiate with us with the electrical side of it with us to what alarms and that sort of stuff that we'd like to see things that we can get rid of. So they do consult with us a bit. [Interview 03]

Eventually, where their contribution does not seem to make an impact, controllers may no longer want to be involved, as shared by this controller:

> They've got to have some sort of consultation prior to it, instead of bringing it along and dropping it on your lap. And if you are going to, like I've been to meetings after we've had [name of system] systems put in, they said 'well, what is it you want?' after it's been put in, and [I said] 'now we've tried it out', we've been down there [with the technicians], we've talked about it, we've got these changes and I'm still waiting for them, but anyway. That's years ago, so once again, I don't even bother putting in suggestions anymore. [Interview 05]

6. In the way of innovation

One obstacle to end-user involvement is the tendency for controllers to hold onto what they know, and this can be a barrier to innovation that has the potential to prevent the achievement of greater controllability in the new technology, as this controller explains:

> I was looking at some graphics being done for another [organisation]. It had all fairly modern graphics as regards, I guess they were sort of similar to what ours were, pretty standard graphics, and then on one of them I noticed over to the side it had this old analogue display of a needle going up and down which was their drum level indication. But because the rest of it was all fairly modern and then it had this old gauge type thing I said, 'What is that?' And the guy said to me, 'that's what they had in the old technology…, and that's what they wanted and wouldn't let it go'.
>
> They wouldn't go to something different. But that's what your trends do for you. If the only information I have available to me is a static value, then it's pretty hard for me to make decisions on that, unless I'm observing it for a period of time. But if I can look at what it's doing on a trend, I can see if it is just moving up and down and around, making pretty much a straight line, or I can see it heading north. Yeah, they didn't need a needle anymore. [Interview 12]

As mentioned earlier, a focus on the activities that end users need to achieve goals (Norman 2012b) may provide a more useful design outcome.

7. **Inappropriate involvement**

A comment of caution noted, is that while a project may commence with a suitable end-user representative from the control room, if they are removed from their normal duties for too long, they can become as ineffective as other representatives, as this designer suggests:

> Do not involve users or if they are involved, remove 'representative users' from their usual work environment (to act as resource people to developers) for too long. They lose touch with their usual work environment. [Survey ID: 263 – Designer/Engineer]

Additionally, end-user involvement needs to be productive and therefore carefully achieved, as suggested here:

> Don't let it die a 'death by over-consultation'. Any change needs a sense of urgency attached to it by management. [Response 409 – Designer/Engineer]

8. **Poor representation**

However, in many cases, the consultation of end users is conducted through local managers, as expressed by this controller:

> They'll do consulting with the local managers, but at the end then when it comes through. But he [the manager] could probably have some input into it during its planning and stuff. [Interview 03]

Lack of due consideration and concern for the valuable contribution that certain end users could make can lead to poor end-user representation, whereby those who are best equipped to be involved are not, as these controllers share:

> I've got all these skills and knowledge that I can see, because I know the system they are assessing, in other words, what's wrong with it… somebody who hasn't seen it before will be just looking what's right with it. [Interview 18]

> But, yeah we do have people getting involved in areas that are not their expertise and [other times] they've been left out when it is their area of expertise. We get a lot of people [controllers] who are very against, or have a level of animosity towards that person then, after that project, because they didn't get involved. [Interview 17]

In some cases, those who volunteer to be involved, are doing so for the wrong reasons and therefore do not make appropriate representatives, as shared here:

> Or, that person only got involved because there was overtime involved with that. [Interview 17]

Finally, the results show that end users can make a valuable contribution during the design process. However, the results also show that end-user involvement needs to be carefully utilised. As presented above, there are many ways in which end-user involvement can hinder the technology adoption process. This is also the case for situations when representatives do not have the right type of expertise for the task, when their involvement is too late, too little, considered a token gesture, or when they are required to tell half-truths about the pending technology. Therefore, the above comments illustrate the complexities associated with decisions made during the negotiation of requirements and furthermore, the importance of collaborative and transparent decision-making to allow controllers to come to make sense of, and thus understand why certain decisions are made.

4.6.4.5 User involvement that helps technology adoption

There are a number of ways that end users can be involved during the design process.

1. **Decision to adopt**

Before progressing too far once a problem or need has been identified, it is important to confirm this need with end users to ensure energy is being focused in the right area. This will also support a more positive attitude toward the technology, as expressed here regarding reasons for technology adoption risk:

Employees were not involved in the decision to adopt a new technology. [Survey ID: 199 – Designer]

2. **Planning**

Once the need is confirmed and it is clear that a new technology will be developed, involvement in the planning phase will not only help end users start the technology adoption process, it helps to develop a sense of ownership of the new product, as expressed here:

> Training & familiarisation, early introduction of concepts to all staff, involvement in planning, design and integration phases, leading to a sense of ownership. [Survey ID: 413 – Designer/Engineer]

In consideration of planning, over-planning has been found to stifle new ideas and does not allow for the iterations that are necessary to achieve an optimal outcome that is usable (Douglass & Ekas 2012).

3. Problem definition

The next useful way to involve users is in the achievement of the 'right' ideas, so that the objectives of the technology meet genuine user needs. One way to achieve this is to ensure that end users are involved in checking that the problem definition reflects the 'right' ideas, as offered by this participant:

> Get user involvement as early as possible; preferably as part of defining the specification of what is required BEFORE buying something! [Survey ID: 162 – Evaluator/Safety]

Furthermore, articulating requirements is not always easy. One participant offered that it can be useful to establish what the technology needs to do and what it is not to do, so that some boundaries around what is needed can be established, as suggested by this designer:

> The frustrating thing [was] to get the detail out of them, because the specification wasn't there. So at least if you have some boundaries put in to say we expect our system to be able to do this and we certainly don't want it to do that, it makes it easier to produce the end product. [Survey ID: 14- Designer/Engineer]

However, while end users may be able to help to establish the boundaries of what the technology should do and what it should not do, much of the knowledge on end-user needs contains 'how to' information, which is tacit in nature (Johnson, Gatz & Hicks 1997; Seurat 1979), and this knowledge has frequently been accumulated over many years (Robinson 1988). Therefore, to articulate requirements into an accurate design specification, it is likely that this will need a social exchange of ideas and a means for thinking together (McDermott 2000). This implies that, to properly understand end-user requirements for the development of designable specifications, a collaborative process is required between end users, managers and designers, as suggested by other human factors experts (Pew & Mavor 2007; Wilson & Sharples 2015).

4. Safety analyses

Also during the early preparatory stages, end users need to be involved in safety analyses, as was discussed earlier in the section on viability, so that controllers feel secure that safety

can be assured. When safety is involved, it has been advised that all stakeholders be involved in analysing potential risks, as stated by this participant:

> Involve everyone in analysing the risks associated with new technology. [Survey ID: 121 – Evaluator/Safety]

5. Prototyping

Early and frequent prototyping has been found to be very beneficial to the development of an optimal solution (Maguire 2001; Parker 2012; Serco Usability services 2002) as also offered by this ergonomist:

> Involve end users from the beginning. Early prototyping and real-time simulations technology should help in solving operational bottlenecks. [Survey ID: 70 – Evaluator/Ergonomist]

6. Pretesting

Once the design progresses to the point of observability or trialability, end users can be involved in a variety of testing activities. It is agreed amongst controllers that this testing needs to be 'pretesting', that is undertaken before it can influence safety outcomes, as offered by these controllers:

> If you are going to control this point in the field from this point in here [control room], it should be tested and that's what it does, before it goes live. [Interview 14]

> If we get a new system too! If it's not tested it will cause more damage than good. [Interview 01]

One of the new issues with computer-based control systems is that they are logic based systems, and while they offer much finer and more accurate control, and often contain in-built system protection, no technology is built to perfection. Therefore, an important way end users can be involved is to help the IT developers to fix errors in logic, a process found to take a few years. Therefore, Controllers who have skills in computer logic can make an extremely valuable contribution, as this controller explains:

> You've also got to be prepared to work with the guys who are implementing the mods because some of them don't know the plant very well, so you have to be very patient and explain exactly what the problem is and in some cases you have to actually tell them what they need to do to fix the problem. So a good understanding of computers is essential and also for a place like this, a good understanding of logic, because logic is huge in this place. There are thousands and thousands of sheets of logic. [Interview 10]

However, it must be noted that end users are not necessarily expected to have logic skills, nor are they expected to write programs (Krishna et al. 2005). Furthermore, for those controllers who have to deal with poorly defined logic, the task of fault finding can require great dedication and a realisation that no new computer-based system will be perfect, as this controller explains:

> And the same thing is for the operators, you have to tell them that everything is not going to be perfect when they first take it over and they're going to have to spend some time writing defects or problems. If they're willing to do that they should get a system. The system that works quite well! [Interview 10]

Some cautionary findings need to be noted about end-user testing. Controllers have expressed a need to know that their efforts are meaningful. Therefore, if fault finding is to continue, faults that cannot be remedied need to be communicated to controllers to avoid disillusionment, as expressed by this controller:

> We've talked about it, we've got these changes [identified] and I'm still waiting for them, but anyway. That's years ago, so once again, I don't even bother putting in suggestions anymore. [Interview 05]

Another reason why testing and fixing should occur before the technology goes live is that the solution to one fault may risk creating new faults, as this controller has experienced:

> The trouble was too, if you had a fault, 'let's say we have to test this', fix that fault may create 12 others. [Interview 04]

While it is recommended that controllers get involved in testing, it should not be their responsibility to identify general faults. Rather, the testing that end users should be involved in should be to check that the work they do, under the conditions they work in, can be achieved from the new technology. Their role should not be to fix copious amounts of logic errors, as expressed by this controller:

> I'd draw back and make sure that the technology is working 100% before you introduce it. Because once you start having problems, or you start losing people because there's the big promise because this is better and it's going to work, when it doesn't you have that culture of not wanting to change get worse in people, so probably that. Just make sure that the technology works. [Interview 08]

7. **Level of automation**

The involvement of end users can help to ensure that a suitable level of automation is achieved. There can be many problems with automation if it is not designed suitable for the operator. Appropriate levels of automation are discussed in the next section on Product Outcomes, but appropriate here as this participant suggests:

> [Involve end users for] securing a suitable level of automation. [Survey ID: 246 – Evaluator/Researcher]

8. **Training**

Also discussed later in this chapter, end users can become involved in training, whether through formal or informal modes. For instance, three of the 36 controllers interviewed were 'train the trainers'. That is they were responsible for training their fellow workmates, a useful way to ensure the training is meaningful and context appropriate, as this controller explains:

> A [controller] goes down, designs it, the same [controller] is then incorporated in developing the training packages, they then deliver the training packages to [their co-workers] so it's in terms that the [controllers] will know. Ideally, you would have a group of people that you can deliver the package to, and what we are doing is close to the ideal situation. [Interview 21]

Most controllers mentioned that they not only mentored novice controllers, but they also rely on helping each other out, as these examples illustrate:

> That's what I've noticed, being a new operator. I've learnt all the rules and theory on everything but the difference from learning from somebody who's got experience, even somebody who has a couple of years of experience, you can't beat it as…, those that have got 20 years' experience they just know instantly, it's amazing… [Interview 02]

> You don't get taught everything that happens on the board, you only get taught the fundamental skills and the basics of everything, everything else comes from being hands on, especially if something is a bit strange. And you have to rely on the knowledge of the people around you, like [person's name] who's been there forever and a day. He says "yeah mate that's happened to me about 15 years ago and I did this and we fixed it," and I go, "…okay" and it's right. [Interview 01]

9. **Parallel introduction**

To phase in the introduction of the new technology is a recognised good practice for safety-critical environments. A common practice is to run both the new and the old systems in

parallel. This process not only staggers the training needs, it also provides a ready emergency backup (old system) should the new system fail for any reason, as explained here, only the term 'ghosting' is used instead of parallel operation:

> So that people aren't doubling up and you come into errors. They stay in the new [control room], working on the new system and ghost it, so that you can slowly tick off different functions, then as we start to meet all the actual goals and guidelines then we can slowly start to take over roles in the new [control room]. Whilst all that is happening, we have training in the background so that the core group of people that are initially in the new [control room], and those in the old [control room] can gradually progress across to the new [control room], then the bulk of the work is done in your new [control room] initially ghosting the old, and somewhere in the middle (half and half) and then we take over the main functionality in the new [control room] whilst still having the old [system] there as a backup if something does go wrong, if unforeseen, and basically then, the last person in the old [control room] turns the switch off and goes to the new one. [Interview 21]

Table 4:14 provides a list of participant contributions that identify how factors within the design process can help or hinder end-user adoption of new technology.

Table 4:14 Design process descriptors that enable or inhibit technology adoption

Attribute	Enable	Inhibit
Approach	Iterative, human-centred; user-centred; participatory; shared decision-making; considers perspectives of all stakeholders; flexible yet structured; well executed; adaptive system development life cycle model; well-structured interactions; designed around business processes and the end user;	Overtly structured, rigid, engineering-centred; no consideration of the end user; tunnel vision
Participants	All stakeholders; developers, engineers, management, users and human factors people; actual users, not just users but end users; appoint a project manager;	Did not involve end users; only geeks and techies; human factors experts not involved in the project from the outset;
Planning	Well planned; establishment of a risks and issues register, that is updated as project progresses; Involve everyone in analysing the risks; consideration of end-user shift work;	Lack of end-user participation in the planning process; risks not identified; failure to prepare the process, re-engineering, or sound business case/justification.
Development	Early involvement of end users and human factors experts; users to provide functional and user requirements; to check that the problem definition caters for user needs; human factors experts (or end users) to ensure user requirements are not negotiated out; user involvement based on task analysis; ensure system contains data end users understand; build around the	Lack of understanding and common agreement on requirements and defining how these can be measured; late involvement of end users; late involvement of human factors experts; ignoring requests for changes to the programming prior to installation; not upgrading or responding to feedback; failure to

Attribute	Enable	Inhibit
	user's conceptual model not the designers; early introduction of concepts to all staff; encourage a sense of ownership in end users; users to help secure a suitable level of automation; obtain shared knowledge and shared outcomes (users, managers, developers); acknowledge that what is not important to one user may be very important to others; a sense of urgency; do not over complicate requirements; listen to users; document process; build satisfiers into the experience; early and often prototyping; designer tunnel vision; continued user engagement.	involve users; failure to consult with end users; representative end users are removed from usual work environment for too long and lose touch in their usual work environment; death by over-consultation; poor requirements management; failure to fully appreciate the systems processes; failure to document processes; failure to adopt recommendations; poorly scoped in comparison to existing technology; no baseline established to build and bridge gaps; low quality project management;
Testing	Proper pretesting by end users; Defects rectified and stable before implementation; tested thoroughly with selected subject matter experts, experienced users, early adopters; re-evaluate and assess for improvements; know how it can fail; strong beta testing; test in real world scenarios and real-time simulations; test not the technology but the user's perception; seek feedback from as many 'test drivers' as possible; test in a mock up not real operational situation; conduct user acceptance testing; conduct situational awareness testing; simulate several critical situations and operate system against its manual; use training to test tech compatibility.	Wasn't tested to determine suitability with users; no pilot runs; wrong or inaccurate interpretation of test results; failure to conduct pre-implementation testing; failure to verify user acceptance;

4.6.5 Product outcomes

Reasons for poor technology adoption due to product outcomes were found to fall in a number of categories. To encourage end-user adoption, technologies need to be: (1) the 'right' idea, (2) beneficial to the operators, (3) be functionally and technically reliable, and (4) compatible with existing systems in terms of human, organisational and other technical systems. These findings can be categorised into the two broad attributes borrowed from the MIS literature: (1) useful and (2) easy to use. Therefore, these results contribute to the unresolved questions that ask what makes technology useful, and what makes it easy to use (Lee, Kozar & Larsen 2003).

4.6.5.1 What makes technology useful?

This study has found that a technology useful to controllers is one that is the right idea and that it offers some kind of benefit toward their work performance.

1. **The right idea**

According to end users, the most important thing to get right in the design or selection of new technology is to ensure it is the 'right' idea. Controllers expressed that they want the right tools to do their job properly. The achievement of the 'right' idea has been expressed by controllers in terms of 'what it does', 'it's philosophy of how it should work', 'the aim of it', and the ability to 'fix what I am doing', as expressed here:

> Well the important thing is, get what it does right first, then the how is always easy. Just the philosophy of how it should work, that's where it comes from! I'm not interested in the how of it all and the development of it. [Interview 18]

> The aim of it, the outcome, do they really know what we want, what we need? Basically, ask the people exactly what do they want the system to do before you go and do it. [Interview 33]

Sometimes these needs are expressed metaphorically:

> Poor specification of requirements from not understanding [user] requirements. User wanted a turkey but ended up with a chicken. [Survey ID: 298 – End User]

To achieve the right idea also suggests that the new system is able to perform tasks it is designed to perform, correctly and in the way work is actually done, and not as it might be imagined to be done, as this controller explains:

> I don't care how it works internally. I care about how to fix what I am doing. So it is important how it is used in the real world, from the users themselves. [Interview 32]

This finding is consistent with a recognised design principle that the system must be *competent* (Balfe et al. 2012).

Sometimes, the right idea is a top priority need that is not obvious to others outside the control room, as explained by this controller where he needed improved situational awareness, over new computer screens:

> Open up those dark areas. You give me that [large screen] where I can actually see every [vehicle] where it is… If that diagram was put in our room and gave me all the tools that I've

> got now, in regards to the radio, none of that [existing screens] needs to change. All of it can stay the way it is, but let me see it all. That would make a difference. [Interview 34]

In the above account, the controller was requesting a system that allows for greater *visibility*, one that provides all relevant information needed to do his job correctly. This request is consistent with other studies and visibility is a design principle for automated systems (Balfe et al. 2012). Finally, advice provided on how to achieve the right idea shared, included:

> Detailed analysis of the needs of the work and in the potential of technology [Survey ID: 84 – Designer/Developer]

> Making sure that the technology fits the intended task. [Survey ID: 99 – Design/Engineer]

> Get user involvement as early as possible; preferably as part of defining the specification of what is required BEFORE buying something! [Survey ID: 160 – Evaluator/Ergonomist]

2. Beneficial

Another useful attribute is that the technology offers some benefit to its operators. For instance, participants indicated that new technology is considered beneficial when it either offers some form of work performance improvement for the controller, or at least does not make work any harder or worse. Performance improvements identified include various forms of functionality, such as helping to improve work consistency, efficiency and quality of work, and easing workload somehow.

As control systems become progressively more automated, changes required of controllers need to be careful considered. Therefore, those that do not create too great a change in work processes are considered beneficial to end users, as this ergonomist advises:

> Take into account the way former work was done and don´t bring new constraints into the new situation implying a too big change in automatisms or rules to apply to workers. [Survey ID: 24 – Evaluator/Ergonomist]

Positive experiences with new technologies have been found to instil trust (Gefen, Karahanna & Straub 2003) and thus are more likely to encourage acceptance that leads to technology adoption. Advice on how to deliver real benefits is offered by this designer:

> Make sure it can deliver real benefits (e.g. efficiencies, easy information, more consistent or better quality) to those who use it. This should be part of the initial design, and should be

> checked before implementation to ensure that it has not been compromised out. [Survey ID: 346 – Designer/Supplier]

Conversely, technologies not considered useful are those that do not offer any benefit to the operator. Therefore, unbeneficial technologies are likely to hinder end-user acceptance of the system. Examples of technology traits that were identified as not being useful included technologies that create some loss, or are perceived as unnecessary. Perceived losses included increased workload, requiring excessive user input or monitoring duties, evoking fear of job loss and uncertainty, automation that does not communicate with the user, decreased performance and efficiency, and personal losses such as an undesirable shift design, loss of work benefits, reduced cash, and lifestyle losses. Technologies that are considered unnecessary have been described as those that do not meet end-user expectations, those perceived as gadgets, those that have no demonstrable positive effect, and those that do not realise any benefit.

3. Functionality

In most cases, benefits arise from the way the technology allows the human to function and thus the system can be considered 'fit' for human use. As control systems become increasingly computer-based and automated, new concerns for functionality arise.

To be of any use, the data presented to controllers needs to be *understandable* to them, a recognised design principle for automated systems (Balfe et al. 2012), as expressed by this ergonomist:

> Ensure that the system contains data they know and understand. Ensure the developers build around the user's conceptual model not their own! [Survey ID: 403 – Evaluator/ Ergonomist]

As well as understanding the data presented, the information required must be relevant and readily available to the operator, for reasons that this pilot explains:

> The black box effect making impossible the right answer to any situation unless it is previously foreseen. [Survey ID: 147 – End User]

As the above participant explained, the need to be left in the control loop is consistent with other studies that reported problems in control when progressive automation removed the information necessary for operators to make remote control decisions (Farrington-Darby et

al. 2006; Joe et al. 2014). To be removed from the control loop has also been found to reduce the operator's ability to develop an accurate mental model of the system, and thus undermines the achievement of situational awareness (Pickup at al. 2007; Pickup, Wilson & Lowe 2010). Thus, automation must make the relevant information *visible* to its operator, a recognised design principle for automated systems (Balfe et al. 2012).

Similar to visibility is *observability*, whereby the automated system must provide the necessary feedback to ensure the operator can know what the technology is doing, its current operational state (Balfe et al. 2012), as this participant implies:

> The Rasmussen rule: 'The operator has to be able to run cognitively the program that the system is running. [Survey ID: 147 – Evaluator/Researcher]

Another useful attribute for controllers, is that the technology allows them to direct the system to do what they want it to do effectively and with little effort, and thus the technology must have the recognised design attribute of being *directable* (Balfe et al. 2012), as this controller illustrates:

> You let me see all that with the [work colleagues] that I have on the floor here and we can run a service and be frequent. Not run to a timetable, but guaranteed that I will have a [vehicle] there every 3 or 4 minutes. And then I'll change it. If it is running 4 [minutes] late, I'll change that [vehicle] into something else. The public won't even know. You do that and that would just, it'll be a massive difference for this company, and for [the city]. [Interview 34]

In consideration of progressive automation, an important functionality that makes automated systems useful is to continue to allow the controller to be in charge of control. Therefore, a useful system is one that is *accountable* to the controller (Balfe et al. 2012), as this ergonomist identifies:

> Critical tasks should not be automated. Keep the human in the loop such that the human can still be the final decision maker and technology is supporting this and the cognitive processes of the human operator. [Survey ID: 70 – Evaluator/Ergonomist]

With the rise in remote control, operators increasingly find that those technologies that allow them to follow trends can give them the ability to pre-empt failure. This attribute is a known design principle for automation, as it helps to facilitate *proactive control* (Balfe et al. 2012), a very useful functionality, as this controller shares:

> I need to know the status of the equipment, remotely, but I should also be able to interrogate it. It [needs to] bring back the information that is out there and I [need to] access the information that's out there. It needs to tell me the current state of where it is now, but also the history, so we can see the trend, get some information to make an analysis of what's been happening. [Interview 18]

An example of how proactive control is achieved has been shared by this controller:

> For instance, a recloser might be tripping every two hours, or every two days or something like that, and you have a look at that and you think, "oh shit, there's probably a tree near the line," or something like that. So you can get on guys, "next time you're out there, just have a look and see if there is a tree near the line," you know, that might be the case just when the wind blows from a northerly direction which would be unusual, but once it blows in that direction, it might just blow the tree closer to the line and we might get a trip and a reclose.
>
> So instead of having to wait until there is an outage to find it, you can get it knocked off before hand, so that improves continuity of supply to your customers and it also reduces your maintenance, because eventually the tree will go like that until it burns the cable, or something like that, and it'll snap and drop to the ground, and you've got to go out and fix it. [Interview 18]

Reliable systems are also considered useful. *Reliable* systems are those that function in a consistent manner (Balfe et al. 2012), as illustrated by this technician:

> Ensure it works the first time before operations lose confidence in the new system. [Survey ID: 37 – Designer]

Closely associated with reliability, are systems that are *robust*, that are capable of working even under less than normal conditions (Balfe et al. 2012), as this controller shares as he tests the technology under as many different scenarios to check the robustness of the system:

> Our involvement then becomes to look at, learn it and try to break it in the testing phase. Then after some years [when] it's been proven to be effective, we then dispense with previous processes which we used to support the [particular] system. [Interview 03]

To maintain reliability and robustness, participants recognise that manufacturers will need to provide an adequate service level. As mentioned previously, reliable technologies that consistently work as expected instil trust (Gefen, Karahanna & Straub 2003).

Conversely, an unreliable system would have the reverse effect and thus would not be considered useful. Unreliable systems as described by participants include those that have intrinsic defects, increasing numbers of unfixable failures, do not work as intended, have 'bugs' or 'glitches', have high false alarm or miss rates, lack spare parts, and those that do

not have available technical support to maintain the system. The past idea that higher levels of automation were always advantageous (Hollnagel 2010) is a recognised problem today, as this participant offers:

> Overtrust in technology leading to a higher level of automation (LoA) than suitable. Often the LoA [level of automation] has not been measured and evaluated against the planned work tasks, and the intended support the technology will give. [Survey ID: 249 – Evaluator/Ergonomist]

These findings are consistent with the literature that also reports that operators need to trust their automated counterparts (Balfe et al. 2012). Automated systems that do not allow the operator to make appropriate control actions will quickly undermine their trust in the system (Parasuraman & Miller 2004). Therefore, functionality is an important attribute for the achievement of overall system competence in control room environments.

4. Compatible

Technologies that are not compatible with existing systems (i.e. human, organisational and technical) can cause workflow disruptions and, in other cases, may be useless. Therefore, being compatible with existing systems can be a step towards a useful system. To achieve compatibility, systems are to be designed to fit the human operator, as offered here:

> To the extent possible the technology should not require changes of the end user. [Survey ID: 151 – Designer/Engineer]

The incompatibility of systems is often noticed when workers begin to work in alternative ways to make the system work, as identified by these participants:

> Difficult to use, non-intuitive user interface and 'workarounds' due to lack of compatibility with other systems that also have to be used [Survey ID: 289 – Manager]

> If the technology does not prove to be useful or work as intended, if it is not intuitive or somewhat transparent, and/or if it is buggy, users will resist, resent, or find workarounds. [Survey ID: 214 – Evaluator/Ergonomist]

The above quotes illustrate the importance of designing for work as done (how work is actually accomplished), rather than work as imagined (how the work is expected to be done) or work as hoped will be done (Hollnagel et al. 2011). Inconsistencies between work as imagined and work as done introduce system vulnerability to failure due to the unpredictability and added burden they impose (Hollnagel 2008; Woods 1993). The

inconsistency gap has been described as the design-reality gap (Heeks 2006). Heeks argues that the distrust that develops in new systems stems from incompatibility between the design and realty-of-use and offers that by reducing this gap one reduces risk of systems failure.

Technical incompatibility can result when interfaces between systems are not well integrated [Survey ID: 429 – Designer/Engineer] or when the existing infrastructure does not support the new system [Survey ID: 150 – Manager]. Reasons behind incompatible systems shared by participants include:

> If a product designed for a different scenario is bought 'off the shelf' and then an attempt is made to try to tweak it to fit the new application, usually results in an unsuccessful way. [Survey ID: 323 – End User]

> The manufacturer does not know the environment of the operation, weather, frequency [of use] and level of [operator] knowledge. [Survey ID: 209 – Manager/Logistics]

Concerns over compatibility are consistent with the literature that states for a design to be fit for users they must also be compatible across all systems (Wilson 2000), such as existing technical (Beatty, Shim & Jones 2001), organisational (Ghobakhloo et al. 2012; Premkumar & Roberts 1999; Premkumar 2003), and human systems (Luecke 2003; Rogers 2003). More specifically, greater compatibility through standardisation, interoperability and interconnectedness has been found to influence technology adoption positively (Chau & Tam 1997). Furthermore, these findings are consistent with leading HFI authors who recommend designing for optimal system compatibility for wellbeing (Booher 2005; International Ergonomics Association 2016; Norman 1983; Pew & Mavor 2007; Wilson & Sharples 2015).

One reason why designers may become complacent about incorporating human factors is that people are very adaptable, and as such, are their own worst enemy. However, adaptations such as: improvised solutions (e.g. workarounds) have been found to have long-term costs to health, job satisfaction, and safety where emergencies or unexpected events occur (Wilson & Sharples 2015).

4.6.5.2 What makes technology easy to use?

Technologies that are easy to use have been described in a number of ways, such as: user-friendly, intuitive and usable. Essentially, these terms imply the design qualities make it easy

for the user to interface and interact with the new technology. Therefore, many useful traits can also make it easier for people to use. Characteristics offered that make a system easy to use, shared by participants, include technologies that have appropriate error tolerance levels, do not require further calibration, are easy to adopt, are similar to the previous system, provides easy information retrieval, takes into account how the way work is done, and do not introduce any new constraints, such as: additional rules or changes in automation. The quote below shows that technologies that are difficult to use tend not to be used or not used to their fullest potential, as this controller notes:

> Well, the HMI [human-machine interface], the biggest area with that is when you have to move labels around on the screen to de-clutter it to work out what is what. And there're lots that it can do. [We] probably use maybe 5 to 10% of what goes on with that. [Interview 27]

Furthermore, technologies that require effort to adopt have been described by participants as those that are overly complicated, those that change workflow completely, are an imposition, require high levels of learning and effort to unlearn old practices, and those that affect current working pace and proficiency. Table 4:15 provides an overview of the attributes of the new technology that participants identified to enable or inhibit technology adoption.

Table 4:15 Product outcome factors that help and hinder technology adoption by end users

Attribute	Help	Hinder
Right idea	Caters for high priority need; fits task intended for; helps user or owner to succeed in accomplishing their mission; Technology is designed to fit the human;	Does not solve the problem it was designed to; does not meet end user's needs; not fit intended purpose; not fit for purpose; meets all requirements defined by the engineer dysfunctional interface;
Functionality	Reliable: works the first time it is used; Robust: good service level from manufacturers; Competent: does correctly as it is designed to; Visible: necessary information readily available; Observable status: provides feedback, human kept in the loop; Understandable: user roles and	Unreliable - has fatal (intrinsic) defects; does not work as intended; buggy; high false alarm or miss rate; increasing number of unfixable failures; Not robust: lack of spare parts; lack of technical support; Incompetent: does not support the user; Information not visible: automation does not communicate with the user; Status unknown: there is a black box effect (i.e. not situational awareness);

Attribute	Help	Hinder
	perceptions are incorporated, operator can run cognitively the program that the system is running; Accountable: human is final decision maker; Directable: enables work to be done as user's desire, critical tasks are not automated, designed with varying degrees of human intervention from fully automatic to fully manual; Proactive control: track trends, can interrogate	too hard to understand: overly complicated; too hi-tech; too advanced for the end user Not accountable: not somewhat transparent; Not directable: excessive trust in automation leading to higher level of automation than suitable;
Benefits	Appropriate level of error tolerance; similar to the previous system; solves operational bottlenecks; is easily adopted; saves time; eases work tasks; does not reduce current functionality; more efficient; easy information retrieval; more consistent; better quality; takes into account the way work is done and doesn't introduce new constraints (e.g. additional rules, change in automation)	Too complicated; adds to workload (requires too much user input or monitoring); requires a large amount of learning; it changes workflow completely; decreases performance and efficiency; imposition; a gadget; no demonstrable positive effect; personal losses (i.e. new shifts, loss of benefits, cash, lifestyle); evokes fear of job loss; uncertainty; requirement to unlearn old practices (affecting current speed and proficiency); not intuitive; unfriendly; alters or change the user role or task; over emphasis on output (manager needs) with little or nothing from the input (user needs); not better than the previous system; slower than standard tools (e.g. a pen);
Contextual compatibility	Compatible with current systems (seamless integration); customised for new workplace; interacts appropriately with people processes and other systems;	Unforeseen systematic incompatibility; not supported by existing infrastructure; does not interface with existing systems; does not fit current workflow; incompatible with processes and procedures; 'off the shelf' but tweaking fails compatibility; user has to adapt to make it work; lack of consideration of human factors; inadequate attention to how people will use it;
Expectations	Works as intended	Operates differently in reality than training

4.6.6 Implementation

Results found a number of factors that influence the adoption of new control-room technology that is concentrated during the implementation phase. Once a well-designed

product is considered ‘fit’ for human use, has been developed, successful implementation is reliant on operator skill to competently use the technology. The achievement of technology adoption is also reliant on how desirable technology adoption may be perceived to warrant the effort that will be needed to become competent in the new system. Therefore, two primary areas of influence emerged from the data, firstly the end user's ability to adopt the new system, and secondly their desire to adopt. Both of these topics are discussed below.

4.6.6.1 Ability

While some of the onus falls with the individual controllers to take the steps to ensure they fully understand how to operate the new equipment, support from the organisation can go a long way towards positive technology adoption outcomes. Organisation support can be demonstrated in the following forms of management, learning, technical and social support provisions.

1. **Management support**

Participants shared that management support can be demonstrated by how they resource various activities. For instance, controllers recognise that training that allows them to learn in a safe environment can only occur if time off the desk has been resourced as part of the project commitments, as shared by this controller:

> Small classroom based training, better than the individual computer packages, which can be alright as well, but: we have various refresher modules that we do on the computer, you just log in, read this stuff, answer a few questions. I find those of limited value. It is better to get in a group of a few people. They start to ask questions, questions I may not have thought maybe, issues come up and you can knock ideas around a bit. But just individual computer based type training you don’t get that. You need resources to allow groups of people to get away from the work-face to do this sort of thing and so that tends not to happen. [Interview 26]

Project budgets that fail to provide the necessary funds for final training can put the project at risk of not being used, particularly if local management cannot or do not find the necessary funds to support final technology adoption, as this controller identifies as a significant problem to their adoption of new technology and to the public’s safety:

> No. Because they haven’t set it up yet. It’s a budget thing. They spent $40 million on that over 6 [centres] and it’s down to like a couple of thousand dollars to spend and then [local management] just said ‘that’s not coming out of my budget, you [controller] find the time

> [to learn it on your own].' I could not even tell you one thing about it, so there's no way they will expect me to go and use that thing after 2 days training a year ago.
>
> So, it is just sitting there not getting used. It just ridiculous, it is just this manager just says to this manager, 'that's your budget'. There are places overseas where there are controllers in jail because of that sort of thing didn't get implemented. It is frustrating. But, we've been doing without it for years and years. [Interview 27]

2. Learning support

One of the biggest concerns that came out of the data is that training needs to be effective and that controllers need to be skilled before going live with the technology, for reasons that this controller shares:

> Well, the biggest problem is the lack of training. Like it's basically a bit of sink or swim type situation. With the training that I've got for the operating systems I use, has been quite poor. I mean you learn new things everyday obviously, in your tasks but I just think that the training I should have been given to operate those systems should have been a lot more thorough. Certainly because of the ability to use it for what it is meant for and to make sure that you don't make mistakes when using it which could then cause things like [a particular system failure], or anything like that. [Interview 15]

Furthermore, this controller offers that the tools [new technology] are only as good as the training received:

> Basically, to make sure that the appropriate training facilities are there to incorporate the change from the old system to the new system, so that it is not just thrown in and we learn all the things as we go along. Don't allow it to be a sink or swim situation, make sure that the tools are there for us to learn before it is given to us to use. Because the tools are only as good as the training package that shows you how to use them. [Interview 15]

Another concern that emerged from the data is that online training is increasingly replacing other forms of learning. The general consensus across participants is that online training is not suitable for learning how to operate new control-room technology, as this controller notes:

> We've got two problems. All our experienced field staff have gone into an office somewhere so we have lost our experience in the field, that's why we're are getting… I think it is a combination of the online training and the fact that our experienced people left the field is why we are getting all these incidents. [Interview 14]

Online training is a huge concern for controllers and is often viewed as a quick way for management to protect themselves if something goes wrong, as expressed by this frustrated controller:

> You see, it's this whole organisation, this training, all this online training we've got, it's all an arse covering exercise. The online training, it might be there and I can jump on in twenty minutes and do a course on using [a mission-critical communication system] or our phone system and it means jack shit. Because you haven't been put in front of a console, you know, or in a classroom situation where you can discuss things and issues or whatever in a training situation. Yeah, it's just a bit of theory and a few tick boxes, and yep you've passed the course. But no-one's getting enough out of them.
>
> So training is a big issue. It always has been. So that's with any technology, or anything that's rolled out, everything seems to be online training these days and it's pretty frustrating. And all the blokes know how to, not cheat the system, but you don't have to sit there and read every fricken question hey. You could try the test straight up if you want to and get your 80%+, what have you learned? Nothing! You are just doing it, because management says 'you need to do this', they're happy because they have ticked the box. Anyway [Interview 16]

A further problem with online training is that it may not be reliable, it may have been developed by someone who does not fully understand the nature of the work, or it may contain software logic errors, as was experienced by this controller:

> What's my favourite saying, online training is no substitute for real training' its crap. I just did two online courses this morning. But a lot of our online stuff that we've sent our feedback on. They'll ask this question and there are five answers. Next time that question gets asked they'll shuffle up the answers. So the right one might be here, and it might come up to here now, but they still marked it over here, so might have the right answer, but they will mark you down as wrong. [Interview 14]

However, when it comes to using technology that can influence safety, others have advised that a variety of learning opportunities need to be available to cater for different learning styles, as this controller/trainer explains:

> Everyone is different. I guess I'm spoilt as a trainer in this organisation because people who are employed as controllers, basically have to jump through certain hoops to get that position, so I know they can read and I know they can write and I imagine they are not colour blind, and so on. So I think I've got a bunch of smart cookies and admittedly that would be correct. But everyone learns different. Some people are good with their hands, some people aren't. Some people like big pretty colours, pictures and graphics, other people like to read books. Some people like to read it off the computer, other people like the hard copy, so hopefully my training style can address everybody all at once, so I'll mix in demonstrations, graphics, they got the chance to read the computer or have the hard copy book and so on and so forth. But at the end of the day, I want them to do a process, everyone must be the same. [Interview 06]

Essentially, controllers prefer hands-on training and an opportunity to practice without it being able to impact safety. Additionally, hands-on experience before receiving the theory was also identified as a useful strategy for sensemaking, as this controller shares:

> Yeah, it was pretty boring during the nine days of classroom training on a whole new computer system that didn't mean anything because you didn't get to play with it as such, but in the last few days of the course, we actually get in and actually played with it and I'm a visual learner. I can learn by just having a fiddle with it and playing with it. But if you give me a textbook and say now read the instruction manual, straight over my head. Yeah, probably even to get your hands on it, and have a fiddle and a play with it first [before the theory]. It obviously makes a lot more sense then, when you are reading it. You think 'oh that's what they are talking about'. [Interview 27]

Furthermore, practical application takes time for a controller to become competent, as this controller shares:

> I've been in the [control room] for 18 months but I've never had an [approved] rating until about 6 weeks ago, that's the first time, so it is all new to me and everything you have got to just process and rethink and because it is new to you, you check it, you triple check it. Whereas, after 6 months down the track, you become more familiar, you know if something is going to work, it just becomes instinct. At the moment it doesn't come naturally to me and it is just extra thinking power. [Interview 27]

However, controllers recognise that people learn at different rates and that this should be catered for because, at the end of the day, everyone must be ready, as this controller explains:

> Everyone learns at different rates, so you are not rushed. They make sure you are ready for it before they let you loose. [Interview 27]

One shared note of caution is that, even if the training has been effective, new skills that are not rehearsed are easily lost, as this controller explains:

> Actually that training was pretty good, because they had ½ a dozen of those screens set up in a classroom downstairs, and you could play with them and do workbooks that say, do this and this and this and actually play with the machine. But even so, I've probably kept that in my mind for a month, but because I wasn't using it, I lost it. [Interview 27]

One final note that came out of the data is that controllers are generally quite smart, and their ability is possibly why many organisations do not see the need for providing in-depth learning support. Experience in the control room can be used to support the learning of others, as this novice controller shares:

> That's what I've noticed, being a new operator. I've learnt all the rules and theory on everything but the difference from learning from somebody who's got experience, even somebody who has a couple of years' experience, even just watching them, you can't beat it. Those that have got 20 years' experience, they just know instantly, it's amazing. [Interview 02]

3. Social support

Controllers expressed that workloads should not be so high that they are prevented from supporting each other. As indicated in the previous section, support from co-workers is highly valued in the control room, as this controller explains:

> A team within the [control room] itself! There is a significant amount of coordination that will go on to each person. They'll discuss, plans, ideas and what the other people would prefer if we are about to make a decision that is going to affect them… We'll take guidance on the other persons' workload, we'll suggest what is convenient for us and ask what is convenient for them. It's anything like that. We'll interact and see each other almost every two minutes with a query or something. [Interview 28]

The shared experience within the control environments is particularly important for the resolution of perplexing problems, as shared by this controller:

> And you have to rely on the knowledge of the people around you, like [Name of controller] who's been there forever and a day. He says 'yeah mate that's happened to me about 15 years ago and I did this and we fixed it', and I go, '$%/# okay' and it's right. So he's got that knowledge. [Interview 01]

In certain cases, controllers use peer support to compensate for the lack of formal training, as expressed by this controller:

> But then I think we have a workforce in here that is pretty switched on and they're smart enough to ask questions and you know we have a lot of discussions, just amongst controllers ourselves. We probably get more stuff resolved out there [in the control room] than involving management. [Interview 16]

4. Technical support

One final item of support is the need for technical support, particularly during implementation and the early stages of transfer, as this participant advises when transferring across to the new system:

> Ongoing support for users including technical backup available within specified (short) time frames [Survey ID: 05 – Evaluator/Safety]

The above quotes help to show that support to adopt is very important, and particularly so during the early stages of implementation and early post-implementation stages.

4.6.6.2 Desirability

One factor that can help to expedite the adoption of new technology is if the end user actively desires to proceed through the adoption process. This section provides some insights into how this desire to adopt might be instilled.

1. **Technical preparedness**

A well-designed product that is proven technically sound will go a long way to the achievement of being a desirable product to adopt and therefore technical preparedness is paramount. For instance, when controllers feel insecure that safety can be maintained, the product will be viewed in a less desirable light, as expressed by this participant.

> Test it thoroughly using selected SME's [subject matter experts] and debug it beforehand. Employees will reject it if they feel at all threatened, and something goes wrong while they are using it. [Survey ID: 234 –End User]

Therefore, all the preparatory work mentioned in the previous sections helps to build end-user confidence that the system will deliver on their needs and is thus viewed as desirable to adopt. For instance, having an organisation that has strong values goes a long way towards decisions made on the design of the new product. Studies that have been conducted to check feasibility of the proposed outcome can help to plan for an appropriate product that is realistically achievable, otherwise, it runs the risk of being compromised, as this controller shares:

> I guess, I would look for in any new technology is that it would be complete. One of the things that have frustrated me, working in this organisation over the years, is that they will come up with a plan to do something and it will be great what they want to do, but invariably it seems to get watered down, it's going to be too expensive and you end up with a half-baked thing at the end if you get anything at all. And it becomes a daily frustration to work with these systems that are not quite right – not as good as they could have been. That's the kind of thing that tends to happen, you get these things, almost complete things [Interview 26]

Some of these problems can be mitigated by obtaining stakeholder input during feasibility studies, and by constant checking to ensure the product can be realistically achieved. A technology that has been prepared well for implementation will go a long way towards it being desirable to adopt.

2. **Controller preparedness**

The next step is to ensure that the controllers are prepared for the pending implementation process. To be well trained is only a small part of becoming prepared. For instance, preparation starts from initial awareness that a new product is being considered. At this point, controllers have said that they want to know about it. Early commencement of sensemaking activities allows time for end users to resolve uncertainties and to become acquainted with the new system as its development progresses, as this quote implies in response to factors that put end-user technology adoption at risk:

> There is not time to grapple with the novelty. [Survey ID: 53 – Evaluator/Researcher]

As identified earlier, end users want to know that the new product is something they need and that it can be achieved safely and completely. All of these factors influence likely desire to put effort into becoming competent in use, well before ever going live. Failure to help controllers become prepared early puts implementation and thus user adoption, at risk as explained by these controllers:

> To make those changes, they've got to have some sort of consultation prior to it, instead of bringing it along and dropping it on your lap. [Interview 05]

> So now they [management] have to decide what they want because otherwise if we don't like it, we won't operate it, we won't accept it. [Interview 33]

Early preparatory action includes two-way communication to ensure end users understand the benefits, but also so that they have the opportunity to ask questions, and to be listened to. Resolution of fears and uncertainty is important to the technology adoption process (Rogers 2003). Part of this communication includes being able to understand what will be expected of them during the change, and how the transitioning process will occur. Opportunity to test the developing system has also been identified as a way to help prepare end users, as this quote offers:

> There's so much… resistance to change, that I think that any sort of change when it comes to [certain system] is going to have to be thoroughly, thoroughly tested amongst [the] controllers so that they have a good idea... Certainly a workstation for everyone to test it would be great. [Interview 28]

Sometimes, organisational incentives can help to motivate end users, as suggested here:

> I've noticed that the older I get, the slower I get and the harder it is to learn something and you get less enthusiastic as well. When you are young at the start of your career and back then, it was a pay scale sort of thing, you want to be seen keen and get all the ratings, and so

> you can jump up on the higher pay scales. But I've been on the top pay scale for years, so it just doesn't matter anymore, that is not an incentive, and at the end of the day you are employed to do a job and it is up to you to make sure you are up to standard. [Interview 27]

However, incentives do not work for everyone. Developing ownership of the project has been identified as an effective way to achieve technology adoption. The following quote shows how a group of controllers achieved ownership of the part of the project that impacted them and how this led to their adoption of the new system:

> [Name of controller] will be involved in the training because he's been involved in the setting up the local adaptations for all of these technologies and we've had him on the project from day one, so what we've done is, he is most familiar with it, so he'll go away and do a Train the Trainer course and he'll come back and show us how to work the whole system. [Interview 20]

At the end of the day, controllers need to be confident that they can use the technology and use it safely, as this quote suggests:

> Yes, and be confident. I never understood that when I went through the College, but it becomes very evident in the field that you need to be 100% confident in your decisions. [Interview 28]

3. Execution

Controllers recognise that the moment things change in the control room trigger distractions from awareness of a potential risk to safety, as this controller explains:

> Yes, I think they have determined that this is the system that allows them to operate optimally and to be flexible within that system and the moment that the system begins to change, that's when things become distracting to them. [Interview 28]

Controllers have been known to strongly resist adopting something new when they perceive the change will undermine their ability to fully concentrate on their job, as this controller shares:

> Yes they are very small [changes], very simple to anyone else's understanding as was mine. But had I first had come here it would have appeared a very minor change, but something as minor as that has actually has some very strong opposition. [Interview 28]

Table 4:16 provides a list of participant contributions that identify how aspects of the implementation process can help or hinder end-user adoption of new technology. A summary of the technology adoption enablers and inhibitors is presented in Appendix A4.8.

Table 4:16 Implementation descriptors that help and hinder technology adoption

Attribute	Help	Hinder
Management support	Lots of timely information; available to help smooth transition; End users are given plenty of warning; sufficient resources for training and for resolving unexpected issues.	Implementation not planned; not present with users during changes; no incentives for staff (work satisfaction, work efficiency).
Technical support	Developers are with the user to establish new system and tools; the expert user is available during day shift and by phone during night shift.	Failure for ongoing technical support or quick backup; no expert to call on to remedy perplexing problems.
Learning support	Face to face and classroom training; seminars explaining how it works; training the increases operator's understanding of the technology and the risks; when on new application, mentored with a master operator; training applicable to industry sector; training is timely when user is ready, just before they need to use it; confidence is achieved; continuous repetition of training; prior training before expected to use; mentorship; relevant training including realistic simulation of the new technology; practices on simulators; training in context; on the job training; theoretical and practical instruction; education of end user must match as required to use new technology; people using the technology get the most training.	Online training; over complication of simple procedures; training as an 'add on'; little to no training; failure to develop training and mentoring roles within the organisation; tacit, 'how to' knowledge is not transferred to client; manual is not understandable; manual has key information missing;
Technology transfer (phase-in)	Phased introduction; two teams, one on new, the other on old as a backup; run new and old systems in parallel until phased in.	Parallel operations of old and new are perceived competitively, or that those on new are somehow better.
Contingency planning	Fall-back position during phase-in for emergency/unusual situations; old system remains in situ for backup if required; maintain some of the old competence (also for maintenance) of old equipment until all teething problems are overcome; identify as many potential sources of error introduced by the technology; monitor usage so that problem areas can be identified and addressed.	Usage was not monitored and users reverted back to the old system.

4.7 A Systems View of Technology Adoption

To examine the results using systems thinking each of the six thematic areas found to influence technology adoption and system success was represented in the four levels of thinking model as developed by Maani and Cavana (2007). Figure 4:11 provides a systems thinking perspective to show how the various underlying categories might be placed within

an iceberg analogy, where the events are those that appear above the water line, and thus represent the observable symptoms, the by-products of the underlying conditions.

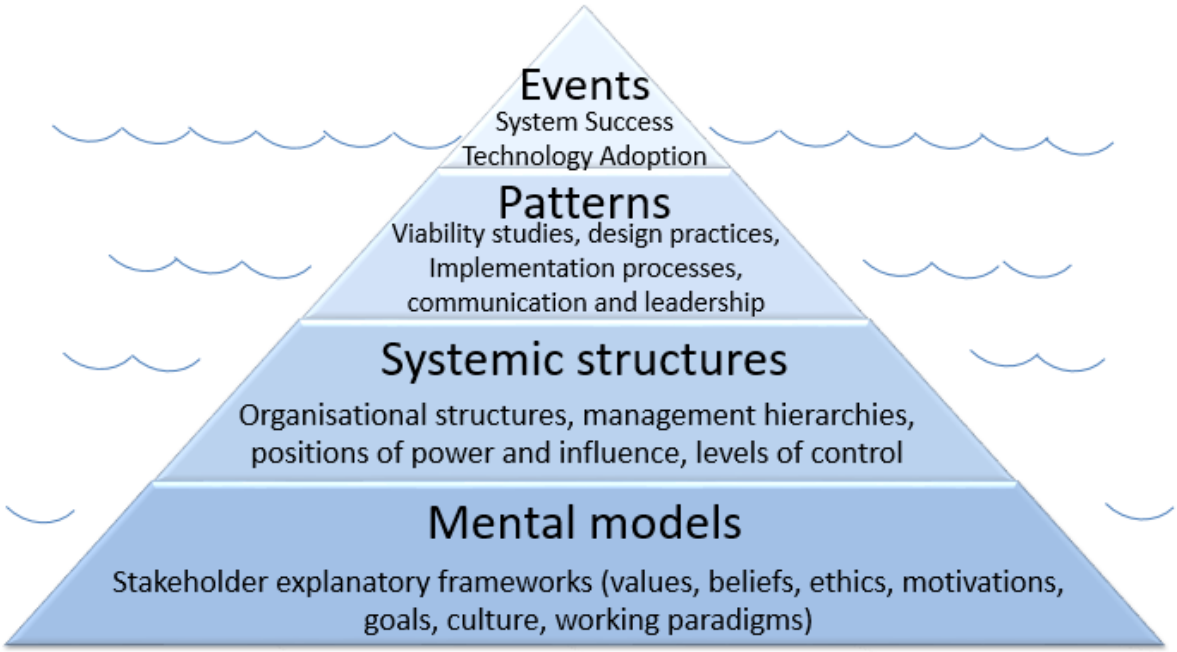

Figure 4:11 Underlying factors that influence system success

Adapted from: Bosch, Maani and Smith (2007, p. 60)

Results from this study showed that a focus on system success leads to an emphasis on technology adoption and system success, symptoms of underlying conditions. Alternatively, a focus on end-user adoption of technology puts greater emphasis on patterns and processes of work such as: the design process, viability studies, communication and implementation. A focus on technology adoption also extended to organisational matters and the mental models of the organisational leaders such as integrity, honesty, and values. Figure 4:11 shows that the patterns of practice directly influence technology adoption and system success outcomes and thus more readily observed; systemic structures that influence the way individuals work are harder to observe and include how organisations are structured, personnel hierarchies, positions of power, authority, and influence.

Results showed that deeper level thinking resulted when problems were experienced in the control room. For instance, when work patterns of behaviour were perceived to be incongruent with optimal system outcomes, controllers began to question organisational values, ethics, and motivations. Therefore, a focus on technology adoption can produce

deeper level thinking than occurs when focused on system success. Table 4:17 illustrates this point by showing the areas of emphasis when the focus of thinking is on systems success in comparison to technology adoption.

Table 4:17 Frequency of themes that influence observable achievements

Focus: System success	Freq.	%	Focus: Technology adoption	Freq.	%
1 End-user tech adoption	142	25%	1 Design process	224	33%
2 Product outcome	109	19%	2 Implementation	170	25%
3 Implementation	96	17%	3 Organisational factors	114	17%
4 Design process	92	16%	4 Viability	61	9%
5 Organisational factors	83	15%	5 Product outcome	55	8%
6 Viability	43	8%	6 End-user tech adoption	51	8%

Therefore, the findings show that a focus on technology adoption can provide a more informative way to address the underlying factors than a focus on system success. Of note is that a focus on technology adoption is not an explicit domain for HFI or a specific focus of human factors engineers. In light of problems associated with new technology interactions, it seems prudent to include the interactions experienced by end users as they interact with new technologies as a human factors concern. Therefore, the approach taken to focus on the underlying factors that influence technology adoption has been found useful for this study.

4.8 A Discrepancy in the Findings

While progressing through the results, it became apparent that controllers were not being involved in new technology projects in ways that were conducive to technology adoption. This finding was incongruent with earlier findings that revealed an overwhelmingly high regard (i.e. 97% of all stakeholders) for obtaining end-user input. Furthermore, most (81%) surveyed respondents indicated that user input was valuable. However, in reality, the involvement experience of participant controllers was found to be infrequent and often damaging to technology adoption outcomes. Of the 36 controllers interviewed, only one-third (*N*=12) indicated that they had experienced some form of involvement in a new

technology project that they viewed as appropriate. However, frequently if involved, their involvement was often too late to make a significant difference, and many were not consulted at all. In other cases, their involvement was detrimental to adoption outcomes. Therefore, the experiences of controllers are contradictory to the intentions of stakeholders.

The achievement of early user involvement has been problematic for many years (Woods 2002), leading engineers to rely on intelligent guesswork when it comes to catering for the needs of users (Chapanis 2015). Thus, lack of user input during concept development may explain why other scholars have noted that the engineering design process is not supported to achieve HFI (Ferreira & Balfe 2014; Norman 2010; Woods 2002). Therefore, advice provided by study participants to involve end users can help to develop methods to resolve this disparity between stakeholder intentions and end user experiences. Examination of viewpoints on the introduction of new technology may give some clues to why this disparity in the findings exists.

4.9 Summary

The results presented in this first study phase represent an attempt to explore the underlying factors that influence how end users come to adopt new control-room technology. Quotes have been used extensively to give the end users a voice on the topic and to enhance the significance of the quantitative results.

The results have shown that technology adoption is a concern to all stakeholders of control-room technology. The variables selected from the literature were found to represent half (49.6%) the total variance of opinion on matters that influence technology adoption. Gender was the only variable not found to influence technology adoption of end users in control rooms. Participants indicated that end-user input was the top factor for the achievement of technology adoption and system success.

Sensemaking was found to be an important predictor of how an individual adopts new control-room technology under mandatory conditions. The results showed that three dimensions of sensemaking explained 20.8 percent of an individual's technology adoption *state*. The statistically significant sensemaking dimensions were: *plausibility* (opportunities

that allow for plausible meaning to be created), *fears* (the negative emotional response to conflict or uncertainty, and *reality* (opportunity to enact the plausible meaning created). The prediction score, while modest, was considered useful, as a study of this kind has never been conducted before. Therefore, this study provides a useful starting point for future studies that wish to investigate the influence of sensemaking on how individuals come to adopt new technology.

Of further note, the results showed that technology adoption increases as end users come to make greater sense of the new technology. However, sensemaking is uniquely individual. Therefore, it is difficult to know whether sensemaking can fully bring an individual, or group of individuals, through to complete adoption whereby they become expert users of the new technology. Nevertheless, the results from this study suggest that sensemaking may at least satisfy end user needs and is thus useful towards achieving system success.

Analysis of the qualitative data helped to enhance the statistical significance of this study by revealing six thematic areas that help or hinder end-user adoption of new control room technology. These themes are organisational factors, viability, the design process, the end product outcome, implementation practices, and end-user technology adoption. The results showed that the six areas are bi-modal in that factors can either lead to technology adoption or user resistance, and thus help or hinder technology adoption. Furthermore, the results showed that the six areas represent the duality of technology adoption and system success. A summary of the technology adoption enablers and inhibitors is presented in Appendix A4:8.

In meeting the first research objective, mixed methods successfully revealed matters of statistical significance, as well as providing an opportunity to explore new knowledge. In this way, mixed methods provided a useful means for moderating any researcher bias that may have been apparent when selecting study variables. Furthermore, the MIS literature was useful for establishing a first set of variables found to be transferable to a safety-critical context.

Quantitative data analysis provided a means for testing a newly developed scale for examining technology adoption from a sensemaking perspective. To strengthen the

reliability of the scale results from qualitative data analysis provided insight into how to develop the scale further in the event of future research studies. Qualitative data analysis also enabled greater depth of investigation and disclosed a number of other conditions, in addition to sensemaking, that influence technology adoption in control rooms. Interviews with controllers provided greater insight into how end users are affected when the adoption of new technology is mandatory, and how new technology is currently being introduced into safety-critical work environments.

Application of the sensemaking perspective proved useful for exploring factors that influence an individual's technology adoption state. Sensemaking was found to be an important predictor of technology adoption, highlighting the need for early end-user involvement in new technology projects. This finding was particularly important since end users are typically tertiary technology adopters in large corporations.

Finally, participants in this study have helped to provide greater insight into the issues modern controllers face when expected to adopt new technology. In so doing, this study provides a more holistic picture of technology adoption in control rooms and how new technology is currently being introduced. These findings revealed a discrepancy between stakeholder opinion and their actions, a matter that requires further investigation to better understand. Therefore, this study contributes to the literature on technology adoption in mandatory situations, and in particular from a safety-critical perspective.

4.9.1 Limitations

It was noted that sensemaking is unique to each individual, and therefore, sensemaking alone may not account for all facets of the technology adoption process. For instance, the awareness that a new technology is being considered is reliant upon other stakeholders to make end users aware. Therefore, while sensemaking may help to bring the users closer to the technology and thus help to close the technology adoption gap within organisations, it is unlikely to fully close the gap. In light of these limitations, it has been recognised that while the sensemaking perspective may not fully close the technology adoption gap, it can help to satisfy end users and help to inform decisions made in regards to more productive design processes and the development of effective implementation strategies that commence earlier than is current practice.

Chapter 5: Results and Analyses – Phase Two

5.1 Introduction

This chapter provides the results of the second research phase conducted and thus represents the second set of results as highlighted in Figure 5:1. Q methodology was used to meet the second objective of this study, 'to explore viewpoints on how to best approach new technology projects for control rooms.'

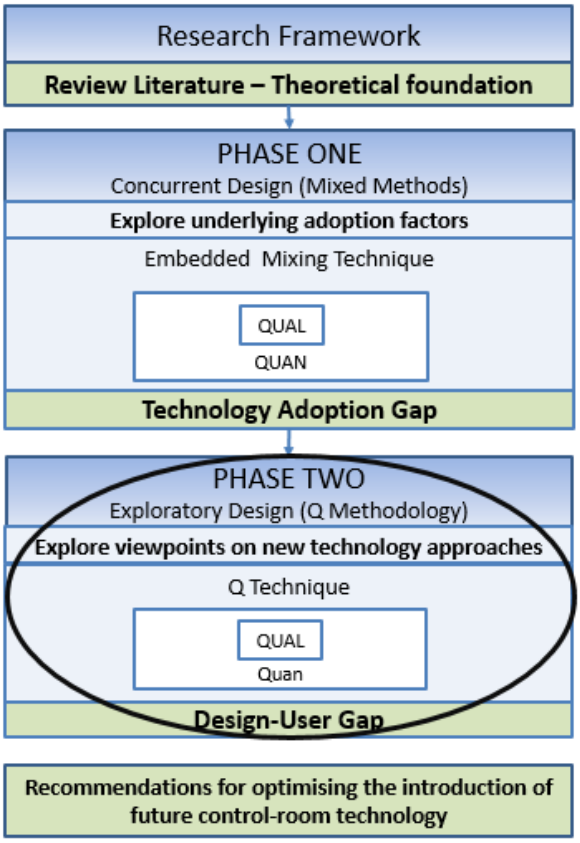

Figure 5:1 Research framework - phase two

The concourse (communication on the topic) was drawn inductively from the qualitative data captured in the first research phase and the Q-sample was established by applying the principles from Hollnagel's (2009) Efficiency-Thoroughness Trade-Off (ETTO) theory. Thus, a structured Q-sample of 18 statements (N = (2)(9) = 18, m=1 replication each) was sorted by participants into a quasi-normal bell-curve distribution.

Demographic information about participants is first provided, followed by the statistical findings and the interpretation of the results. Details of the analysis are presented in a three

step process to explain how the results from the Q-sorts were transformed into factors, how the factors were transformed into individual factor arrays, and how the factor arrays were interpreted into meaningful viewpoints. The viewpoints have been labelled to reflect the communication that distinguished the viewpoint during interpretation (McKeown 1990).

Each viewpoint is described followed by a table of position statements to show ranking comparisons across other viewpoints. In this study, statements were ranked on a seven point scale and thus range from +3 to -3. Statement numbers and participants are indicated in brackets. For example, statement five is represented as (s5). Similarly, a participant with an identification number of 1216 is presented as (Participant ID: 1216). Participant comments are cited to clarify interpretations either in the text or indicated by indented quotes. Each viewpoint description is concluded with a summary of demographic details about the participants who loaded significantly ($p<.01$) on that factor.

Insights are drawn from the viewpoints to provide explanations for why the design-user gap continues to exist and implications for the future adoption of new technology.

5.2 Research Question 4

***Research Question 4**:* What viewpoints exist on the best way to approach new technology projects?

Q methodology was used to address the fourth research question to explore viewpoints on how to best approach new technology projects. The factor interpretations are provided in this section.

5.2.1 Participation

Sixty-four participants completed the Q-survey. The majority of participants were male (90%), and 36 years of age or older (90%), and almost two-thirds (61%) had six or more years of experience in their current role. Industries represented included: rail (n = 28), aviation (n = 20), power (n = 11) and technology (n = 5). Role types represented included: 11 managers (organisational and project managers), 16 designers (from technology design/supply companies), 15 evaluators (safety and human factors professionals), and 25 end-users (controllers). Respondents represented seven countries: Australia (n = 48), Canada (n = 4), France (n = 1), Germany (n = 2), New Zealand (n = 6), Sweden (n = 2) and the Netherlands (n = 1) (Total n = 64).

5.2.2 Statistical results

5.2.2.1 Q-sorts to factors

Analysis of the Q-sorts was conducted within Q-Assessor. An exploratory technique, by-person factor analysis, was conducted to reveal viewpoint commonality amongst participants. Centroid factor analysis, as recommended by Brown (1993), was used to extract the factors to maximise the choice of rotated solutions for theoretical alignment (Watts & Stenner 2005). A clearer take on cluster groupings can be seen by rotating the factors. After exploring a number of rotational solutions, the one chosen used the VARIMAX technique. Factors were considered applicable based on three criteria: (1) eigenvalues were greater than 1.0, (2) factors with at least two loaded variables, and (3) those at a significance level of ($p<.01$), as obtained from a factor loading score of 0.608 according to the Fuerntratt criterion (Watters & Stenner 2005). The complete correlation matrix between sorts can be found in Appendix A5:1.

5.2.2.2 Factors to factor arrays (distinct viewpoints)

To reveal the distinct viewpoints (i.e. factor arrays), weighted averages of the statistically significant ($p<.01$) scoring Q-sorts were taken, as is a convention (Watts & Stenner 2012). Using PQMethod, these viewpoints were captured in a scatterplot to illustrate the cluster groupings, as displayed in Figure 5:2.

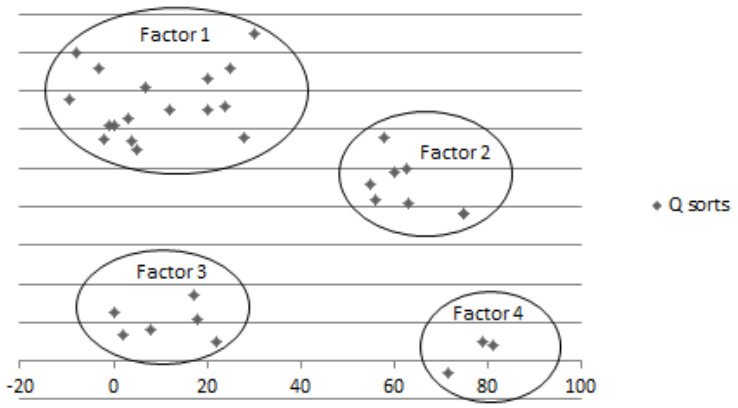

Figure 5:2 Defining factors (p<.01)

Four factors emerged from the by-person analysis with statistically significant ($p<.01$) loadings for half (n=33) of the total (n=64) participants, accounting for 65% of the total

variance. Q methodology convention typically sets the statistical significance at p<.01 in contrast to many other methodologies whose convention is often p<.05 (van Exel & de Graff 2005). Individuals who did not load significantly at p<.01 according to the Fuerntratt Criterion were excluded from the analysis along with the one individual with a confounding Q sort. Table 5:1 itemises the statistical characteristics of each factor.

Table 5:1 Factor characteristics

Characteristics	Factor 1 [a](Pragmatists)	Factor 2 (Democrats)	Factor 3 (Traditionalists)	Factor 4 (Strategists)
Eigenvalues	16.36	11.15	9.17	5.09
Percent of Total Variance	26	17	14	8
Number of Defining Variables	18	8	6	3
Composite Reliability	0.986	0.966	0.96	0.889
Standard Error of Factor Scores	0.12	0.186	0.2	0.333
Number of confounding Q sorts	1	1		

[a] Factor labels provided here are explained in Section 5.2.3.1

The four-factor arrays that emerged represent four distinct viewpoints on how to achieve technology success in control rooms. The defining variables represent the Q-sorts that significantly loaded onto each factor at p<0.01 (van Exel & de Graff 2005). Their saliency is illustrated by the low correlations between factors, as displayed in Table 5:2. Within these viewpoints, particular interest on the role of the end user was drawn. As is a convention, the four factors were assigned labels to reflect the identity of the viewpoint (McKeown 1990). They were given the following names to reflect the viewpoints: (1) Pragmatists, (2) Democrats, (3) Traditionalists, and (4) Strategists. How these viewpoint names were chosen is described in greater detail in Section 5.2.3 of this chapter.

Table 5:2 Correlations between factor scores

	Factor 1 (Pragmatists)	Factor 2 (Democrats)	Factor 3 (Traditionalists)	Factor 4 (Strategists)
Factor 1	—	—	—	—
Factor 2	0.22	—	—	—
Factor 3	0.23	0.27	—	—
Factor 4	0.35	0.38	0.39	—

The weighted average loading scores by factor for all participants can be found in Appendix A5:2. Table 5:3 provides the standardised item scores for each factor by name.

Table 5:3 Standardised Q-sort value for each statement (i.e. factor arrays)

Statements		Factor 1 (Pragmatists)	Factor 2 (Democrats)	Factor 3 (Traditionalists)	Factor 4 (Strategists)
1	When introducing new technologies, managers must consult with the intended users	2	2	0	3
2[a]	Standardising technologies across all sites will improve productivity	1	1	0	0
3	End users make unreasonable demands when they are involved in the design of new technologies	-2	0	1	-1
4	Greater productivity results when end-user preferences are incorporated into the design	1	2	1	-2
5	End users are not interested in participating in the design phase of new technologies	-3	-2	-1	-1
6	Newly created technologies are safer than modifying 'off the shelf' or existing technologies	-1	-1	-1	1
7	End users do not need to be consulted when human factors professionals are involved in the design	-2	-3	-1	-1
8	End users need to be involved at the initial design phase of the new technology	2	3	1	0
9	To avoid problems, 'in-house' technical support must be consulted during the initial design phase	0	1	1	0
10[a]	Meeting deadlines can	1	1	0	0

Statements		Factor 1 (Pragmatists)	Factor 2 (Democrats)	Factor 3 (Traditionalists)	Factor 4 (Strategists)
	impact the design quality of new technologies				
11	Fine tuning the technology is not necessary as people are very adaptable	-1	-1	-2	1
12	Safer outcomes result when human factors professionals are involved in new technology projects	1	0	0	-3
13	Online training is as effective as hands-on learning prior to implementation	-1	-2	-2	-1
14	During implementation, an 'expert' on the new technology must be available on site	0	1	2	2
15	Business sustainability takes priority over safety concerns	-1	-1	-3	-2
16	Unless something can be done safely, it should not be done at all	3	-1	3	1
17	Businesses will benefit from technologies that anticipate future trends	0	0	2	2
18	The more job tasks change, due to new technology, the higher the level of risk	0	0	-1	1

[a]Consensus statements (statements 2; 10)

5.2.2.3 Demographic comparisons across factors

In line with Brown (1978) who suggested that it is not the number of people associated with each factor that is important, but *who* is associated with each factor, statistical tests were conducted to explore variance between factors concerning demographic attributes. The dominant gender in this study was male. This is not considered unusual since safety-critical and technology industries are male dominant (Munro 2014).The female participants loaded only on Factor 1 (Pragmatists = 12%) and Factor 3 (Traditionalists = 17%); no female managers or designers participated in the study. The most experienced managers and

evaluators aligned with Factor 1 (Pragmatists) and the most experienced designers and end users with Factor 4 (Strategists) as shown in Figure 5:3.

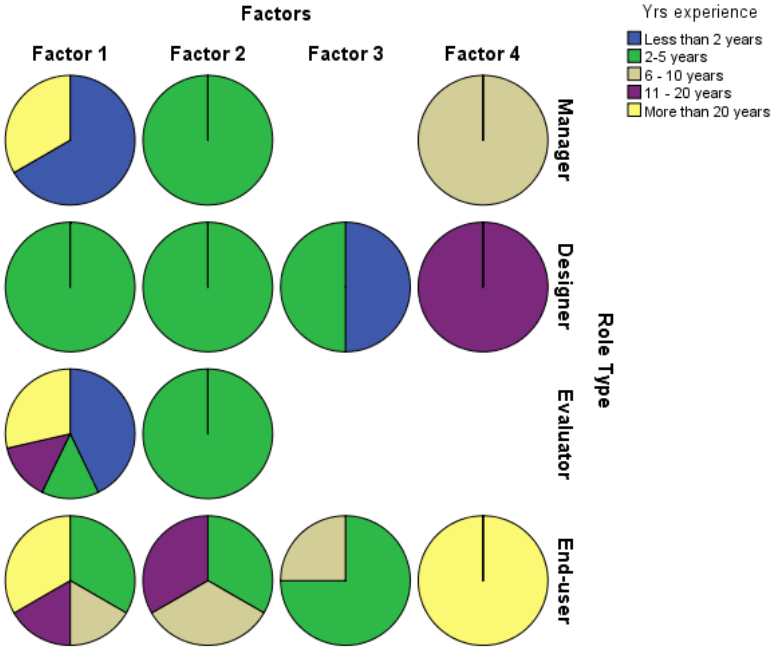

Figure 5:3 Experience variance between factors

Overall, Factor 4 (Strategists) is dominated by very experienced participants (excluding evaluators), between six and more than 20 years. The more experienced managers and evaluators, both with more than 20 years, aligned with Factor 1's viewpoint (Pragmatists). The more experienced designers (11-20 years) and end users (more than 20 years) aligned with Factor 4's viewpoint (Strategists), as displayed in Figure 5:3.

Age group representation across the factors, as indicated in Figure 5:4, found that older people align more with Factor 1 (Pragmatists), with almost a quarter aged greater than 55 years (24%), while no-one from this age group represented the viewpoints of the other factors. Factor 2 (Democrats) and Factor 3 (Traditionalists) are dominated by younger people, with the youngest age group being 26-35 years, representing over a quarter for Factor 2 (29%) and one-third (33%) for Factor 3 (Traditionalists).

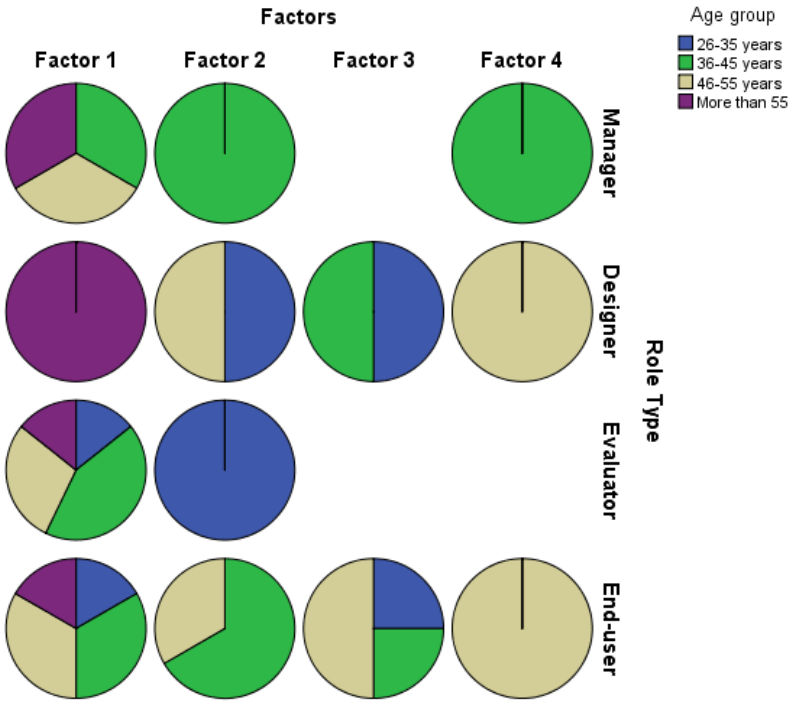

Figure 5:4 Age variance between factors

Factor 1 (Pragmatists) had representation across all four industries, although dominated by rail (53%). Factor 2 (Democrats) also had all four industries represented and were dominated by the aviation industry (57%). Factor 3 (Traditionalists) were only represented by two industries, namely rail (67%) and aviation (33%). Factor 4 (Strategists) were also only represented by two industries, namely rail (67%) and technology (33%). The power industry represented both Factors 1 and 2 (Pragmatists and Democrats), while the technology industry primarily represents the viewpoint of Factor 4 (Strategists). The rail industry was dominant in Factors 3 and 4 (Traditionalists and Strategists), and somewhat in Factor 1 (Pragmatists); while the aviation industry was a prominent representative of Factor 2 (Democrats) as displayed in Figure 5:5.

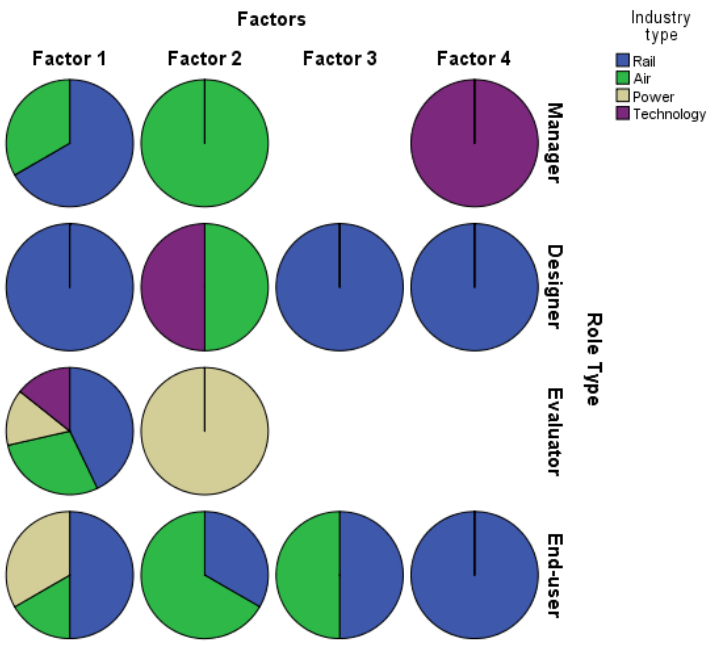

Figure 5:5 Industry variance between factors

Figure 5:6, provides the total percentage of industry representation amongst the four factors.

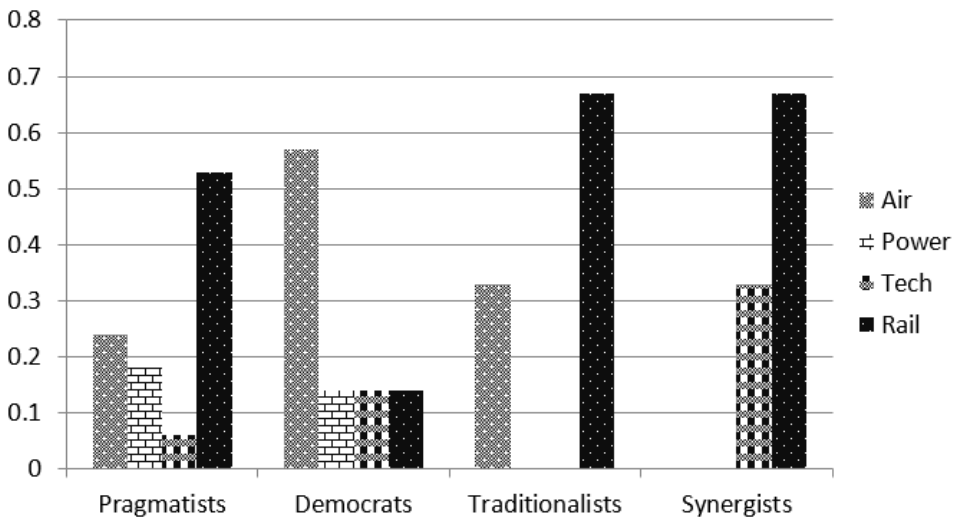

Figure 5:6 Viewpoint per industry

Examination according to stakeholder role shows that no evaluators represented viewpoints for Factors 3 (Traditionalists) and 4 (Strategists) and no managers represented viewpoints expressed in Factor 3 (Traditionalists). Application of a One-way Analysis of Variance revealed that demographic differences were not statistically significant. Table 5:4 lists the

demographic details and percentage of representation for each of the factors which have been discussed above.

Table 5:4 Demographic representation per viewpoint (reported in response percentages)

Participant Attribute	Viewpoints				Total
	Factor 1	Factor 2	Factor 3	Factor 4	
Industry					
Rail	52.9	14.3	66.7	66.7	48.5%
Air	23.5	57.1	33.3	0	30.3%
Power	17.6	14.3	0	0	12.1%
Technology	5.9	14.3	0	33.3	9.1%
Role					
Manager	17.6	14.3	0	33.3	15.2%
Designer	5.9	28.6	33.3	33.3	18.2%
Evaluator	41.2	14.3	0	0	24.2%
End User	35.3	42.9	66.7	33.3	42.4%
Age					
26-35	11.8	28.6	33.3	0	19.2%
36-45	35.3	42.9	33.3	33.3	36.4%
46-55	29.4	28.6	33.3	66.7	33.3%
>55	23.5	0	0	0	12.1%
Years of Experience					
<2	29.4	0	16.7	0	18.2%
2-5	23.5	71.4	66.7	0	39.4%
6-10	5.9	14.3	16.7	33.3	12.1%
11-20	11.8	14.3	0	33.3	12.1%
>20	29.4	0	0	33.3	18.2%
Gender					
Male	88.2	100	83.3	100	90.9%
Female	11.8	0	16.7	0	9.1%
Ever a Control Room Operator					
Yes	76.5	71.4	66.7	66.7	72.7%
No	23.5	28.6	33.3	33.3	27.3%
Country					
Australia	48.5	9.1	12.1	6.1	75.8%
Canada		3	3		6%
Germany		3		3	6%
New Zealand		3	3		6%
Sweden		3			3%
The Netherlands	3				3%

5.2.3 Interpretation of the factor arrays (viewpoints)

To capture a holistic perspective, a gestalt process was taken to interpret factors as outlined in Appendix A3.2. The gestalt process involved the careful reading of all statements, particularly those that may set a factor apart from others (known as 'distinguishing statements') and those positioned at the extremities (most and least) points of agreement (Watts & Stenner 2012). The justifications (qualitative data) offered regarding individual choices was also taken into consideration, while communication with participants who scored highest on each factor was considered to further refine viewpoint interpretations. As is the practice in Q methodology, factors have been assigned a name to reflect the overall persona of the viewpoint.

5.2.3.1 Labelling factors

The four factors were given the following labels to reflect the implementation philosophy of the interpreted viewpoint, namely: (1) Pragmatists, (2) Democrats, (3) Traditionalists, and (4) Strategists. Philosophical approaches toward the introduction of new technology have been drawn from various sources to reflect the distinct approach considered best when introducing new control-room technology.

Pragmatists –a philosophy that holds that truth and value is measured by its practical consequences (Dictionary.com Unabridged 2016b). A defining feature of pragmatism is that it favours practice as its foundation for knowledge rather than theory (Brinkmann 2013). This philosophy has been offered as the foundation for which the art of evidence-based practice arises, as truth is experience-based, context-specific, and motivated by gradual improvement (Cornish 2015). In line with the above description, the distinguishing statements (DS) that focus on early and further end-user involvement throughout the design process (DS Nos. 8 and 3) support the practical nature of pragmatists and their search for truth based on evidence rather than theory. This philosophy is clearly articulated by this participant: 'Incorporate what is actually required to improve the system and not what someone "thought" was a good idea at the time.' (Participant ID: 1201)

Democrats –a philosophy that advocates for democracy, that believes in social equality for all (Dictionary.com Unabridged 2016a). To avoid civil society's tendency to take a one-sided

perspective, the philosophy of democracy emerged (Hegel 2002). As such the terms, liberty, equality and participation are often attributed to democratic processes (Hedrick 2012). This label reflects the factor's distinguishing statements that focus on incorporation of end-user preferences, and the need to involve and consult with end users (DS Nos. 4, 8 and 7). This philosophy is expressed passionately by this participant: 'They, after all, have to live with the system for the next 25+ years!!!' (Participant ID: 1181)

Traditionalists –a philosophy that adheres to traditional values (American Heritage® Dictionary of the English Language 2011). Traditionalists derive truth from first principles, the principles of natural laws (Henrie 2004; McCool 1977). For this reason they relegate testing towards the end to address errors during implementation (Norman 2010). In design, Traditionalist approaches have been described as technocentric (Papert 1987) and follow a pre-planned sequential process that assumes tasks can be effortlessly identified, predicted and repeatable (Ambler & Lines 2012). The technology focus is expressed in the viewpoint's three distinguishing statements: The relatively positive agreement (higher than other viewpoints) that end users make unreasonable demands when they are involved in the design process (DS No. 3), the neutral feelings (lower than other viewpoints) towards the need for managers to consult with end users (DS No. 1), and recognition (higher than other viewpoints) that fine tuning the technology will be necessary (DS No. 11). These views align well with the traditional design models (Section 2.6.3), and further supported by this participant's comment: 'Job tasks are able to be changed without risk to the end result. Fine tuning of technology must be an ongoing process.' (Participant ID: 1229)

Strategists - a philosophy that subscribes to planned action for future success (Merriam-Webster 2015). A strategist is taken to reflect people who are big-picture, future thinking problem solvers, but who often act with incomplete information. They therefore make decisions in a calculated manner by seeing problems through the lens of others. Strategists have been described as good synthesisers, and integrators. They are often engaged to find business solutions to help organisations achieve specific objectives (Thomas 2013). Distinguishing statements support the business minded strategist in that they are not afraid of taking risks (SD No. 1), and thus do not assume that end-user preferences incorporated into the design will improve productivity (SD No. 16). The strategist viewpoint is articulated

well by this comment: '…be mindful of the end user's needs and incorporate the "main" features.' (Participant ID: 1225)

5.2.3.2 Consensus statements

Before providing the unique interpretations for each factor, statements that placed across all factors were examined. These are known as 'consensus statements'. In this study, no consensus statements were statistically significant (p>.05). However, two statements placed on all four factors and provide a point of common opinion regarding issues that fall in the middle of each viewpoint distribution. In this study, all groups agreed that *standardising technologies across all sites would improve productivity* (Statement 2 (s2)) and that *the pressure from meeting deadlines can impact the design quality of new technologies* (s10).

5.2.3.3 Factor interpretations

Factor 1: Pragmatists

Pragmatists believe that safety is the top business priority (s16), that it should be a condition of work (Participant ID: 1156), and that it is more important than any other business concern (s16). Thus, all decisions about new technology are driven by safety concerns. Pragmatists also hold that safety underpins the effectiveness and productivity of system performance (Participant ID: 1216) and thus value safety for its practical consequences. Essentially, Pragmatists believe that safety is good business and they aim to help improve business effectiveness through safe design practices. For instance, past experience has helped Pragmatists to learn some hard lessons which have shaped their viewpoint on safety as one Pragmatist offers:

> Safety is my primary focus. I have personally lost friends at work because of a series of compounding incidents. The trauma and flow-on effects of workmates and workgroups can be seriously affected because of such incidents. Workgroup productivity decreases and individuals seem to be more prone to make mistakes after safety-related events, more particularly after fatal events. (Participant ID: 1184)

Furthermore, Pragmatists recognise that productivity gains and better business (practical consequences) are not obtained through short-term goals and quick fixes, as has been expressed:

> Placing sustainability over safety may be profitable in the short term but not in the longer term. (Participant ID: 1217)

> Some productivity improvements are easily measured others can be measured over time, e.g. absences, turnover (Participant ID: 1251)

The above comments express that Pragmatists are long-term thinkers. Careful forward thought and planning helps the Pragmatist to influence system effectiveness (Participant ID: 1295). Pragmatists strongly believe that end users must be consulted by managers in regards to new technologies (s1). While being long-term thinkers, Pragmatists also appreciate that timely interventions contribute to safer outcomes. Therefore, delayed consultation is a major concern to Pragmatists who regard end users as valuable company resources when it comes to embarking on a new system (Participant ID: 1205), as this Pragmatist explains:

> It is more difficult to change a system once it is in place rather than have it user friendly to start with. The user often thinks of things more simply than an engineer or programmer. I have been on both sides of this argument and found it is better to consult at the design phase rather than after implementation. (Participant ID: 1184)

Furthermore, to take advantage of the best opportunity, Pragmatists feel end users can help to improve the effectiveness of the system if they are granted the opportunity to be involved early enough (Participant ID: 1201; 1184). Therefore, Pragmatists believe that end users need to be involved at the very early, initial design phase of the new technology (s8) if the right idea is to be achieved, if users are to become familiar with the product, and if safety is to be maintained, as expressed by these Pragmatists:

> Incorporate what is actually required to improve the system and not what someone 'thought' was a good idea at the time. (Participant ID: 1201)

> Involving end users at all stages will develop ownership and buy-in, as well as provide the ability to address concerns end users have. This begins at the critical design phase. If these concerns are not addressed, you will fail to get confidence in the changes by the people that matter most, the end user. (Participant ID: 1236)

> For some environments, full automation without due deference to operators can approach the 'arrogant software' scenario which can itself import risk. (Participant ID: 1205)

Thus, through forward thinking and by being realistic about what can happen if end users are not involved from the beginning, Pragmatists involve end users early to avoid

unnecessary workarounds, reliance on users to adapt, need for supplementary training (Participant ID: 1216, 1201), and worse, designs that are not fit for purpose and risk being discarded upon implementation, as experienced by this Pragmatist:

> Management often do not consult with the 'end user' at the 'work-face' until the final stages of implementation of a new system or functional change. This has in the past created situations where the intended technological change has actually been unsuitable for its intended purpose and has therefore not been introduced to the operational platform. (Participant ID: 1201)

Experience in design situations has led Pragmatists to strongly disagree that end users make unreasonable demands when they are involved in the design of new technology (s3). Rather, they believe quite the opposite that end users are domain experts on how they work and what they require from a new system, as these Pragmatists illustrate:

> In my experience I have found that the end users can often have great ideas which are simple to implement. The user often thinks of things more simply than an engineer or programmer. (Participant ID: 1184)

> It's also definite that they have unique insight, and are able to see things and make suggestions that those who aren't end users may not be able to. (Participant ID: 1295)

This unique insight is a type of 'how-to' tacit knowledge (Bolt 2006; Johnson, Gatz & Hicks 1997). Thus, their involvement is considered the key to designing a fit for purpose and usable system. For this purpose, Pragmatists fully appreciate why end users want to participate in the design phase of new technology (s5), and that a lack of interest may be just a symptom of deeper problems, as this Pragmatist explains:

> In over 20 years as an Ergonomist involved in design, I have never met an end user who is not interested in the end design. I have met some who have not been interested in the design process as they believed their input would not be incorporated or considered in the design phase. (Participant ID: 1251)

Pragmatists draw on the right people for the right job to achieve system wellbeing. For instance, expertise within and external to the organisation can be drawn on, as expressed by these Pragmatists:

> Improved productivity occurs when the knowledge and experience of staff is considered. (Participant ID: 1251)

> HF [Human Factors] as a domain, given that it's professional and based on scientific results and proven experience, has a sound and real contribution to offer in technology development. The strengths and the limitations of the human being (the end user) and the organisation have a lot to say in the success of using new technology. (Participant ID: 1279)

However, while human factors professionals are also considered to be valued resources regarding understanding the capabilities and limitations of people, Pragmatists do not suggest that they can replace the need to consult end users (s7). Furthermore Pragmatists believe the benefits of end-user input achieve much more than a good design, because it also supports user acceptance and change. This Pragmatist puts it this way:

> Where end users are involved in the design, I believe it is likely they will more easily be able to adapt to using it, and have increased buy-in and desire for it to succeed. This is not to say that all suggestions by end users need to/ should necessarily be incorporated, but by being involved and having input, there will be less resistance to the change. …Also, where safety and change management/ human factor concerns are addressed, the adjustment will be more easily accepted. (Participant ID: 1295)

Role of the end user: Pragmatists believe that end-user input into new technology projects avoids potentially risky workarounds, heavy reliance on users to adapt to the technology, excessive user training, and project abandonment. As such, Pragmatists consider the role of end users as a valued *design partner* due to their domain expertise, and thus creators and curators of know how knowledge. In light of these findings, it is likely that Pragmatists believe that end users will proactively adopt the new technology they help to create.

Interpretation of the Pragmatist viewpoint suggests that they would prefer human-centred and user-centred design approaches. Position statements for Pragmatists are itemised in Table 5:5.

Table 5:5 Position statements for Factor 1 (Pragmatist)

No.	Statement	Theme	Factor 1	Factor 2	Factor 3	Factor 4
16	Unless something can be done safely, it should not be done at all	Safety	3	-1	3	1
1	When introducing new technologies, managers must consult with the intended users	End-user input	2	2	0	3
***8**	End-users need to be involved in the initial design phase of the new technology	End-user input	2	3	1	0
7	End-users do not need to be consulted when Human Factors professionals are involved in the design	Human factors	-2	-3	-1	-1
***3**	End-users make unreasonable demands when they are involved in the design of new technologies	End-user input	-2	0	1	-1
5	End-users are not interested in participating in the design phase of new technologies	End-user input	-3	-2	-1	-1

*Distinguishing statements

Demographically, Pragmatists accounted for 26 percent of the variance and represented the Q-sorts of 17 participants (52%, p<.01). Participants were comprised primarily of evaluators *(n*=7, 41.2%) and end users *(n*=6, 35.3%*)*, while three managers (17.6%) and one designer (5.9%) also represented this group. There was a representative spread of ages (min. = 26, max. = >55), while experience ranged from quite inexperienced (29.4%, <2 years) to highly experienced (29.4%, >20 years). One participant indicated that he had 32 years of experience with control-room technologies in various roles.

While all industry types were represented, the rail industry dominated this group (53%). Over three-quarters, (*n*=13, 77%) of the respondents had experience as an operator in a control-room environment and most respondents were male. In comparison with the other viewpoints, defining demographics show that the Pragmatist viewpoint is mostly held by evaluators, has the broadest range of experience from less than two years, to more than 20 years, and a high representation from the rail industry. Furthermore, a large number of participants had experience as a controller.

Factor 2: Democrats

Democrats take a democratic approach to technology acquisition decision-making in that they believe end users have a right to be involved in the design of new technologies that will impact them, as this Democrat explains:

> They, after all, have to live with the system for the next 25+ years!!! (Participant ID: 1181)

This democratic stance has been described as the political and technical feature of participatory design (Ehn 1993). Therefore, the approach taken by those with the Democratic viewpoint can be described as politically correct. Decisions are not motivated by safety, but rather their priority is to achieve quality, an acceptable technology to guard against the risk of being rejected by end users due to safety concerns (Participant ID: 1198). This viewpoint is consistent with agile design processes that carefully attend to quality, as a way of improving and managing safety (Douglass & Ekas 2012). As a result, they believe that the end user determines the ultimate success of new technology projects regardless of the inherent level of suitability, sophistication and perceived usefulness by others (Participant ID: 1202, 1214, 1228, 1283). Put simply, Democrats view the end user as the one who accepts or rejects, and thus determines the fate of technology projects. Democrats emphasise the achievement of user buy-in for the purpose of mitigating user resistance that can put the project at risk of failure, as expressed by these Democrats:

> In my experience, getting user buy-in is fundamental to the success of control room projects. (Participant ID: 1228)

> For any project to be successful it must deliver a system that the users want to use and embrace. (Participant ID: 1198)

> It is absolutely imperative that end users are consulted/ involved in the initial design phase of new technology. Ultimately, it is the end users who determine the ultimate success of new technology with regard to intended goals/ aims. Additionally, the success of new technologies is often linked to the level of 'buy-in' achieved from end users from a Project Management perspective. (Participant ID: 1283)

One of the problems if end users are not involved in new projects is that the design often becomes an engineering solution rather than one more suitable for controllers (Participant ID: 1202, ID: 1214). In this regard, an engineering solution has been described as one that

‘may result in a technically elegant solution that is difficult and unappealing to use’ (McNeill 2013, p. 1). Democrats also stress that, by involving end users, they develop a sense of ownership that will help to lead to buy-in and thus minimise resistance to the new product (Participants ID: 1198 and ID: 1181). As such, they believe most strongly that end users need to be involved in the initial design phase of the new technology (s8; Participant ID: 1283), as well as throughout the design process (Participant ID: 1198). In support of this involvement, Democrats believe that managers must consult with the intended users (s1). Furthermore, they believe that, while end-user involvement can help to develop user buy-in, they also recognise that greater productivity can be achieved by incorporating site-specific end-user preferences into new designs (s4). A democrat has expressed this opinion in the following way:

> Users are normally the most familiar with the control requirements. Seeking user opinions and incorporating user obtained requirements into the project provides an optimal outcome and will minimise user resistance to the end product. (Participant ID: 1228)

Furthermore, unless users are involved, Democrats feel undocumented requirements, such as tacit knowledge on how control work is actually performed, will not be uncovered (Participant ID: 1214, 1228). This viewpoint illustrates the subtle differences between the contributions that human factors professionals and end users can make, and thus Democrats believe both parties should be involved in an optimum solution. Thus, Democrats strongly disagree that human factors professionals can substitute for end users during the design process (s7). Democrats put it this way:

> End-users and Human Factors (HF) professionals have complementary, but fundamentally different, perspectives. A purely HF design will likely not please end-users, and end-user designs will typically have elements not viewed as universally appropriate to a wide range of users as determined by HF. (Participant ID: 1214)

> Human factors persons cannot compensate for data collection among expert users. The experts are the ones that know their domain best. (Participant ID: 1166)

> Users have practical experience of control room requirements whereas Human Factors tends to be theoretical. (Participant ID: 1228)

As a consequence, design activity is focused on achieving a quality design for the human user. It is the Democrats’ opinion that end users desire to participate (Participant ID: 1181,

1198) and that their involvement leads to user ownership, optimal outcomes and minimal user resistance (s5). To this end, the most effective way for end users to learn about new systems is through hands-on learning prior to implementation (s13). In a control-room environment, online training is considered a poor alternative that undermines end-user buy-in to new technology. Democrats have expressed this view in the following way:

> Online training is seen by most [controllers] as a 'box ticking' exercise rather than of any real benefit. (Participant ID: 1202)

Role of the end user: In light of these findings, it can be reasoned inductively that Democrats view end-user buy-in as the most influential reason for the success of newly introduced technology, and thus it can be inferred that the role of end users is the *gatekeeper* to project success. Furthermore, it can be reasoned that Democrats view end users as proactive adopters of the technologies they help to create.

Interpretation of the viewpoint suggests that Democrats prefer participatory design and agile development processes. Refer to Table 5:6 for statements which define this factor.

Table 5:6 Positions statements for Factor 2 (Democratic)

No.	Statement	Theme	Factor 1	Factor 2	Factor 3	Factor 4
***8**	End-users need to be involved at the initial design phase of the new technology	End-user input	2	3	1	0
***4**	Greater productivity results when end-user preferences are incorporated into the design	End-user input	1	2	1	-2
1	When introducing new technologies, managers must consult with the intended users	End-user input	2	2	0	3
5	End-users are not interested in participating in the design phase of new technologies	End-user input	-3	-2	-1	-1
13	Online training is as effective as hands-on learning prior to implementation	Learning support	-1	-2	-2	-1
***7**	End-users do not need to be consulted when Human Factors professionals are involved in the design	Human factors	-2	-3	-1	-1

*Distinguishing statements

Descriptively, Democrats accounted for 17% of the variance and represented the Q-sorts of 7 participants (21%, p<.01). Participants comprised primarily of end users *(n*=3, 42.9%) and designers *(n*=2, 28.6%*)*. One manager (14.3%) and one evaluator (14.3%) also represented this group. A range of age groups was represented (min. = 26, max. >55). Most (72%) individuals in this group had two to five years' experience in their current work role (min. = 2, max. = 20). Five out of seven (71.4%) individuals had experience as a controller and all respondents were male. All industry groups were represented in the Democratic viewpoints, while the highest industry represented were from the aviation industry (57%). As with Pragmatists, many Democrats had experience as a controller (71%). In comparison with other viewpoints, defining demographic features include: they are primarily comprised of aviation personnel, they represent the younger age groups, the majority are end users, and as with Pragmatists, a large proportion of participants had controller experience.

Factor 3: Traditionalists

Traditionalists unwaveringly believe that safety comes first and, regardless of any other pressing priorities or requests, safety takes precedence (s15, s16). Traditionalists express safety as a priority in the following ways:

> If a business has no control or care with safety concerns, then that business will have no sustainability. Safety must take priority before production. Meeting deadlines can impact the quality of new technology, but safety still must not be compromised. (Participant ID: 1229)
>
> Safety is number one, could be people's lives at risk (Participant ID: 1224)
>
> Safety is our business. If things go bad we don't stop producing burgers, we can cause multiple deaths. (Participant ID: 1199)

Traditionalists take a competitive approach toward business and thus technology plays a significant role. For instance, Traditionalists believe that business will benefit from technologies that anticipate future trends (s17) and that cutting-edge technologies can provide on-sell opportunities that can in turn fund further enhancements and development of new products (Participant ID: 1229). Furthermore, Traditionalists believe that standardisation of technology helps to achieve safety as expressed by this traditionalist:

> Standardisation and safety are the two primary considerations in critical control operations. (Participant ID: 1268)

Traditionalists believe that end users can make unreasonable demands during the design process (s3), and thus are less convinced that end-user consultation offers significant advantages (s1). Rather, a recent study found that the designers surveyed preferred (77%) to consult with the client, that is, the commissioning manager. However, for large businesses, commissioning managers are often positioned at head office and rarely have contact with end users and thus are the least likely to know what requirements would be for control rooms (Day 2012). This may explain the significant costs that are incurred after the design phase. One study, during the time when Traditionalist processes were popular, reported that 80 percent of all costs were incurred for product and services after the design phase (Kern 1995). From a Traditionalists point of view, these cost breakdowns were considered normal (Ambler 2014; Day 2012).

While active involvement of end users is not considered appropriate, Traditionalists do recognise that end-user input at the initial start of a project can help to establish user requirements of what the technology needs to do, as shared by these Traditionalists:

> User involvement at an early stage allows for buy-in and effective identification of requirements and workflows. (Participant ID: 1268)

> End user consultation is important, initially to find out that the software will actually do what is required for the end user, [since] some software may not cover what is currently being done. (Participant ID: 1173)

However, establishing requirements up-front is difficult to achieve, considering these requirements are in the form of tacit knowledge that is difficult to articulate, as mentioned earlier. The need to know and design for what end users do reflects a functionalist-oriented approach that aims to design for functionality, rather than for aesthetics that can increase complexity. Between the 1920's and 1970's, the functionalist approach was the leading architectural style (Funkce n.d.) and aligns with traditional approaches.

However, as alluded to earlier, end-user consultation, as indicated in the above quote, does not imply that end users should be involved, that is, to actively participate during the design process. Rather, and more typical of traditional design methods, is for end users to be

involved during the implementation phase. One reason offered is that this is to help the end user become familiar with the new product, as shared by this Traditionalist:

> The assistance of experts [end users] during the implementation phase often avoids misconceptions regarding the technology resulting from lack of familiarity or fear. (Participant ID: 1172)

Another reason shared for involvement during implementation shared, is to determine whether the design is being operated in a safe manner, and thus there is an emphasis to ensure that end users become suitably skilled to operate the new technology safely (s13). Learning support considered appropriate involves hands-on training, and although considered a potential waste of time, is well worth the time taken as identified by this Traditionalist:

> Full use training where the user can use the system is much better than just giving them a tutorial. They have to do it in the field might as well have them do it for training (this is very time consuming though, better to waste time training than having to fix errors later). (Participant ID: 1173)

The approaches shared here suggest that Traditionalists view the end user as a passive adopter, a recipient of support in both a technical and learning sense, and whose performance variance offers a risk to safety. Nevertheless, Traditionalists value the feedback provided by domain experts (i.e. end users) as they test the new system to examine whether the design is able to perform the functions required of the end user as offered by this Traditionalist:

> Unsafe practices or situations if tested in a controlled environment are important for assessing the robustness or response of a critical system. (Participant ID: 1268)

Furthermore, the above statement shows that as domain experts, end users can play a useful role in evaluating how well the technology meets their needs from a functional, goal-oriented perspective, suggesting that end users are useful fault finders. As such, approaches like this recognise that the technology will require adjustments upon implementation (s11) and possibly even more so now that control systems are increasingly computer-based. Furthermore, Traditionalists also feel that in some cases, it may be safer for end users to adjust their work tasks. These views have been expressed in the following way:

> Fine tuning technology, so long as it does not impact on the safety of a system, is important to developing and implementing systems that are more accepted by the end users. (Participant ID: 1172)

> Job tasks are able to be changed without risk to the end result. Fine tuning of technology must be an ongoing process. (Participant ID: 1229)

Therefore, whether technical or human, adjustments upon implementation align with the high importance allocated to the statement that a technical expert needs to be readily available during implementation (s14).

Role of the end user: Traditionalists view end users as domain experts, but also as passive adopters and thus recipients of support to ensure they can use the new technology in a safe manner. Traditionalists consider end users can support the introduction of new technology by being *fault finders*. They believe that a well-engineered design that is used in a safe manner is the most influential reason for the success of newly introduced technology.

Interpretation of the Traditionalist viewpoint shows that Traditionalists are heavily focused on the technology, and thus on sound engineering as the solution to safety. To ensure this safety, Traditionalists emphasise appropriate site-specific scenario training for the end user. Preferred design models are likely to include first generation models that follow a serial process, and possibly a second generation (that includes iterations), namely: the Waterfall, V-model, Incremental and Spiral models. Table 5:7 shows the defining statements for this factor.

Table 5:7 Position statements for Factor 3 (Traditionalist)

No.	Statement	Theme	Factor 1	Factor 2	Factor 3	Factor 4
16	Unless something can be done safely, it should not be done at all	Safety	3	-1	3	1
17	Businesses will benefit from technologies that anticipate future trends	Technology	0	0	2	2
14	During implementation, an 'expert' on the new technology must be available on site	Technical support	0	1	2	2
***3**	End-users make unreasonable demands when they are involved in the design of new	End-user input	-2	0	1	-1

No.	Statement	Theme	Factor 1	Factor 2	Factor 3	Factor 4
	technologies					
***1**	When introducing new technologies, managers must consult with the intended users	End-user input	2	2	0	3
13	Online training is as effective as hands-on learning prior to implementation	Learning support	-1	-2	-2	-1
***11**	Fine tuning the technology is not necessary as people are very adaptable	Technology	-1	-1	-2	1
15	Business sustainability takes priority over safety	Safety	-1	-1	-3	-2

*Distinguishing statements

Descriptively, Traditionalists accounted for 14 percent of the variance and represented the Q-sorts of 6 participants (18%, p<.01). Participants comprised of primarily end users *(n=4)* and two designers *(n*=2*)*. This group represented the least experienced amongst the viewpoints (i.e. no-one with more than 10 years of experience). Most (83.4%) participants had five or fewer years' experience, while one participant had less than two years' experience (min. = <2, max. = 6-10). Traditionalists were a fairly evenly represented by age (min. =26, max. = 55). Four of the six (67%) respondents had experience as an operator in a control-room environment and most (83%) were male. Only two industries were represented in this group, namely rail (66.7%) and aviation (33.3%). In comparison to the other viewpoints, defining demographics for Traditionalists include: a high representation of end users, the least amount of experience, a high representation from the rail industry, and an obvious absence of evaluators and representation from the power and technology industries.

Although most age groups are represented, the relative youthfulness and lack of experience as compared with other viewpoints are worth commenting on. Many employers have expressed their dissatisfaction with their newly employed engineering graduates. One reason provided is the graduate's theoretical approach towards design due to a lack of practical experience (Silva, Fontul & Henriques 2015). Higher education scholars suggest that this is a result of a persistent traditional teaching model whereby the scientific foundation is well established before any practical designs are approached. Thus criticisms

of engineering curricular offer that engineering is too science focussed and lacking in projects that help to develop teamwork (Mills & Treagust 2003; Silva, Fontul & Henriques 2015). This suggests, that those who have had a traditional education may be less familiar with other design approaches, and potentially uncomfortable with approaches that require working with others.

Factor 4: Strategists

Strategists are business-minded (Participant ID: 1225). As a result, they plan their actions astutely so as to avoid productivity losses (s4), and are thus motivated by design efficiency and the best return on investment (Participant ID: 1225). Although safety is important from a sound business perspective, strategists are less focused on safety matters during new technology development (s16). Additionally, Strategists have not had good experience with human factors professionals and believe most strongly that their involvement during the design does not lead to safer outcomes (s12). Rather, they believe that, while other benefits may arise, human factors professionals can only improve safety in cases where 'other professionals are not involved' (Participant ID: 1225). Furthermore, Strategists believe that the effectiveness of human factors professionals is indicative of their level of experience (Participant ID: 1165).

As future thinkers, Strategists believe that better business can be achieved by focusing on new technology, particularly where new technology anticipates future trends (s17). As a result, strategists do not believe that greater productivity results when end-user preferences are incorporated into the design (s4). While the design is not driven by user preferences, Strategists accept that obtaining user input is 'a must' (Participant ID: 1225). However, Strategists consider that user inputs have to be carefully managed, otherwise, they believe that projects risk failure where time to develop them becomes uncontrollably delayed, as expressed in this way:

> If the end user controls all desired features from the outset, it can delay a project immensely (Participant ID: 1225).

To expedite systems development to prototype, strategists believe it is necessary to carefully consider when to incorporate user inputs and for what precise purposes:

> In early stages of development to a prototype stage, you must be mindful of the end user's needs and incorporate the 'main' features that internal engineering can provide. This speeds up the delivery of a prototype, keeps end users 'interested' during the process etc. If the end user controls all desired features from the outset, it can delay a project immensely. (Participant ID: 1225)

To design effectively, but also efficiently, Strategists adopt a synergist-orientation. That is, to intentionally work with others to enhance the effectiveness of the process (Curley 1998). An example of this synergist-orientation is expressed by this Strategist:

> [To illustrate how I work with end users, I may have] a situation where I have an idea, [then it is further] promulgated by end-user needs [because I] want to come up with a product/system that engages him in the process. So in reality [the design] is driven by both parties going forward. (Participant ID: 1225)

In this way, Strategists have a system-centred approach. Furthermore, to ensure user needs are captured in the design, strategists believe most strongly that managers must consult with the end users over their intended new technology (s1). Although a potential time saver, Strategists do not support the notion that online training is as effective as hands-on learning for control-room technologies (s13). Additionally, Strategists strongly believe that end users require technical experts on site to support them during implementation (s14).

Finally, the comments and statements show that Strategists are future thinkers and focused on achieving informed efficiency. They are aware of project risk and thus practice in a more explicitly astute manner than any other viewpoint. Their priority is to achieve the best possible cost-benefit by carefully involving end users. While Strategists appreciate the importance of obtaining end-user input, they also believe that their involvement must be utilised strategically to keep them interested, and to ensure the technology meets their essential needs. Furthermore, training and technical support are high priorities.

The role of the end user: Strategists view the end user as a necessary design contributor but also a potential threat to the project's success, and thus the end user is viewed as a *necessary inconvenience* to design quality. Strategists consider end users to be passive rather than active adopters. Nevertheless, project success is achieved by taking informed action and managing end user input carefully. Table 5:8 shows the defining statements.

Table 5:8 Position statements for Factor 4 (Strategist)

No.	Statement	Theme	Factor 1	Factor 2	Factor 3	Factor 4
1	When introducing new technologies, managers must consult with the intended users	End-user support	2	2	0	3
14	During implementation, an 'expert' on the new technology must be available on site	Technical support	0	1	2	2
17	Businesses will benefit from technologies that anticipate future trends	Technology	0	0	2	2
***16**	Unless something can be done safely, it should not be done at all	Safety	3	-1	3	1
13	Online training is as effective as hands-on learning prior to implementation	Learning support	-1	-2	-2	-2
***4**	Greater productivity results when end-user preferences are incorporated into the design	Productivity	1	2	1	-2
***12**	Safer outcomes result when Human Factors professionals are involved in new technology projects	Human factors	1	0	0	-3

*Distinguishing statements

Descriptively, Strategists accounted for eight percent of the variance and represented the Q-sorts of three participants (9%, p<.01). This group comprises managers, designers and end users, but no evaluators *(n*=0*)*. This group represents the most experienced amongst the viewpoints (i.e. no-one with less than six years' experience). The ages of Strategists fell in the middle range (min. =36, max. = 55). Two out of three (67%) respondents had experience as an operator in a control room and all (100%) respondents were male. Only two industries were represented in this group, namely the rail (66.7%) and technology (33.3%). In comparison to the other viewpoints, defining demographics for Strategists include: the highest level of experienced participants, a high representation from the rail industry, and an obvious absence of evaluators and participants from the power and aviation industries.

5.2.3.4 A comparison of viewpoints

A comparative analysis of the viewpoints is presented in Table 5:9 to examine commonalities across viewpoints further.

Table 5:9 Comparative Analysis of Viewpoints

Matter of interest	Factor 1 Pragmatist	Factor 2 Democrat	Factor 3 Traditionalist	Factor 4 Strategist
Priority	Safety	Quality system	Safety	Cost-benefit
Approach	Practical, long-term, forward thinking, human-centred	Participatory, user-centred, risk aware	Functionalist, technology-centred	Synergist, risk aware, System-centred
Focus	System wellbeing	Quality for users	Sound engineering	Informed efficiency
End-user role	Design partner, domain expert	Gatekeeper to project success	Fault finder, domain expert, recipient of support	Necessary inconvenience
End-user input	Initial and throughout design, increases safety	Initial and throughout design, increases satisfaction	During implementation, risk to safety	Initial and strategically during design, increases project success
Human Factors professionals	Design partner	Ensure human factors are addressed	Not mentioned	Value is experience dependent
System focus	Overall system – Systems have humans	Usable system – user solution not an engineer's	Cutting edge – humans use systems	Anticipates future trends – has main user needs
Productivity	Increases when safety is assured	Technology incorporates end-user preferences	Increases through a competitive advantage	Increases by strategic and astute action
Safety	Paramount for business success	Managed through quality	Paramount for business success	A concern, but not the primary focus
Learning support	Reduced when design matches end-user needs, not online	Hands-on essential. not online	Full end-user training required for safe use, not online	Inadequately trained user will delay implementation, not online
Technical support	Reduced when design meets needs	Not a primary focus	Necessary to support end-user	Essential during implementation
Adopter type	Proactive	Proactive	Passive	Passive
Key to success	Involved end users	Satisfied end users	Well-engineered design, used safely	Informed action, astute end-user input
Demographics	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Response loaded	52%	21%	18%	9%
Primary Roles	Evaluators & End-users, others	End-users & Designers, others	End-users & Designers	Manager, Designer, End-user
Age	26-55+	26-55	Youngest	26-55+
Experience	Full range 26-20+	Middle	Least	Most
Gender	Mostly male	Male	Mostly male	Male

Matter of interest	Factor 1 Pragmatist	Factor 2 Democrat	Factor 3 Traditionalist	Factor 4 Strategist
Industry	Rail, Air (some Power, Tech)	Air (some Rail, Power & Tech)	Rail, Air	Rail, Tech
Country	AU, NE	AU,CA,GE,NZ,SW	AU,CA,NZ	AU, GE
Ever a controller	3/4 (+)	3/4 (-)	2/3	2/3

Some obvious similarities amongst viewpoints include:

- The only commonly held view between all viewpoints is that they consider online training unsuitable for learning how to use the safety-critical equipment.
- Pragmatists, Democrats and Strategists value end-user input during the development lifecycle of new projects. However, Strategists reserve this input to only pertinent points during the design.
- Pragmatists and Democrats are both heavily human-centred and explicitly recognise that end users are proactive adopters. Democrats have been described as aligned with user-centred design, a subset of human-centred design (Gasson 2003). Both Pragmatists and Democrats also appreciate the contribution that human factors experts can make to the project outcomes.
- Traditionalists and Strategists consider end users as passive adopters and are dubious of the value that human factors experts can add toward project success
- Both Traditionalists and Pragmatists believe that the achievement and maintenance of safety are paramount and that nothing should be done if it will undermine safety.
- Both Democrats and Strategists are driven by risk concerns. Where Democrats are mindful of the risk of user resistance, Strategists are mindful of the risk of taking action that can lead to costs that do not add value to the business.

Some obvious differences amongst viewpoints include:

- Traditionalists and Strategists do not align with human-centred design approaches. Rather Traditionalists are technology-centred, while Strategists are system-centred.

- Traditionalists represent the only viewpoint that does not value end-user input during the design of the new technology.
- Democrats and Strategists are less focused on safety than Pragmatists and Traditionalists.

Figure 5:7 provides a schematic view of the major commonalities between viewpoints. From an observational perspective, one might conclude that Pragmatists and Democrats think most alike, while Democrats and Traditionalists think least alike. Traditionalists have more in common with Strategists, some commonality with Pragmatists, but few commonalities with Democrats. Pragmatists have more in common with other viewpoints.

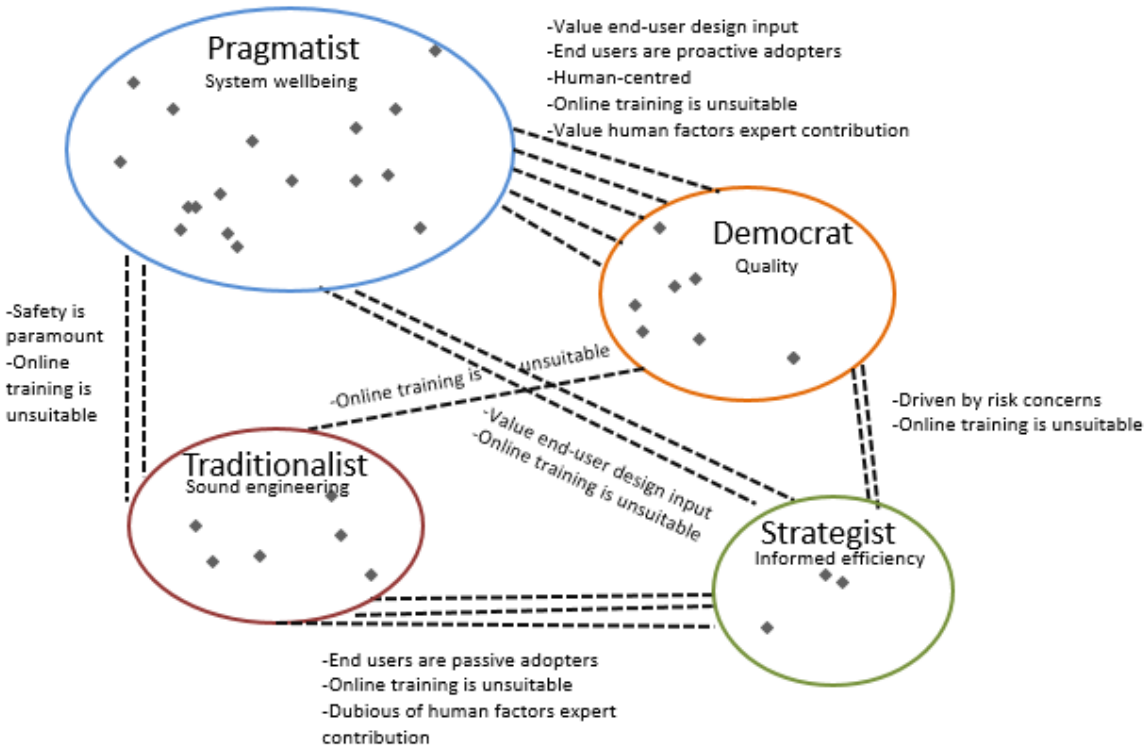

Figure 5:7 Observable commonalities between viewpoints

5.3 Summary

This study explored the viewpoints of 64 control-room technology stakeholders regarding how to best approach the introduction of new technology projects. Four salient viewpoints were elicited using Q methodology and named: *Pragmatist*, *Democratic*, *Traditionalist*, and

Strategist. Persona names were assigned to each viewpoint based on the gestalt approach. Table 5:9 summarises main attributes for each viewpoint, while Figure 5:7 illustrates the commonalities amongst the viewpoints. Each viewpoint has differences and commonalities as summarised below:

Pragmatists approach design in a practical way. They prioritise safety and thus focus on the system as a whole. This leads them to take a human-centred approach to capturing the practical knowledge of the users. Pragmatists value the contribution of others during the design process and view the end user as a design partner and domain expert. Most participants (52%) aligned with the Pragmatist viewpoint.

Democrats approach design in a democratic manner due to a belief that people have the democratic right to be involved in matters that will affect them. Thus, Democrats take a participatory design approach which is user-centred. Their priority is to achieve a quality system, one that will be willingly adopted, meets functional demands and safe. End users are regarded as the project success gatekeepers because project success is reliant on their acceptance. A little over one-fifth (21%) of all participants aligned with the Democratic viewpoint.

Traditionalists approach design in a traditional functionalist manner and are therefore technology-centred, also described as technocentric. Driven by technology, Traditionalists also focus on cutting-edge technology and the achievement of a competitive advantage. They focus on sound engineering to achieve safety and utilise end users as domain experts to inform user requirements before the design process commences and to find faults in the new system once the design process is complete. Almost one-fifth (18%) of all participants aligned with the Traditionalist viewpoint.

Strategists are risk aware and approach the design very strategically to ensure cost-benefits are realised. To achieve an optimal outcome, Strategists maintain informed efficiency and aim to anticipate future trends. Strategists view the end user as a necessary inconvenience to the achievement of project success and thus employ user input at deliberate points during the design process. The Strategist viewpoint represented the lowest number of participants (9%) across all viewpoints.

5.3.1 Limitations

Q-study findings are inherently contextually bound and thus are not generalisable. Therefore, the four viewpoints identified in this study only represent the viewpoints of the participants in this study. As such, the results cannot be generalised across to other control-room technology stakeholders. This is normal for Q-studies as the expectation to claim population generalisability is not achievable (Baker et al. 2010), and nor is it expected (Watts & Stenner 2012). Additionally, the existence of other viewpoints is also possible but would require further studies involving different participants to confirm this. Confidence in the interpretation of the Q-sorts was achieved with the support of qualitative data collected during the survey as well as post-survey email communication to confirm viewpoint narratives.

Chapter 6. A Synthesis of Results

6.1 Introduction

To answer Research Question 5 the results from Phase One and Phase Two were synthesised.

6.2 Research Question 5

- ***Research Question 5***: How might these viewpoints influence end-user adoption of future new technologies?

A number of key findings were drawn from both study phases and discussed to address the fifth research question, namely: the unique insight of end users, implications for future end-user involvement and technology adoption, and the challenges identified that inhibit the design of desirable new technology.

6.2.1 Unique insight of end users

The main reason Q-participants shared for valuing end-user input was because end users have unique insight that no other stakeholder has. In Chapter 4, this unique insight was called 'praxical' knowledge to reflect the 'art of controlling'. In this regard, end users can help to achieve the 'right idea'. Participants explained that end users have unique insight regarding what they actually do when they control system safety. They also know why and how they actually do it. Therefore, they know what they need from technology to ensure they can keep doing the work they do. Again, these findings reflect the need to capture praxical knowledge as identified in Chapter 4. Praxical knowledge is a very specific 'hands-on' type of insight (Bolt 2007, 2011). Furthermore, since this unique insight cannot be provided by any other stakeholder, praxical knowledge is what makes end users domain experts.

While it is paramount to incorporate praxical knowledge into the design, this is not an easy task, as explained in Chapter 4 due to its tacit nature (Bolt 2006). Therefore, it is difficult to articulate (McDermott 1999) let alone turn into design specifications. Therefore, to help praxical knowledge to emerge and be comprehended by the design team, the design process taken will require an effective opportunity for social exchanges of knowledge and

ideas to occur (McDermott 2000). Increasingly, safety-critical organisations and their safety regulators are seeing the value in seeking tacit, hands-on knowledge in assessing the safety of new technologies, as has been found by the Federal Aviation Administration (Downer 2010).

Therefore, the results from this study suggest that the benefits of incorporating praxical knowledge into the design of new technology may help to reduce the gap that results when user needs have not been appropriately catered for in the design of new products (Akiki, Bandara & Yijun 2014; Göoransson, Gulliksen & Boivie 2003, Neilsen 2008; Soares et al. 2012). Furthermore, the tacit nature of praxical knowledge may explain why it is useful to keep end-users involved throughout the design process, to ensure their unique insight is captured and continually captured with each design iteration. Additionally, continued involvement can ensure that praxical knowledge is not lost as the design process progresses. It is for these reasons that participants in Phase One of this study noted that representative users that are not current controllers cannot substitute for end users, and how end users who are removed too long from their work duties can lose this insight (Section 4.6.4).

6.2.2 Implications for future end-user involvement

In light of the findings from a synthesis of results, the future involvement of end users is uncertain. For instance, while a majority of design team members may value end-user input and would prefer user requirements to be an evolutionary process, achievement of end-user involvement may not be supported by management or where a traditionalist perspective is dominant within the commissioning organisation. In such cases, the utilisation of surrogate users is likely to be high and thus increase the risk of obtaining inaccurate user requirements (Day 2012). Furthermore, the results suggest that, due to lack of resourcing and advocacy, where end users are involved, their involvement may not be adequately supported and thus be perceived as a token gesture rather than as a necessary part of the process (Section 4.6.4).

In light of the 82 percent of participants who aligned with viewpoints that encourage end-user involvement during the design process and the lack of active end-user involvement as noted by interviewees, the necessary cultural change that was anticipated in engineering fields to shift the design paradigm to emulate one that is more socially responsible

(Johnston, Gostelow & Jones 1998) may be commencing. However, evidence that the Traditionalist viewpoint dominates the others suggests that many projects will continue to be developed without a more holistic approach that human factors experts recommend (Norman 1990; Pew & Mavor 2007; Wilson & Sharples 2015).

The discrepancy in the findings during Phase One of the study (Section 4.8) motivated an examination into viewpoints on how to best introduce new technology. The findings showed that while some priorities can be shared amongst viewpoints, how these priorities are achieved can be very different. Sometimes these approaches to priorities are in direct opposition to another viewpoint. For instance, both the Pragmatists and Traditionalists are highly motivated to achieve safety. Design team members could be in total agreement with this point. However, how they seek to achieve this priority can be very different. An example that emerged in this study is that Pragmatists actively and intentionally involve end users to achieve safety, whereas Traditionalists believe that end users are threats to safety and that they are best left out of the design process. Rather, Traditionalists believe that safety is best achieved by developing a well-engineered product that is used in a safe manner. This suggests that reaching agreement on a particular priority does not presuppose how that priority will be addressed. Thus the potential for latent conflict amongst design team members may present unexpected challenges throughout the new systems' lifecycle.

Notably, this may be a particular concern for the future design of control systems in cases where design standards are interpreted with a dominating traditionalist viewpoint. In light of the results from this study, advice provided in Section 4.2 of the International Standard on the *Ergonomic Design of Control Centres* specifies that the 'human-centred design approach needs to be integrated into the traditional function-oriented design approach' (International Standards Organisation 2000, p. 3). In light of this study's findings, if human-centred design principles are not fully appreciated, they will be easily reasoned away especially since, Section 4.8 (International Standards Organisation 2000, p. 5) advises to involve end users throughout the design process for the purpose of instilling a 'sense of ownership'. While important for technology adoption outcomes, ownership alone undervalues the real purpose for involving users as identified earlier. Furthermore, by making no mention of this domain expertise, those who do not understand the value of praxical knowledge may disregard the advice given in the standard in favour of keeping to

deadlines and keeping costs down, as other scholars have suggested (Ambler 2014; Douglass & Ekas 2012). Since the standard was developed before the adaptive and agile systems development model began to emerge, it is likely that a Traditionalist viewpoint informed the development of the ISO11064 standard, and thus it is considered that it is time for a review.

6.2.3 Implications for end-user adoption

Decisions made from the different viewpoints that emerged in this study can have a significant influence on successful adoption of new systems in two major ways. Firstly, many problems experienced during implementation have been traced back to the design of new technology (Day 2013; Sambamnurthy & Subramani 2005), with concept development being particularly vulnerable to Traditionalist approaches (Heeks 2006). Therefore, viewpoints that do not value end-user involvement during the design process, and particularly during the concept development phase, risk developing a design that has not gained praxical knowledge and thus may be based on potentially misconceived needs and serve no useful purpose for end users upon delivery. Therefore, as already highlighted, where the Traditionalist viewpoint is present either within the design team or within the organisation, end-user involvement is at risk. An undesirable technology, especially one that has no readily perceived benefit, will be difficult for end users to accept.

Scholars have found that during the early concept stage, a traditionalist mindset has often led to a design-reality gap, where the design does not match its reality of use (Heeks 2006). This problem stems from a belief that the user is not part of the system, but rather must find a way to fit within the system (Butler & Murphy 2007). Furthermore, researchers have found that any new system that in any way reduces the trust from the end user is going to create adoption problems (Bekier, Molesworth & Williamson 2012). As identified in the opening chapter, distrust in a system has led controllers to reject multi-billion dollar technologies.

Furthermore, if not totally rejected, a design that end users do not accept or perceive to undermine their ability to maintain safety, will not succeed without suffering unnecessary delays, additional costs from extra training or redesign fixes (Norman 2010). Therefore, the

greater the disparity is between the design and the needs of its users, the higher the risk of user resistance or rejection will be.

If the Traditionalist viewpoint continues to dominate technology acquisition thinking in safety-critical industries, end users are likely to have little say in the design of new control-room technologies into the future. Significant difficulties in use and /or problems with system incompatibility upon implementation can lead end users to lose confidence that the system will suitably support them in their endeavour to maintain operational safety (Gefen, Karahanna & Straub 2003; Hofmann, Ellard & Siegle 2012; Yamada & Itsukushima 2013). In such cases, it is more likely that end users will reject new technologies that they do not trust (Moray, Inagaki & Itoch 2000; Sætren, GB & Laumann, K 2015). As the previous study (Chapter 4) established, one way to resolve the problems associated with the usefulness and usability of new technology is to involve end users before the technology is implemented.

In consideration of the incongruence identified in Chapter 4, these findings indicate that stakeholders may be desirous of a design approach that values end-user input, however, in real world situations, ideals may not be achievable. This study has found that the presence of a traditionalist viewpoint in design teams and within organisations can wield considerable power against popular opinion and thus work against the achievement of praxical knowledge and safe design outcomes. Furthermore, it is likely that this power is fuelled by a safety paradigm that is steeped in the belief that people undermine the safety of otherwise very safe systems (Borys, Else & Leggett 2009; Hale & Borys 2013). Finally, traditionalist dominance may be a legacy from past practices that were well structured, well-known and successful at a time when control systems were more mechanically oriented and thus may be difficult for individuals to let go of (Hollnagel 2012; Kern 1995).

Furthermore, as identified in this study, the traditionalist viewpoint does not consider humans as part of the system, but rather an external agent that operates the system. This line of thinking leads to the compartmentalisation of humans and technology as two separate entities, rather than considering them both as 'the' system (Booher 2005; Butler & Murphy 2007). When humans are believed to be a separate entity to the system at hand, the focus during design will naturally fall on the technical componentry (i.e. software and

hardware). This approach is problematic because of a focus on human needs, particularly those of the end-user, is not considered important. Usability concerns have traditionally been addressed, not in the design phase, but just before, and sometimes during, initial deployment (Norman 2010). This is problematic for safety-critical systems. Often the attitude is to then make any necessary adjustments if they can be done safely. This stance implies that it is the humans' responsibility to make the necessary affordances to ensure they can operate the system properly and in a safe manner.

Human factors practitioners are well suited to address the human needs when designing new technology. Human factors engineers (HFEs) specialise in optimising interactions between humans and other system elements (International Ergonomic Association 2016). In support of these unique tasks, the human factors community adopt and develop various tools and techniques to help them to systematically analyse and evaluate these interactions (Hendrick 2000) (Section 2.6.2.3). As a matter of good practice, designers typically consult relevant design standards. However, authors of a recent study explain that standards, even those related to human factors, cannot accommodate contextual differences. Pertinent differences may include: characteristics of the user population, the context of use, existing systems, and activities to be performed within the particular work domain. These matters are better understood through the analytic tools used by human factors engineers (Crawford, Toft & Kift 2013). Furthermore, the study showed that many HFE activities are being conducted in safety-critical industries. One hundred and fifty-six tools were identified by 180 contributors. The tools aligned with fourteen technical areas, including tools that can be used during the initial concept development stage.

Many organisations have developed their own industry specific Human Factors Integration (HFI) plans to help operationalise consideration of human factors during the design process (Federal Aviation Australia 2000; Ministry of Defence 2006; O'Hara, Higgins & Fleger 2012; Rail Safety and Standards Board 2008; Widdowson & Carr 2002). However, the literature reports that many well-developed HFI plans do not get implemented or are ignored, and thus their effectiveness goes unrealised (Pew & Mavor 2007). While, there have been success stories (Wilson & Sharples 2015), many more stories, including this study, find HFI poorly achieved. Greater appreciation of human factors is necessary if HFI is to be effectively achieved.

6.2.4 Challenges to desirable new technology

End-user involvement can provide many benefits to those who are involved, including increased confidence in and attraction towards the new technology. However, the achievement of end-user involvement, while recognised as desirable by most stakeholders, is challenged by a number of conditions that result from high-level decisions made. Each of the challenges that emerged from the data are discussed here.

6.2.4.1 Challenge 1: Involving the right user in a timely manner

Controllers shared that the right representative is not always chosen to be involved in new projects. For instance, business unit managers are sometimes perceived by personnel in head office to be suitable user representatives. However, the managers' involvement upon realisation of the new technology has been described as having had no effect, as this controller expressed: 'well, he could have been a ghost' [Interview 16]. Sometimes a controller from the control room is selected to be involved, but according to other controllers in the control room, he is unsuitable due to inadequate experience that another controller may have [Interview 18]. In this regard, it would be difficult for this representative to be able to represent their control room adequately.

Timing is also important to controllers. Late involvement, means that significant changes required often meet with hostility due to the added costs and delays associated with major changes. In some cases, major changes cannot be made and controllers have to make the 'best of a bad situation' [Interview 05]. Therefore, to overcome this obstacle, end users need some form of an advocate who understands the unique insight that only 'actual' end users with extensive experience can provide.

6.2.4.2 Challenge 2: Lack of end-user advocacy

An obstacle that prevents end users from being suitably involved in new projects is that they do not have an advocate with sufficient influence to ensure involvement of end users. A reason for the low advocacy suggested by this study is the presence of a domineering oppositional viewpoint that does not value end-user involvement, particularly during the very early stages of concept development. This study found that the traditionalist viewpoint dominates technology acquisition decision-making in safety-critical organisations.

Traditionalists believe that safety is achieved through sound engineering and that involvement of end users or human factors engineers can interfere with this process by increasing costs and time unnecessarily. To be effective, the end-user advocate needs to be well respected within the organisation and have sufficient authority to make a meaningful impact.

6.2.4.3 Challenge 3: Lack of appreciation for human factors

A significant gap in understanding of what human factors professionals do emerged from this study. Lack of understanding of the discipline can lead to missed opportunities to include those most qualified to achieve optimal functioning between system elements. There is a growing perception that human factors have already been addressed in off-the-shelf technologies, as this Ergonomist offers:

> Despite the increasing awareness of human factors in industry circles, there seems to be an increasing reliance on the belief that modern technology has (somehow) taken all relevant human factors considerations into account during its development and has ultimately produced the most optimum outcome for the performance of its users (i.e. a simple case of 'if it is the latest technology and/or if it expensive, it must be most optimum for its users').
>
> Consequently, the need to further fine tune such technologies is rarely acknowledged. In those rare cases where the risks associated with technology fine-tuning are acknowledged, the mitigating risk control strategy seems to falsely be to rely on end-user adaptability and user 'training'. Newly developed technologies should be adapted to measure (or at least, consider) human capabilities/limitations rather than relying on the individual to adapt to the shortcomings/limitations of designed systems and processes [ID: 1216]

The above quote illustrates the general lack of understanding for what human factors is and the need to address context-specific needs. The human factors space of interest is very broad and interfaces with many discipline types. Researchers have noted that it can be difficult to understand what the discipline actually does due to the multiplicity of names and specialities (Norman 2010). Such common terms used, include: Human Factors, Ergonomics, HFI, Human Systems Integration, Human Factors Engineers, Human Factors Experts, Human-Centred Design, User-Centred Design, Human-Computer Interface, Human Systems Integration, Applied Psychology, and Cognitive Systems Engineering. Therefore, it can be useful to the human factors research community to benchmark current perceptions of the role of human factors in system design. Studies of this nature can help to identify gaps in

understanding and to help assign educational interventions for both higher education and industry domains.

6.2.4.4 Human Factors Integration a Design Aid

Late user involvement is often due to a belief that HFI is a design aid that helps to create more usable technologies (Pew & Mavor 2007). Thus, HFI is often considered a usability aid and not one that increases the usefulness. If the design team understood the necessity for obtaining praxical knowledge and that praxical knowledge is tacit in nature, they may value end-user input much more, particularly at the initial design stage, but also throughout the design process.

Furthermore, fuelling this problem is the dominant viewpoint of traditionalists. Engineering focused design paradigms that do not accept the human as a key system element will not be adequately supported to integrate human factors (Ferreira & Balfe 2014; Norman 2010). Therefore, the advice to embed HFI activities into existing engineering/systems design processes (Houghton, Balfe & Wilson 2015; International Standards Organisation 2000) may not be achievable, as others scholars have suggested (Heeks 2006; Norman 2010). Rather, to draw upon the strengths of well-established design processes would be more fruitful (Pew & Mavor 2007). Therefore, considering today's modern complexity and progressive integration of systems, those who continue with traditional 'engineering' design processes need to identify and be explicit about assumptions made (Kaplan & Mikes 2012; Six 2015).

Scholars have advised that HFI activities need to be embedded as part of the design process, not as a design add-on (Pew & Mavor 2007; Houghton, Balfe & Wilson 2015; Houghton, Barber & Chaudemache 2008). But to do this effectively there needs to be a shared viewpoint so that design team members are grounded with the same understanding of the project, its goals, and the approach to take. Again, if the perception that HFI is only a design-aid perpetuates,is it likely that HFI activities are once again viewed as threats to budget and time constraints and thus perceived as a risk to ultimate success of the project (Ambler 2014; Douglass & Ekas 2012; Pew & Mavor 2007). To achieve this type of respect, the importance of HFI needs to be valued and given the same respect and acknowledgement as the technical (software and hardware) components of the developing system.

6.3 Conclusion

To conclude, matters highlighted in this chapter are summarised and summarised and the discrepancy identified in Chapter 4 is addressed. Firstly, in light of the incongruity found (Chapter 4), this study suggests that the Traditionalist viewpoint has considerable power of influence and thus dominates other viewpoints within safety-critical organisations. Where this power continues to be exercised, the safe design of safety-critical systems cannot be guaranteed and thus the engineering design process continues to be ill-supported to integrate human factors. Secondly, given the knowledge that a number of viewpoints exist on how to best introduce new technology, it is important to not ignore the diversity within viewpoints and how this diversity may impact decision-making. For instance, it is questionable whether a single decision rule can be developed to satisfy all design considerations from viewpoints in one sitting. Rather, due to the complexity of designing for safety-critical systems and the diversity of viewpoints described here, it seems more useful to ensure viewpoints are identified and revisited throughout the design process and before making major decisions.

Thirdly, in safety-critical contexts, decisions made regarding new technology may be more effective if a more inclusive decision-making process could be achieved to ensure a balance of viewpoints can be represented and that lessons learned from other disciplines might be incorporated. However, it was noted that this would require the power attributed to the traditionalist viewpoint to be distributed across all viewpoints in order for shared knowledge to be a valued idea. Fourthly, as discussed in Chapter 4, technology adoption involves a sensemaking process by which the end user comes to be aware of and then develops greater knowledge and skill through enacting plausible meanings. Therefore, being given the opportunity to experience design iterations allows for greater time for end users to resolve uncertainty, to understand how the new technology will impact them, and to learn and come to comprehend how to use the new system. Viewpoints that value end-user input early and throughout the design process also support the sensemaking process and thus promote a more amiable attitude toward end-user adoption.

In an era where automation is on the rise, new technology acquisition decision-making is becoming increasingly important, especially considering the extent that end-user

involvement in safety-critical systems design is poorly achieved. Adding to this situation is the recognition that the engineering design process is currently not well supported for the achievement of HFI, and may not able to be supported, unless levels of dominance and power shift. Therefore, insights into existing viewpoints on how to best approach new technology are highly relevant if the adoption and design of new control-room technology is to be optimised in support of greater system competence.

Finally, this study helped to shed light on an apparent incongruity between stakeholder intentions to involve end users in new technology projects, and actual end-user involvement, as reported by controllers (Chapter 4). While this study found that most participants value end-user input on new technology projects, particularly, during the design process, and that end-users want to be involved (Chapter 4), the reality is that end users are infrequently involved. This study found that while considered important before and after the design process, results showed that traditionalists do not value end-user input during the design of new products. In consideration of the perceived lack of involvement, as shared by interviewees, these findings suggest that while not the most popular, traditionalists have significant power of influence over technology acquisitions decision-making and the design of new products. At least, this was the case for the safety-critical organisations represented in this study. If this practice continues to be a trend across industry, as other studies have noted, it could mean that the traditionalist viewpoint will continue to overpower other viewpoints into the future. It is likely that, where this is the case, all system design processes will continue to inadequately cater for human factors in safety-critical environments. Such a condition would put both the ultimate success of future control-room technologies at risk.

In circumstances where safety is critical and technology adoption is mandatory, Q methodology provided a useful means for disclosing the context for which problems with technology adoption arise. The Q-study revealed that decisions made throughout the design lifecycle have a strong influence on how well end users come to adopt new technology. The traditionalist approach, while not the most popular according to participants, was found to dominate alternative viewpoints held within the design team. As a result, this dominance was found to exercise significant influence over decisions made that were found to inhibit opportunities that support end-user sensemaking necessary for effective and efficient technology adoption outcomes.

Chapter 7: Discussion

This chapter revisits the two critical gaps in knowledge that can help to inform the introduction of new control-room technologies, namely: the design-user gap and the technology adoption gap. These topics will be discussed in accordance with the main findings that emerged from a synthesis of results contained in Chapters 4, 5 and 6. Challenges to resolving the design-user gap are discussed in light of their implications towards the safe design of control-room technologies. The technology adoption gap as it is in control rooms is briefly addressed along with associated challenges. The chapter closes with some potential ways forward in light of the challenges discussed.

7.1 Challenges to Closing the Design-User Gap

A synthesis of results found that many problems associated with new technology, pointed out by participants, can be resolved during the design process. However, the results showed that safe design techniques are being challenged by a number of conditions that need resolution if the design-user gap is to be diminished and thus warrant mention. These challenges are: to help all team members come to value the contribution that end users can make in the design of new technology, to resolve a power imbalance that is affecting design decision-making, and the need to adopt a new design paradigm to act as a change agent within engineering and operational departments across safety-critical industries.

7.1.1 Design Challenge 1: Value the end user

A major challenge for controllers is that not all decision makers recognise or value the contribution that they could make in regards to the design of new technology projects. Controllers have expressed a desire to ensure that the design is the right idea [Interview 04], has the right philosophy [Interview 18], and that it reflects the intricacies of their work [Interviews 01, 33]. However, calls for expert controllers to be involved in new technology projects were found to occur infrequently. Some participants recognise that controllers have know-how knowledge about how they control systems and have called it *unique insight*. Recognition of the value of this insight is appearing in industry. For instance, the Federal Aviation Administration has begun to engage end users for their how-to knowledge

in safety assessments to help evaluate the safe design of new technologies for the aviation industry (Downer 2010).

This unique type of insight has been described in the fine arts as praxical knowledge. Not to be confused with practice, praxical knowledge is the type of knowing that arises from practice and doing (Bolt 2007). Thus, praxical knowledge results from a type of learning that occurs from doing (Bolt 2011). Praxical knowledge is a very specific 'hands-on' type of insight. It is the 'art of practice' rather than the theoretical approach that might be recorded in a set of instructions or work procedures (Bolt 2014, p. 1). For controllers, this unique insight can be referred to as the 'art of controlling' and praxical knowledge is therefore what makes end users subject-matter experts of control-room technologies. In this regard, end users are the ones who know what they do, how they do it, why they do it and what is required to keep doing it.

The term 'praxical' comes from *praxis* which indicates the inversion of practice and theory (Bolt 2011). It is used to make a distinction between what might be thought to represent a *theoretical* practice and *actual* practice that emerges from doing (Bolt 2014). This idea originated with Heidegger's (1962) philosophy that people come to understand their world through handling and practice.

Thus, this praxical knowledge is what scholars have been trying to express when stating that designs need to reflect the end-users mental model of how work is done (Norman 1986; Heeks 2006), and need to consider work as *done*, rather than work as *imagined* (Hollnagel 2014). Therefore, incorporation of praxical knowledge may offer a solution to the gap between designs developed on theoretical work and the reality in which work is actually performed. Therefore, greater recognition and understanding of praxical knowledge stands to help increase an appreciation for the contribution that end users could make to the design of new technologies, and thus the creation of safer designs.

A plausible reason why managers and designers may not fully recognise that end users have unique insight (praxical knowledge) is that the term 'praxical' has not been explicitly expressed in the human factors literature, nor has it been used in design circles. However, the way controllers talk about their work strongly aligns with other uses of the term, and

this makes it a useful term for this thesis and for plausible transference to the human factors and design literature.

Participants recognise that it is not easy capturing praxical knowledge for design specifications and thus have stated that to capture user requirements in one sitting is not possible. As identified earlier, praxical knowledge is tacit in nature (Bolt 2006; Johnson, Gatz & Hicks 1997), and thus not easy to articulate (McDermott 1999). This explains why it is difficult to capture and transform into design specifications. Scholars have found that tacit knowledge requires a social exchange of knowledge for it to be drawn out (McDermott 2000). Thus, there is a need to be able to have a social discourse. The opportunity for end users to work with designers would help to entice the emergence and understanding of praxical knowledge. Thus, end users can provide unique input towards safe designs that minimise design errors.

Significantly, three of the four viewpoints on how to best approach new control-room technology projects were highly supportive of end-user involvement during the design process, namely Pragmatists, Democrats and Strategists (Chapter 5). Pragmatists value the end user as a *design partner* for the precise reason that they are creators and curators of unique insight and know-how knowledge (i.e. praxical knowledge). Similarly, Democrats consider end-user involvement an egalitarian right to have a say and be involved in matters that will affect them. Thus, they believe end users are the *gatekeepers* of project success. Democrats value end users because they help to create the new technology. While Strategists view end users as a *necessary inconvenience* during the design process, they value their involvement at relevant points within the design process for the purpose of gathering and checking user requirements. They take this action because otherwise, Strategists believe the project's success would be put at risk of failure. Of the many benefits identified amongst all three viewpoints, to capture praxical knowledge was a major priority.

Conversely, Traditionalists were found to not value end-user involvement during the design process as this may interfere with a well-engineered design. Rather, their role comes at the extremities of the design process; at the beginning to provide user requirements and towards the end to be technology *fault finders*.

Lack of recognition that end-user input during the design process can enhance technology adoption and human factors integration efforts is a significant concern for human factors engineers. Without the input from end users, many of the analytical tools, methods and techniques used by human factors engineers (Section 2.6.2.3) become less effective or inappropriate. Furthermore, lack of user appreciation and the needs of human factors engineers places a significant barrier to achieving earlier end-user involvement. The impact of which is likely to undermine efforts to close both the technology adoption gap and the design-user gap as identified by study participants (Chapters 4 and 5).

7.1.2 Design Challenge 2: Balance of power

The second challenge to closing the design-user gap is to achieve an amicable balance of power within the design team. An accepted balance of power amongst design stakeholders can help to ensure priorities and major concerns are considered when design decisions are being made. The incongruent finding that emerged in regards to intentions to involve end users and their actual involvement in new technology projects (Chapter 4) is evidence that a significant power imbalance within design teams of participant organisations exists that is challenging the achievement of human factors integration (HFI) in design. The involvement experiences shared by controllers was found to align more with the values expressed by the least popular viewpoint (Traditionalist) that was opposed to end-user involvement. The Traditionalist viewpoint was only held by 18 percent of Q-participants yet experiences of end users align more with the values within this viewpoint.

Stakeholder satisficing has been found to be a critical success factor for new technology (Pew & Mavor 2007). There are important reasons why stakeholder satisficing is important. As pointed out in the previous section, if the Traditionalist viewpoint dominates others, end-user involvement will be low and designs developed without the aid of end users will find it difficult, if not impossible, to capture the necessary praxical knowledge required to meet end-user needs. These user needs are the very requirements that help controllers to maintain operational safety. Thus the risk of developing a design that fails to meet end-user needs is high.

Furthermore, the traditionalist practice to capture user requirements upfront before the design process commences has been found to introduce other problems. For instance, once

a set of requirements have been established, a problem definition is devised with an associated set of success criteria against which to measure the design at the end of the construction phase. This testing is often referred to as user acceptance testing, the user being the 'client' who commissioned the work, not the end user. Thus the designers are only interested in determining whether the commissioned requirements were met (Bordo 2015; Klein 2003). Thus, end-user acceptance of the design is not what the traditionalist approach is aiming to achieve. Upon implementation, end users are therefore faced with working with a technology that was developed based on theoretical needs and is thus suboptimal in meeting their needs, an approach that did not aim for their acceptance in the first place.

Furthermore, this practice has been found to lead to designs that significantly do not meet the user needs. Such cases often lead to additional costs and design reworking upon implementation (Ambler 2014; Cone 2002). During a time when traditionalist models were popular, at least 80 percent of costs assigned were incurred after the design phase to cater for product adjustments and services (Kern 1995). While the costs associated with involving end users may seem high initially, longer term cost savings are evident. Scholars support the cost-benefits of involving end users early and throughout the design phase (Ambler 2014; McNeill 2013; Optimus Information 2016; Weinert & Mann 2008). Therefore, to involve end users during the design process can significantly reduce the costs related to post design activities and thus offers a significant financial benefit to organisations, as well provide improvements for safety.

Of particular concern to end users is that praxical knowledge will not be captured in the design of new technologies if a traditionalist approach is taken. The practices commonly used in Traditional design approaches illustrate a lack of recognition and appreciation of the value of incorporating praxical knowledge and thus involving the end user in design activities. Words often used in the literature such as useful, easy to use, user needs, and user requirements, are too ambiguous, and thus not very useful for the development of design specifications (Wilson & Sharples 2015). This is not to suggest that advances have not been made, only that advances are sparse and sporadic.

Another problem associated with a lack of end-user involvement due to lack of advocacy in the design team, is that lack of end-user input into the problem definition can lead to

designing from a wrong idea, with the analogy of designing a chicken when end users needed a turkey as expressed by one controller [interview 32]. Should the technology fail to meet the needs of the intended task its value is not only reduced, the potential for delayed implementation is higher (Karsh 2004), potential for workarounds becomes necessary [Survey ID: 151, 214], new constraints may be introduced [Survey ID: 24], and new risks may be introduced (Crawford, Toft & Day 2010). Adjustments required of the end users to ensure the technology can perform have been known to lead to problems in learning how to use the new technology (DesRoches et al. 2008), accidental misuse of the technology (Parasuraman & Riley 1997), and using it as it was not designed to be (Norman 1998).

These types of problems often emerge due to designs that have not addressed human factors concerns (Green 2009; Hollnagel 2007; Stone 2008). Furthermore, poorly addressed human factors has been found to be a leading cause of failed systems and accident causation (Kinnersley & Roelen 2007). Thus, while end users may seem only dissatisfied, the less obvious concern is the risk to safety. This is particularly so in light of current trends in progressive system integration that introduces new interactions, unknown risks, and increased complexity.

The dominance of the Traditionalist viewpoint is consistent with other studies suggesting that the Traditionalist viewpoint dominates decision-making across industry. To illustrate, a study involving participants from safety-critical industries found that 77 percent of engaged designers used traditional systems development models, while only 23 percent adopted the more adaptive and agile models that allow user requirements to evolve throughout the design process (Day 2012). Furthermore, the IT industry also reported a dominance of traditionalist methods (Butler & Murphy 2007; McNeill 2013). These findings are somewhat surprising considering there is quite a large body of knowledge supporting more flexible modes of design that advocate for end-user involvement, particularly in the IT industry (Butler & Murphy 2007; McNeill 2013; Wallach & Scholz 2012), but also for the design of safety-critical systems (Douglass & Ekas 2012). These studies suggest that the problem is much larger. However, if situations are similar across other safety-critical organisations, these findings may be indicative of a problem across safety-critical industries at large.

Nevertheless, this study has found that a relatively unpopular viewpoint within the safety-critical domain dominates design decision-making within participant organisations that are safety-critical in nature. This is a particular concern considering the approach that dominates is less conducive to the techniques human factors engineers prefer to use to integrate human factors, and is in opposition to the majority of other stakeholder viewpoints. Consequently, the dominant systems development process is not supportive of achieving HFI. The problems that emerge from a dominating viewpoint mean that alternative views are not being considered and new advancements do not get tabled. The reasons for this apparent dominance can only be speculated upon here. However, priorities, areas of focus, and values identified in each of the viewpoints outlined in Chapter 5 give some insight into possible areas of conflict that may emerge within design teams. Knowledge of potential points of conflict may help to resolve some of the power struggles that underlie poorly designed technology, and thus may offer a way forward. Action to resolve this challenge is of high importance if safe designs are to be developed into the future.

7.1.3 Design Challenge 3: Adopt a new design paradigm

For many years, scholars have recognised that the approach to industrial design requires a shift in thinking towards one of greater social responsibility (Johnston, Gostelow & Jones 1998). The high percentage (82%) of stakeholders that value end-user involvement in new technology projects is testimony that a cultural change is occurring. Potentially, the changes in thinking may reflect a shift towards the emerging safety paradigm that values the human contribution (Hollnagel, Woods & Leveson 2006; Weick & Sutcliffe 2007). However, the dominance of the traditionalist approach in industry is disconcerting and presents a problem to achieving cultural change within engineering circles. As identified above, this dominance is having a silencing effect on other design approaches that are more conducive to end-user involvement and thus HFI. The domineering nature of the Traditionalist viewpoint is, therefore, an obstacle to the cultural shift hoped for.

One reason that may explain why the Traditionalist approach perseveres is that it has been responsible for extensive productivity gains including safety, for over two hundred years, since the Industrial Revolution (Hollnagel 2012; Kern 1995). Over these years, traditionalist

approaches became well-established and provided engineers high-level confidence in the design process. However, this was a time when engineered designs were developed as a system used by people, rather than a system containing people (Butler & Murphy 2007). Therefore, continued trust in a Traditionalist process may reflect the legacy of a design approach that made significant advances in life quality and safety for many years, well before the advent of computers and integrated systems.

Another plausible reason for the persistence of the Traditionalist approach is that older control systems were more mechanically-driven and thus suited to traditional industrial engineering. However, modern control systems are increasingly information-driven and thus more sociotechnical in nature, whereby the interaction of people and technology is enmeshed. To design modern control systems requires a multidisciplinary team including industrial engineers, software developers, human factors engineers and other specialists, to ensure the human and technical elements can work more as a team rather than as independent components (Wilson & Sharples 2015).

In consideration of the Strategist viewpoint, the strategic involvement of end users implies that the design approach preferred by Strategists is a type of hybrid that is system-centred and thus incorporates aspects of both technology-centred and human-centred design. The Strategists viewpoint suggests acceptance of a more adaptive model, being more iterative in nature as described by Ambler and Lines (2012). It is also likely that the Strategist viewpoint reflects a recognition of sociotechnical systems, thus using second generation traditionalist approaches (e.g. spiral and incremental models) that typically develop technical and human systems in parallel with various human factors concerns being embedded into various stages throughout the systems development process (Houghton, Balfe & Wilson 2015; Salmon et al. 2010). It may also be possible that Strategists are taking advantage of the strengths of more established design processes as scholars have recommended (Pew & Mavor 2007). In this regard, the Strategists' approach falls somewhere between the Traditionalists' and Pragmatists' preferred methods of design and may thus offer a means for instigating cultural change within engineering circles.

Nevertheless, while the design paradigm seems to be making a shift towards greater social responsibility, study results suggest that the design paradigm shift has not yet changed the

design culture within safety-critical industries, and thus, has a way to go to complete the cultural change under progress.

7.1.4 Design Challenge 4: How to best utilise user input

How to best utilise end-user input is poorly understood and identified as an area that is in need of further investigation (Venkatesh & Bala 2008). Nevertheless, to know how to best involve end users can help to not only reduce the design-user gap but also contribute to closing the technology adoption gap. Controllers expressed a desire to be involved in new technology projects. However, their involvement is challenging for designers.

Some recommendations were drawn from the results that addressed: (1) why end-user involvement is important to the design of new technology, (2) reasons for why end users should be involved from their perspective, (3) who should be involved, (4) what types of involvement are recommended, (5) when users should be involved, and (6) how end users should be involved. A list of who, what, when, how and why to involve end users in new technology projects can be found in Table 7:1.

Table 7:1 Who, what, when, how and why to involve end users

1	**Why end-user involvement is important to project management!**
	To see the project from the end-user perspective
	To secure a suitable level of automation
	To ensure operational requirements are met
	To achieve an easy-to-use design
	To ensure the new system can integrate with existing systems
	To achieve easier implementation
	To ensure the system is functional, robust, reliable, suits all areas and users, and is transferable
	To develop a clear project scope that is agreed by all stakeholders
	To support user acceptance
	To understand contextual needs
	To avoid developing the wrong idea
2	**Why involve end users from a user's perspective?**
	To become familiar with and gain understanding of the new system before it is implemented
	To make informed decisions about technology acceptance and adoption
	To feel included and part of the process
	To have a say
	To develop ownership
	To make the change easier
	To help correct potential problems
	To ensure needs are met and safety can be maintained

	To build trust in decisions made
	To gain effective hands-on training (with end-user trainers)
	To resolve fears and uncertainty
	To be able to support implementation and others through the change
	To advise on matters that impact operation and safety
	To become familiar and competent in using the new technology before completely removing the old approach
3	**Who should be involved?**
	Workers who will be using the technology
	Experienced operators
	Subject matter experts of the control room
	Early adopters
	Primary users (i.e. end users)
4	**What types of involvement are recommended for end users?**
	Information provision and receipt of information
	Discussions to develop shared understanding
	Assessment and analysis of design
	Contribute to design decision-making
	Testing and trialling – such as: reviewing drawing and plans, mock-ups, and prototypes. Conducting user acceptance testing, usability, situational awareness, technology in real world scenarios.
	Familiarisation and skill development
	To be trained to train others
	Training others and being trained
	Mentoring others and being mentors
	Help during the implementation process
	To help debug the system prior implementation
5	**When end users should be involved?**
	At the earliest stage of design
	Throughout the design lifecycle from conception through to decommissioning
	Before moving onto the next design stage (to check user requirements)
	For durations that are not too long to ensure the 'representative users' do not lose touch with their usual work environment
	At times conducive to shift arrangements
	Before deployment, to trial without interface to real operation
	During technology transfer between implementation and deployment, to ghost (or mimic) new with old (to help refine design) before cutting across to new system
	During the design to review design iterations
6	**How end users should be involved?**
	Make them an integral part of the development and decision-making team
	To share knowledge and to help develop shared outcomes
	To provide operational and information needs
	As a signatory at each design stage to ensure user requirements have not been negotiated out
	To test and trial the system at various stages of the development, to re-evaluate and assess for improvements
	To familiarise and train other end users
	To act as resource people to developers

	To identify potential problems and how the system could fail
	To obtain user assessment of the design
	To test and seek feedback from as many test drivers
	To develop a rationale for the new technology to affected users (for management buy-in)
	To conduct safety analyses
	To ghost new with old system to ensure safe transfer
	To participate in workshops, focus groups, meetings, communities of practice, vertical and horizontal communication
	To participate in activities such as: drawing and mock-up design, decision-making, problem-solving, planning, future proofing, analysis, confirmation, ghosting, mentoring, training, communicating, negotiating, compromising, supporting, endorsing, signing off.

In support of finding better solutions, participants shared ways in which they felt they could make a valuable contribution during new technology projects. These suggestions have been summarised and positioned in accordance with a generic systems development lifecycle (Table 7:2).

Table 7:2 Summary of end-user input throughout the design lifecycle

Stage	End-user input
Early design	Identify and prioritise needs or problems.
Concept inception – information gathering	Set system objective – what it is to do and not to do.
	Analyse current system – what is working and what is not.
	Determine what needs to stay and what needs to go.
	Brainstorm ideas and solutions.
	Participate in initial task analyses and any early prototyping and concept modelling in support of an appropriate concept.
	Participate in sharing knowledge.
	Participate in focus groups
	Help to create the user requirements document.
	Help to develop design specifications.
	Select at least one suitable user representative, a trusted peer.
Problem definition	Participate in safety analysis.
	Check that needs are included in the problem definition.
	Check that the success criteria measure end-user needs.
	Help to rewrite problem definition or success criteria.
	Agree to current success criteria, knowing they are changeable.
	Conduct familiarisation (info) and Q&A sessions with peers, supervisors, and managers.
	Offer design team new suggestions/solutions where necessary.
Planning	Participate in planning to help set realistic goals, resourcing and timeframes.
	User representative to liaise with peers and faithfully represent the end-user perspective.
	Conduct familiarisation (info) and Q&A sessions with peers, supervisors and managers.
	Offer design team new suggestions/solutions where necessary.
Design/redesign and early	Participate in brainstorming to create and evaluate design iterations: drawings, plans, concept modelling, prototyping, mock-ups and to identify problems and solutions.

Stage	End-user input
construction	Check that the problem definition continues to meet user needs, if not, help to refine. Check that automation meets end-user needs (e.g. understandable, visible, observable, proactive control, directable, accountable). Participate in interface development, software logic if capable, and review (ensure end-user needs for undertaking control activities are met). Conduct familiarisation (observational, hands-on if possible) and Q&A sessions with peers, supervisors and managers. Offer design team new suggestions/solutions where necessary.
Preparation for implementation **Construction**	Identify what current tasks are to be kept, discarded, or created. Design new work procedures in according with new system use. Help to develop user acceptance testing (UAT) scenarios. Help to develop simulations of situational awareness scenarios and critical tasks to test. Help to develop the training program. Become a train the trainer – to train peers. Conduct familiarisation (information, observation, and hands-on) and Q&A sessions with peers, supervisors and management, as appropriate. Offer design team new suggestions and solutions where necessary.
Pretesting & early training **Construction finalisation**	Participate in UAT and situational awareness testing and provide feedback. Test software logic if capable (not a requirement). Test the new system in an environment that does not impact safety (i.e. off-line). Test real world scenarios and critical tasks for technical: compatibility, competence, reliability and robustness. Become competent with the new system. Help test simulators and finalise development of the formal training program. Conduct familiarisation (hands-on if possible) and Q&A sessions with peers. Keep management informed as necessary. Offer design team new suggestions and solutions where necessary. Participate in change management planning, to ensure needs are resourced (e.g. staffing, learning timeframes are suitable and technical support will be available).
Implementation and technology transfer	Lead the technology transfer process from old to new by running both systems in parallel. (Follow the ghosting process, whereby trainees pass through these processes: observe all tasks, mimic all tasks, simulate all tasks, once competent operate on the new system under supervision until proficient, supervise and support peers as necessary, until all end users have crossed over to the new system). Do not allow anyone to move to the new system until deemed competent. Continue to conduct small group and refresher training. Participate in high-level peer and management communication during this process. Should something unexpected occur technically, liaise with technical staff to resolve. Should a difficult situation occur operationally, support each other to find a solution. In cases of emergency, use the old system as a back-up until problems in the new system have been resolved. Dynamically risk manage, identify new hazards and suggest and implement controls.
Early operations **Construction adjustments**	All end users to maintain high levels of communication and peer support. All end users to record issues that require fixing or refinement. All end users to participate in periodic reviews of the system. All end users to continually identify new hazards and suggest new control measures.
Operations –	All end users to continually monitor the system for new hazards, disturbances, items that

Stage	End-user input
Disposal	need repair or maintenance.
Maintenance and updates	All end users to keep management informed of needed adjustments or growing needs via an agreed upon way. All end users to continually identify new hazards and suggest new control measures.

In addition to this list, a recent experience was shared that participants felt set the example of a potentially ideal process for introducing new technology. This stepped out process is outlined below:

7.1.4.1 Useful example for introducing new technology

To bring these results to a close, and to offer a means for best utilising user involvement, a recent experience is shared. The controllers involved considered the process is taken to be potentially an ideal way to approach the introduction of new control-room technology.

The introduction of new technology is closely associated with change management practices. The following example illustrates how the introduction of new technology, considered a large project, was undertaken by one participant organisation that controllers [Interviews 20 and 21] felt was done particularly well. It was described as one that ensured that a major change could be done with minimal adverse impact on the controllers or on safety. It was also described as a long process, but an effective one, and one that helped end-user adoption and transition to the new system.

Step one: Identify your stakeholders

The first stage was to ensure the project management team have identified all necessary stakeholders, particularly those who would be using the new technology.

Step two: Conduct a safety analysis

The second step involved identifying any hazards or risks to safety as a result of implementing the new technology. A sample of questions asked during the safety analysis, before making the decision to go ahead with the change, included:

- Can it be done?
- Can it be done safely?

- Can the hazards identified be appropriately mitigated to a safe level?

Step three: Participate in the design process

The third step involved end-user participation in the design process. At least one representative from each control room was to be involved in project matters. They were to commence from the start of the project to ensure essential needs were identified. Similarly, maintenance staff were also to be involved in the same manner from day one to identify practicalities, such as: local problems and possibilities. The representative controller(s) was to listen and liaise with their co-workers on all matters, such as: needs, suggestions, changes, etc. This input was to be put forward at project team meetings for design decision-making. Items considered included:

- What do controllers need the technology to do?
- What tasks need to be kept doing?
- What new tasks need not be done due to the new technology?
- What do controllers want to be displayed?
- How do controllers want it displayed?
- Can the current display be improved?
- Does the display need to stay as it is now?

As the project progressed, design trade-offs and safety matters were continually reassessed and certain tasks and design attributes that needed to remain or go were justified at each iteration. Ideally, it was thought that a core group of people would be involved in designing the new technology, including the controller representatives. A flexible budget and timeframes also helped to ensure that safety critical issues identified could be resolved. During the design process, communication was high between the project team and the representative controller and between controllers. All controllers were regularly informed of progress and shown samples or demonstrations of prototyped work. All controllers came to understand the reason for the changes and were afforded an opportunity to have any uncertainties addressed. As many faults as possible were identified before the other controllers were trained on the new technology.

Step four: Implementing the change

The change process was fully planned. Staffing numbers were considered and resourced at various stages of the implementation process. By this time, the controllers (back in the control room) had become quite familiar with the technology that they were about to use. Before formal training commenced on the new technology, the representative controller first became proficient on the new technology and was trained to train the other controllers in his control room. The reason behind this was to ensure that language and terminology used would be familiar to the trainees, and so that training activities and scenarios were site specific and thus better understood by the trainee controllers. Throughout the training process, any issues identified were addressed before the new technology was used live.

Next was hands-on familiarisation which allowed all controllers to play with the equipment and to learn what it did and to become well acquainted with its use. Training was delivered to small groups of people to allow for questions and discussions. Once quite comfortable with the equipment, ghosting commenced. The process of ghosting took two to three months to complete and involved the following steps:

1. The trainee controller sat in the background and observed the proficient controller who was now controlling live with the new technology, and in the new location.
2. Next, the trainee mimicked the work of the proficient controller while operating a dummy system.
3. This progressed until the student controller could mimic every action and input every bit of data just as the proficient controller was doing live. At no time during the ghosting period did the trainee operate live on the new technology.
4. Once comfortable with ghosting and certain that all functions could be completed competently, they worked on the live system and never returned to the old one. This was to prevent doubling up and to mitigate any potential for errors.
5. Gradually, as more controllers went live on the new system, the new system took on the main functioning. Then the old system became the backup system in case anything unforeseen occurred and it was needed to regain control.

6. Each controller went through the same process until they had all been ticked off on the various functions and all were controlling live from the new system.
7. While this was occurring, training continued in the background to ensure that everyone could successfully progress to the new system.
8. Eventually, the last person on the old system made the switch to the new one and the old system was turned off.

Step five: Conduct post implementation review

After three months, a review was conducted to assess technology acceptance, adoption, error provocation, the level of satisfaction, aspects that may need to be changed or adjusted, and any new hazards and appropriate controls for these. Reviews were regularly conducted to ensure necessary changes were made and to ensure the system operated safely. Of particular note in the above example shared, is that the design process was included as part of managing the change and that controller familiarisation occurred throughout the entire process.

Furthermore, this process proactively supported sensemaking and technology adoption by ensuring that all controllers underwent regular familiarisation sessions and had ample opportunity for hands-on experience. Thus, once deployed, there were no surprises and controllers were ready to further develop and refine their operational skills on the new technology. Therefore sensemaking and technology adoption progressed, as explained by this controller:

> We actually get in and actually play with it and I'm a visual learning. I can learn by just having a fiddle with it and playing with it. But if you give me a textbook and say now read the instruction manual, straight over my head. It obviously makes a lot more sense when you are reading it - you think 'oh that's what they are talking about. [Interview 27]

The need to experience new technology to confirm the plausible meaning achieved through reading an instruction manual supports the notion that sensemaking is not merely a cognitive process of interpretation, as also suggested by Sandberg and Tsoukas (2015).

7.2 Challenges to Technology Adoption Gap

A synthesis of results from the studies undertaken for this thesis suggests that participant organisations are not introducing new control-room technologies as mindfully as needed to continue to maintain safety into the future. Managers typically perceived the adoption of new technology to be a mandatory condition of the job. This included making the necessary adaptations to ensure that new technology works (Chapter 4). In the past, end users have successfully achieved technology adoption. However, this has not always been easy and not necessarily appropriate for future events. Thus, heightened safety concerns are evident amongst controllers, particularly due to the increased complexities associated with new integrated control-room technologies (Chapter 4). Modern trends towards greater integration between control system elements put doubt in the minds of controllers as to whether these practices can continue to keep unsafe events from occurring when new technologies are introduced. However, end users of control systems are rarely given a chance to voice these concerns. This study has helped to provide that opportunity and as a result has revealed underlying factors that can influence the technology adoption gap in control rooms. The results have shown that both end users and organisations are being challenged in this area.

7.2.1 Challenges for end users

This study has found that, for end users to come to adopt a new technology, they must come to be convinced that the new technology will support their work goals and help them to maintain safety. To know this requires knowledge about the new technology prior to its deployment. Mandatory expectations under safety-critical conditions can put significant pressure on controllers to adopt, and to adopt effectively and efficiently without diminishing safety. These expectations pose a number of challenges for controllers, as revealed in the results.

7.2.1.1 Adoption Challenge 1: End-user involvement

As identified earlier, one of the challenges end users face is their lack of involvement in new technology projects. Without a suitably influential advocate, end users are often left powerless to make a useful impact on the design or choice of technologies that they will be expected to control with. Of the 36 controllers interviewed, only a third (*N*=12) indicated

that their involvement was perceived appropriate and of some use. These results align with scholars who found similar results when examining ergonomic practices in design (Kok, Slegers & Vink 2012).

More commonly, controllers expressed limited and sometimes inappropriate involvement (Section 4.6.4). While some involvement was noted, controllers expressed disappointment overall in how their organisations utilised their input and regarding how they introduced new technology, in general. In some cases, controllers were involved but found that in the end when the technology was introduced, their suggestions were not incorporated and no explanation was provided. As a result, dissatisfied controller's perceived their involvement as socially irresponsible and just a means for management to legally cover themselves should something go wrong. Concerns like these have led controllers to become sceptical about the value that new technologies will provide in the future.

In general, the ad hoc nature of user involvement was quite distressing to controllers. Small opportunities here and there do not satisfy the need to be involved. There were no illusions or expectations that technology would be perfect. Rather, controllers not only accept imperfections, they actively compensate as necessary. However, for some controllers, the compensations required to make the necessary adjustments to allow the new technology to work, were described as inappropriate due to the impacts that workarounds and adjustments may have on safety.

However, on a more positive note, while some of the organisations in this study have a history of poorly introduced technologies, some recent projects have been more successful due to a greater emphasis on human factors, as outlined in Section 7.1.4. This suggests that there is hope that new technology projects may be developed with a greater awareness of human factors in the future.

7.2.1.2 Adoption Challenge 2: Start sensemaking earlier

Controllers expressed a need to be involved in the very initial concept development phase to ensure that the new technology was the 'right' idea from the start (Section 4.6.5). This is a significant challenge for controllers because end users rely on management to make them aware that a new technology is being considered. As identified in Chapter 2, decisions to

adopt have been accepted by senior personnel in head office well before end users are expected to become aware of the new technology. This presents other problems for end users in regards to sensemaking.

In worst case scenarios, controllers reported that technologies that were described as their life-blood were being provided without training, leaving controllers to figure out how to use the particular technology on their own. While it was noted that controllers are smart individuals and have been known to adapt in such circumstances, this has not occurred without much frustration and angst. Controllers expressed that they want to know that the technology will not undermine their ability to maintain safety, and this cannot be assured if they have not had an opportunity to make sense of the product earlier.

Results in Chapter 4 found that sensemaking is an important predictor of technology adoption state. Thus, it makes sense that end users desire to commence this process as early as possible. Table 7:3 provides a list of questions that could be asked of controllers to check how their technology adoption is progressing.

Table 7:3 Sensemaking questions to determine technology adoption progress

Factor	Variable (to be answered by end users)
Plausibility	I am aware that I am getting a new technology
	I (or trusted peer) have been involved in discussions with management about the pending new technology
	I feel my input was valued by management
	I am able to voice my concerns
	I feel my input was valued by the design team
	(If involved) I feel comfortable working with the design team
	I feel management will implement my suggestions or explain why not
	I feel management are making sound decisions
	I have provided my immediate needs to management and the design team
	An appropriate user representative(s) has been assigned
	I (or trusted peers) have been involved in identifying and assessing potential risks
	I expect the project is viable (resources adequate to successfully complete the job – time, money, staff)
Fears	I fear that I may lose job satisfaction
	I fear that I will have less control over what I am expected to do
	I fear that I may lose my job
	I am not sure when I will be trained
	I do not know what the design will be like
	I do not know enough to operate the new technology safely

Factor	Variable (to be answered by end users)
	I do not think my (or trusted peer) suggesting will be adopted
	I do not believe managers are telling all the truth about the new technology project
	I do not know when the new technology will be implemented
	I do not know when the new technology is expected to be deployed (go live)
	I am not sure that my colleagues have the time to help me if I need help
	I am not sure if there will be technical support available when the technology is first deployed (goes live)
Reality	I know who to contact if I have questions about the new technology project
	Aside from commercially confidential matters, my user representative talks freely about the new technology project
	Management has provided adequate resources to ensure a user representative(s) can participate in the new technology project
	I have seen drawings, diagrams, mockups, or prototypes of the design in progress
	The project is running as was communicated
	I have been allowed time-off-the-desk to undergo classroom training
	I have had hands-on time with the new technology (or simulation)
	I have been able to evaluate the new technology
	Problems with the design of new technology identified have been fixed
	Workflow disruption or changes have been identified
	Workflow disruption or changes have been addressed to my satisfaction
	I have been afforded time to grasp how to use the new technology competently
	Top level managers frequently keep me informed about the project
	The new technology is compatible with how I work
	The new technology allows me to know the system's status
	The new technology provides me the information I need
	The information presented is easy to understanding
	I can direct the system to do what I want it to do
	I feel in control of the technology
	The information presented reflects how I think
	The new technology tracks operational trends
	The new technology provides information that allows me to pre-empt failure
	The information presented supports problem-solving
	The information presented supports decision-making
	I know what the new technology is doing at any given time
	The new technology provides the feedback I need
	The new technology interacts appropriately with existing technology
	The new technology interacts well with existing work processes
	The new technology performs as it was designed to and supports how I work
	The new technology consistently functions well
	The new technology allows me to make the final call
	The new technology continues to function under abnormal circumstances
State	I am excited about the change
	I am looking forward to the new technology
	I trust the new technology

Factor	Variable (to be answered by end users)
	I feel confident that I can work on the system deployed
	I have unlearned past practices
	I can operate the new technology without making errors
	I can confidently maintain safe operations and control
	I know what to do if the technology fails
	I know how to right a deviation from normal operations
	I know what I am doing and can support others in an expert manner
	I consider the new technology as an effective and support team player

7.2.1.3 Adoption Challenge 3: Appropriate training

The results showed that training in the control room is extremely important and requires continual attention (Section 4.4.3). However, the results showed there is a growing reliance on online training that is creating a problem for controllers. In one participant organisation, the online training itself had software logic errors making it more frustrating than helpful [Interview 18]. Alarmingly, one participant organisation used online training to train controllers on how to operate a technology that controllers described as mission-critical equipment. No opportunity to see a console or touch buttons and keys was made available to controllers [Interview 16]. The training was only a theoretical exercise. In some cases, no training was provided and controllers felt the technology was simply being dropped in their laps [Interview 05, 33], or they were briefed in an email or ten minutes before a shift [Interview 02, 16]. In many cases, training and familiarisation of new technology were ad hoc [Interview 01]. These experiences are very disconcerting and put controllers under a lot of additional stress.

The extent to which training will be required depends on the new technology being introduced, the level of job changes that result, and the usability of the design. Researchers have found that problems with usability can be overcome in two ways, by making improvements to the design or through training (Pew & Mavor 2007). Therefore, where end users have been involved in the technology's design, many usability problems can be resolved during the design process and implementation will be less confusing to controllers, and thus require less training (Love et al. 2005; Seyal & Pijpers 2004). Furthermore, greater hands-on familiarisation prior to implementation also increases sensemaking and thus reduces training needs (Agarwal, Sambamurthy & Stair 2000; Rogers 2003; Weick 2009;

Yamada & Itsukushima 2013). These are matters that need to be considered when expecting end users to adopt new technologies safely.

It has been noted that not everything can be formally covered in training. Some things come with experience and on-the-job training or the ability to mentor others is thus highly valued by controllers, and can in some regards compensate for some of the inadequacies of the system.

Training considered appropriate by controllers was training that:

1. Provided opportunities to ask questions and to hear the questions asked by others
2. Provided opportunities to discuss the technology openly with the trainer and work colleagues
3. Provided opportunities to play with the technology off-line, to gain hands-on experience in a safe environment
4. Reflected real world scenarios that were site specific
5. Was delivered by a trainer who was knowledgeable and an expert user of the new technology
6. Afforded time to comprehend the new system
7. Allowed time to become competent and to unlearn old practices
8. Provided information in a variety of ways to make learning interesting and easier to comprehend

Controllers also noted that online training that did not have logic errors was considered suitable for theoretical familiarisation and refresher training only.

7.2.2 Challenges for organisations

In all fairness to our participating organisations, there are various constraints that organisations have to work with that help explain the frustration and disillusionment experienced by controllers. For instance, government owned organisations compete for public funds. It can be difficult for managers, let alone politicians, to see a growing need for new technology by a particular organisation. Simply, they are not intimately involved with the internal workings of the organisation.

Furthermore, governments, local and federal, have competing concerns, and who gets the funding may be somewhat determined by the public's perception of need, even further removed from organisational activities. For instance, unless an accident occurs or accidents keep occurring, public attention on a transport system will be low. Additionally, when funding finally comes, the money must be used within a certain timeframe and this sense of urgency can lead to a solution that is expedient but not adequately thought through.

Similarly, once funds are made available, where the system is aging and has been propped up for many years, organisations can inadvertently look for a quick solution rather than take the time to properly identify priority needs. In other cases, the safety regulator may require an immediate response to mitigate an unsafe situation. This can result in the quick implementation of interim controls. Keeping up with small changes can be quite a feat, typically nine changes per week for some organisations [Interview 06].

7.3 Closing the Technology Adoption Gap

In consideration of the need for technology adoption to be optimal in control rooms, a number of ways forward are offered, drawn from the literature.

7.3.1 User resistance not good or bad

In the literature review a number of theories on user resistance were examined (Section 2.4.1). Of particular note is the *Interaction-determined theory* that posits that user resistance occurs when a power balance shifts as a result of interactions with the new system. While Markus (1983) offers that the resistance due to changes should be considered neither good nor bad, it is important to note that those who resist are losing power. Therefore, if new control-room technologies are to be designed in support of positive adoption outcomes, then user resistance must not be ignored or judged as bad. Rather, it can be more useful to consider user resistance as a by-product of an interaction, without placing a judgment on it. For instance, user resistance to a highly defective technology in a safety-critical context can be useful to know, considering its detrimental effect on public safety if it fails. Therefore, resistance including subsequent conflict, as a result of lost power should be investigated to determine whether the power balance needs to be addressed so that conflict can be resolved. This approach aligns well with the political variant of

interaction theory of resistance that sees user resistance as a result of system interactions in its context of use (Section 2.4.1).

Further on addressing conflict, studies have found that people who lose power do not give up power voluntarily, and thus are more likely to resist than those who gain power (Lapointe & Rivard 2005; Markus 1983). For instance, a study on new technology for air traffic controllers found that the tipping point from acceptance to rejection was found to occur when the focus of decision making turned away from the controller (Bekier, Molesworth & Williamson 2012). Hence, a reduction in power would result. The loss of power may well have been the reason why air traffic controllers refused to adopt the new Advanced Automated System (AAS) introduced by the Federal Aviation Administration (FAA) in 1994. While investigators reported that AAS was unreasonably complex and difficult to use suggesting that user resistance was system-determined (Cone 2002), some surmised that FAA's attempts to alter the role of air traffic controller to airspace manager was the real reason for air traffic controller resistance (Breselor 2015; Brown 2011). This suggests that a loss of power due to the new role was being experienced, and thus user resistance was interaction-determined.

Since, the reason for user resistance may not be due to technological inadequacies, scholars have advised to address potential shifts in power before introducing new technology (Markus 1983). The advice provided is to analyse the power balance within an organisation before introducing new technology to determine whether that technology will disrupt the current power balance. If a power redistribution is desired, then it is necessary to make these changes before introducing the new technology (Markus 1983). If not, the design of the new technology needs to be rethought. Furthermore, an assumption that user resistance is always bad can lead to misdirected investigations and incorrect conclusions that leave the real problems unresolved (Markus 1983). Therefore, when analysing who will receive greater or lesser power, it is important for organisational leaders to first consider whether the shift in power is intentional and desirable by organisational leaders. Then, it is important to consider where the shift in power will occur and who will be impacted, so that the shift in power can be addressed before introducing new technology.

7.3.2 Know the power balance

As identified in Chapter 6, the power balance within design teams is in need of a process of power analysis and diagnosis. Identification of each viewpoint can help to inform likely areas of conflict and potential power struggles within an organisation and within the project design team. Diagnosis of potential areas of conflict can thus provide an opportunity to pre-empt and address potential sources of collaborative failure before it occurs.

Similarly, as the results in Chapter 6 indicated, it is also possible that loss of power within a project team will produce designer resistance to alternative viewpoints. If this power imbalance is not resolved suitably, the most domineering viewpoint may end up winning a battle that should not be won. Rather than treating viewpoint conflict as a battle to win, it can be more fruitful to recognise that the source of conflict is a result of an interaction conflict (Section 2.4.1). Therefore, a process is necessary that can help all stakeholders come to respect the viewpoints of others and reach a common agreement regarding the best way forward (Project Management Institute 2013). However, in reality, reaching a common agreement is not a straight forward process. For instance, the design approach of new control-room technologies must be conducive to the methods used to effectively integrate human factors, such as human-centred design principles that include end-user participation and multiple design iterations (Section 2.6).

It is important to accept that everyone who has a stake in the design of a new technology will be biased toward their own needs (Six 2015). Thus, it is safe to say that all control-room technology stakeholders will have a biased viewpoint. To reduce this bias, it is important for each stakeholder to more fully understand the perspectives of others.

Thus, to allow one viewpoint to dominate may impair the development of potentially new design approaches that may be better suited to highly integrated systems, but not given a chance to develop or be refined. As with the advice provided to organisational leaders by previous scholars (Lapointe & Rivard 2005; Markus 1983), before embarking on the design process, the balance of power within the design team needs to be identified, and conflicts need to be diagnosed and resolved before embarking on the design process.

The integration of information systems is on the rise in control room environments, and if the power imbalance within design teams is not addressed, it is likely that the already challenged approach to HFI will get worse. While it is difficult to identify how this will exactly impact human factors and accident prevention efforts into the future, this study suggests that the technology adoption gap will not be resolved anytime soon but will continue to grow worse into the future. In light of these results, it does not seem reasonable to ignore the potential impact that an inappropriate power balance within a design team may have.

7.3.3 Improve team collaboration

The design of modern control-room technology typically requires the collaborative efforts of members of diverse disciplines (Moore & Lottridge 2010). Tension and misunderstandings within design teams are not unusual (Houghton, Balfe & Wilson 2015; Pace 2011). A number of factors can cause conflict in the design arena, namely different thinking styles (Kim 1990), use of different terms or terms that have different meanings (Sharp, Rogers & Preece 2007), and different values, priorities and goals (Blevis & Stolterman 2009). However, while multidisciplinary teams and interdisciplinary teamwork are commonplace in many professional settings, as identified earlier (Section 2.6.4.5), a need for greater collaboration is needed so that new designs can be created that satisfy the real needs over those imagined (Toft 2007).

Therefore, it is important to resolve tensions so that teams can function effectively. An emerging area of interest in the literature is the development of a shared understanding amongst team members so that everyone is on the same page and moves forward in the same direction. Scholars recognise that team performance can be improved if team members have a shared understanding of the project (van der Bijl-Brouwer & van der Voort 2014; Wildman et al. 2012).

One suggestion to achieve effective collaboration amongst design team members requires interdisciplinary learning (Yeager 2005). Thus to work together towards a shared goal requires a shared understanding. Interdisciplinary learning is reliant upon the acceptance and application of three core constructs, namely: (1) each discipline makes an important contribution, (2) each team member must be free to use skills, expertise and judgement

when planning and delivering services, and (3) each team member is committed to the mutual benefit of the project goals (Yeager 2005). Some approaches found useful for the achievement of a shared understanding are briefly discussed below.

7.3.3.1 Play the devil's advocate

Scholars are finding that greater mindfulness has led to more appropriate resourcing when managers have come to appreciate the needs of end users and how those are best achieved. To achieve project mindfulness and thus a shared understanding the various perspectives must be voiced to give relevance to priority needs. Sammon (2008) offered that it can be useful to run workshops with managers and end users together. During these workshops, the designer plays the devil's advocate by purposefully drawing out or presenting opposing viewpoints, what if's, and potential areas of conflict to strengthen meaning made. This practice has been found to lead to mindful decision-making that leads to greater satisfaction amongst stakeholders (Sammon 2008).

7.3.3.2 Communities of practice

Focus groups and workshops are frequent tools for bringing a group of people together to find solutions or to share insights. However, the ability to open up and to share insights is often moderated by trust within the group (Cox 2004; Roberts 2006). One way proved effective in industry for enabling learning together and deeper learning is through communities of practice.

Communities of practice are groups of people that come together with a common interest to create new knowledge through social exchanges of ideas, knowledge, and insights (Lave & Wenger 1991). They are characterised by having a defined domain, a shared practice, and community, and shared artefacts created by the community, that is put back into the community (Wenger 1999). By tapping into the energy and new knowledge that propagates from these social exchanges, businesses have reported financial gains through the achievement of a competitive advantage and greater market share (Nagy & Burch 2009). However, to be effective, communities of practice need to be acknowledged and legitimised within the organisation. Legitimisation can be achieved by allocating time for discussions and thus resourcing to maintain the group without stifling the vitality they create by imposing overly formal processes or business structures. Under the right conditions,

communities of practice progress quite easily because, when people care about a topic, they are naturally drawn to others who also care (McDermott 1999).

Increasingly, researchers are finding that communities of practice do more than share and create knowledge, they have also experienced improved work performance (Nistor et al. 2015), greater motivation to learn (Schmidt & Moust 2000) and increased acquisition of tacit knowledge amongst the group (Nonaka & Takeuchi 1995). More can be learned about communities of practice from the following authors: Wenger (1999), Wenger, McDermott and Snyder (2002), Wenger & Wenger-Trayner (2015), and Zboralski (2009). They thus warrant further investigation for this purpose.

7.3.3.3 Graphic representations

While misunderstandings abound in multidisciplinary teams and thus challenging, graphic representations of knowledge can be useful. Rather than sharing documents, which is a common practice but found to be an ineffective way to manage knowledge across multiple stakeholders, it can be more useful to use other objects to develop shared representations associated with the project (Hall-Andersen & Broberg 2014). Alternatives to formal documentation include narratives, pictures, sketches, flow charts, and later prototypes and simulations (Pew & Mavor 2007). Knowledge maps have also been found to be an effective way to share knowledge and to enhance tacit knowledge elicitation (Ting et al. 2011). To develop shared representations together can help to encourage 'thinking with' and thus a shared understanding, rather than trying to collate individual offerings (Hall-Andersen & Broberg 2014). Open sharing of ideas and insights assists the act of learning together and helps to grasp the thinking behind what is being said and how this relates to the bigger picture. This is a systems thinking approach that achieves far deeper understanding and thus much more meaningful results (Bosch, Maani & Smith 2007).

As with other forms of documentation, studies have shown that human factors guidelines can be easily reasoned away if not properly understood (Broberg, Andersen & Seim 2011; Hall-Andersen & Broberg 2014). One suggestion found useful by scholars is to develop representations of the project that can be grasped by all team members. Attributes of representations considered useful include those that (Pew & Mavor 2007, p. 63):

- Establish a shared language – that suitably aligns with development and communication needs (e.g. storyboards, maps, sketches, and prototypes)
- Provide a strategically chosen amount of ambiguity versus definition
- Facilitate the desired social process that critiques redesign versus accept/reject decisions
- Makes differences and relationships apparent to ensure that assumptions and viewpoints are explicit
- Facilitates group 'thinking with' to transform knowledge and create new understandings
- Provides representations that have a meaningful structure, content and appearance to not only the creators but also other stakeholders

7.3.3.4 A word of caution

While team members may implicitly feel a shared understanding is achieved across the team, this is often not the case. Scholars are finding that a shared understanding is not automatic and that more conscious awareness of the work to be done is necessary (Aubé, Rousseau & Tremblay 2015). One of the benefits of achieving a shared understanding is that it allows for a shared learning (Gotcheva et al. 2015). However, while multidisciplinary and multigenerational team members can provide benefits to the development of new technology differences, values held can hinder knowledge sharing (Sanaei, Javernick-Will & Chinowsky 2013).

7.4 Conclusion

The results from this study have shown that end-user concerns over safety are particularly heightened due to advances towards more highly integrated technologies. Concerns over how new technologies are designed and how organisational leaders make new technology decisions have arisen because of problems experienced during interactions with new technology that end users seek to adopt and become expert users of. As a result, this research has highlighted a number of challenges that need to be addressed if the introduction of new control-room technology is to be optimised. However, it must also be noted that these challenges cannot be overcome without effort and genuine intentions on the part of all stakeholders. To address them effectively requires a new way of thinking that

better reflects emergent conditions. Old paradigms about safety, design, and business management need to be questioned, analysed and evaluated to accommodate new ideas.

Currently, industry is struggling to integrate human factors into the design of technologically advanced systems. However, for system elements to be integrated without undermining safety, human factors concerns must be addressed. An integrated system requires a team to be able to design in a transdisciplinary manner in order to create and innovate. However, one of the barriers to transdisciplinary approaches is that collaboration across multiple disciplines is not easy. As this study has shown (Chapter 6), collaboration in some safety-critical industries is being challenged by a domineering viewpoint that appears to persist across other industries, not just those with safety-critical systems. Therefore, if new control-room technologies are to be safely introduced in the future, stakeholders from potentially disparate disciplines must learn how to work together for the joint achievement of optimal outcomes. The fact that 82 percent of the Q-participants were advocates of end-user involvement during the design of new technology indicates that a new way of thinking is developing amongst control-room technology stakeholders. However, while this is promising, stakeholders need to be open to change and to recognise the necessity for changed thinking if effective safety is to accompany technological advancements.

Chapter 8. Conclusion

Effective design and introduction of new technology are essential if optimal system performance is to be achieved. This is particularly so when safety is critical, as is the case for organisations in high-risk industries. The control room provides the user interface to a control system that often has integrated human, hardware and software elements. However, progressively, control systems are becoming more highly integrated creating new interactions that introduce new human factors concerns. Thus, the introduction of new control-room technologies presents a unique challenge to controllers as they adopt new interface technologies for safety-critical systems.

The technology adoption gap, revealed in the literature was found to be quite pronounced in participant control centres. While the use of control-room technology is mandatory, an assumption is often made that controllers will adopt new technology and will do so expertly. However, the reality is that controllers frequently do not feel supported during the introduction of new technology in a way they perceive will provide safety assurance. Controllers reported frequent experiences of 'sink or swim' or 'dropped in the lap' implementation strategies. Practices like these were found to stem from underlying conditions that can be traced back to values, priorities, and motivations of organisational leaders that lay the foundation for business practice. This study identified a number of contexts in which conflict amongst stakeholders arise, including the power distribution in organisations, decision making and communication styles, design approaches, and the manner in which new technology is implemented. Furthermore, the challenges noted indicate that making the necessary changes will not be easy.

While some advancement has occurred, human factors integration (HFI) in general is poorly understood. Analysis of the results revealed that the traditionalist approach to design, while not the most popular approach, dominates the others as evidenced by end-user experiences. This indicates a significant power imbalance amongst design team members. Alternative viewpoints could add value to the design outcomes. However, marginalisation has often prevented this potential from being realised in system success.

Furthermore, the presence of a domineering approach has not been brought into question by organisational leaders, and it, therefore, continues to be resourced and encouraged to dominate. While it is clear that every stakeholder is biased towards their own needs and thus may have different priorities, values, and needs than others, the dominance of one perspective is not supportive of effective collaboration, cooperation, change or innovation. Unfortunately, without an appreciation for alternative viewpoints, many valuable contributions will go unrealised.

The glimpse of reality inside control rooms that this study provided has highlighted the types of challenges stakeholders is experiencing. Therefore, if the design of new control-room technology is to become more supportive of practices that lead to effective system performance, more effective collaboration is necessary so that the strengths of all stakeholders can be considered for incorporation. Results from this study indicate that a process of viewpoint analysis and diagnosis is necessary if conflict amongst stakeholders is to be resolved. Identification of each viewpoint can help to identify likely areas of conflict and potential power struggles within the project design team. The results presented here may, therefore, offer an opportunity to devise more effective strategies so that factors that contribute to collaborative failure can be pre-empted.

The research undertaken for this dissertation has helped to explain events that surround the design and introduction of new control-room technologies. Analyses showed that advocates and experts of HFI need more power within the organisation to positively influence organisational decisions, including within the design team. Without this, the safe introduction of new technology cannot be assured for organisations with safety-critical systems. These results have shed light on the underlying conditions which lead to technology adoption problems that are not readily observed. Thus, this study provides some clues to the contexts in which safety issues arise. This type of information is, therefore, useful for informing more effective design strategies, and possibly the development of future accident prevention programs.

In conclusion, it is no longer acceptable to apply past practices for new circumstances. Rather, a genuine effort is required by corporate managers of safety-critical control systems,

to analyse and diagnose the influences of power within their organisations so that the challenges identified in this dissertation can be addressed before they lead to unsafe events.

8.1 Lessons Learnt

A number of lessons have been learnt as a result of this study and these have a potential use by way of transfer to new technology projects in safety critical control environments. A major finding from this study was how easily the design and adoption of new technology can be quickly undermined if an inappropriate balance of power exists within the organisation or within new technology acquisition project teams. Therefore, if organisational leaders with safety-critical systems are willing to change or refine how they approach this process, the following lessons learnt can be useful to inform the design and introduction of new control-room technology:

1. *Accept that purpose-built technologies provide a noteworthy opportunity to do much of the HFI work before the new technology is introduced into the control room*. To achieve greater project mindfulness so that this unique opportunity can be fully taken advantage of, an expert on user-centred design and participatory processes must be present in the design team. Best suited to this role are human factors engineers.
2. *Develop a shared understanding of the project.* A shared understanding of how the new technology project will be approached is particularly important for key stakeholders, namely managers, designers and end users. Furthermore, this shared understanding must be maintained. Hence, when expectations are violated or where conflict or resistance arises, the project team must once again share knowledge to resolve issues for a renewed shared understanding. The achievement of a shared understanding requires effective collaboration skills such as a strong commitment to a mutual agreement, effective communication skills particularly listening, a desire to fully appreciate other stakeholders' perspectives, to negotiate without bias, and to act when action is necessary.
3. *Consider the utility of praxical knowledge.* End users have unique insight into how they 'actually' control, not 'theoretically' control. In this dissertation, this know-how has been termed *praxical* knowledge. To draw out praxical knowledge requires an

acknowledgement of its tacit nature. Thus, it will be necessary to involve end users actively during the design process, from initial concept inception, and throughout the design lifecycle.

4. *Value end-user input.* To appreciate the value of end-user involvement in projects requires an acceptance that end users are the domain experts of their work environment, and that their involvement is much more than about achieving 'ownership' as the international standard ISO11064 implies.
5. *Appoint an end-user advocate.* For end users to be able to have any influence on decisions made regarding the technologies they use, they will need an advocate. The advocate must have the power to ensure appropriate resourcing to allow end users time away from normal duties so that they can be actively involved and have time to grasp new concepts. Furthermore, end users need someone to be able to make them aware that a new project is being considered, so that early involvement can be organised and achieved.
6. *Promote early sensemaking.* Once it has been decided to introduce a new technology, ensure all stakeholders are identified and made aware of the pending project. The actual end users are overlooked for inclusion in technology development projects. Two benefits can be realised through the early involvement of end users. Firstly, end users can begin making sense of the new technology early and thus have a better chance to progress through the adoption process more efficiently. Secondly, end users can help designers to integrate human factors and praxical knowledge into the design by participating in various human factors related activities, and thus influence design quality.
7. *Consider the learning implications for end users.* Analyse and identify how much the proposed new technology will change the way end users control. End users will be the best judge of this. Then ensure that opportunities to learn how to use the new technology are resourced appropriately to allow for time-off-the-desk. Consider how user participation can support this learning process, as this study has shown.

8.2 Recommendations for organisational leaders

Upon reflection of the lessons learned outlined above and in the change management literature, a number of recommendations have been devised for organisational leaders:

1. *Know the balance of power within the organisation.* When considering the introduction of new technology, it can be useful to conduct an organisational analysis of the power positions within the organisation and to then to evaluate whether the new technology being considered will impact this power balance. This is particularly important when it is anticipated that the new technology will revolutionise current practice. The purpose of this analysis is to explain and predict power shifts and thus to identify areas of conflict.
2. *Bring about the organisational change before implementation of the new technology*. If a redistribution of power is deemed necessary, bring about the organisations change first before implementing the new technology. This is to ensure that the new technology is not perceived as the reason for user resistance.
3. *Distribute power mindfully within the organisation.* Consider where the power needs to be distributed and evaluate the effects a power shift might have on those who will experience losses. Follow this up by addressing the change.
4. *Know the balance of power within the project management team*. Many purpose-built technologies will employ a mix of internal and external sources of expertise and the team will be multidisciplinary. Tension within design teams is not unusual. Therefore, when forming the project management and design team, it is important to know where the power is distributed so that potential for conflict can be pre-empted and mitigated. Furthermore, the power balance must be re-examined each time a team member leaves or a new team member is included.
5. *Distribute power mindfully within the control system.* As with organisational settings, the distribution of power amongst system elements is equally important. The functional allocation that influences decision-making power between technological and human systems must be mindfully placed. Therefore, help in this area can be sourced from the human factors community. Additionally, consideration of automation design principles can help to inform how to distribute the power balance within a control system (Section 2.6.2).
6. *User resistance as a design adjustment indicator.* Rather than viewing user resistance as a problem, it can be more useful to view it from an interaction theoretical perspective. In this regard, user resistance is neither good nor bad. Rather, it can be

used as a useful indicator of how well human factors are being integrated into the design or an indicator of some technical defect.

8. *Genuinely grasp an appreciation for the roles of other stakeholders.* Many of the sources of conflict in design teams result from team members do not always fully appreciating what other stakeholders do and why it is necessary for their inclusion in the design team. While roles may overlap, some obvious team players for the development of modern control systems may include:
   - Commissioning manager to resource the project.
   - Project managers to attend to project governance and direction.
   - Engineers to attend to hardware design.
   - Software developers to attend to logical and coding.
   - End users to provide praxical knowledge.
   - Human factors engineers to attend to the 'interactions' between the human and other system elements and advocate for human-centred design principles.
   - Maintenance staff to help identify site-specific constraints, issues, etc.
   - Safety and quality personnel to guide the identification of safety risks or inefficiencies.

8.3 Opportunities for Further Research

This study found a number of areas where the current understandings associated with introducing new technology into safety-critical environments can be improved with further research. Areas that could benefit from future research include:

- There is a growing perception that human factors have already been addressed in off-the-shelf technologies and thus no further action is necessary. This perception illustrates a general lack of understanding that additional human factors issues arise when humans interact with the new technology within its context of use. Therefore, it can be useful to benchmark current perceptions of what human factors professionals do and where their expertise is most needed. Studies of this nature can help to direct more suitable interventions to reduce identified gaps, for both the higher education and industry communities.

- Further research on how sensemaking contributes to improved technology adoption outcomes is necessary to enhance and validate this foundational study.
- This study produced a number of ways that end-user input might be achieved as well as a potentially ideal process for introducing new control-room technology. Future research could test these practices in other work environments to refine their development and to validate their effectiveness.
- Studies that identify viewpoint traits and patterns of behaviour can help to develop an inventory of design approaches for the development of a 'collaboration indicator test'. This type of test is likely to be useful for predicting and mitigating the potential for conflict between the stakeholders.
- A review of the International Standard on the *Ergonomic design of control centres – Principles for the design of control centres* (ISO11064-1:2000) is necessary. In light of current trends, advice to integrate human-centred design (HCD) approaches into the 'traditional function-oriented design approach' appears to be impossible to achieve, and is thus considered detrimental to HFI efforts.
- There is currently no design process that explicitly addresses technology adoption. Therefore, there is an opportunity to develop and test a design process that also facilitates end-user adoption of new technology.

8.4 Implications of this Research

The lessons learnt from this study have specific application to new technology projects in safety critical control environments. However, while three industries were focused on in this study (aviation, rail, and power), the learnings equally apply to other safety-critical industries. Additionally, the lessons shared have applications in industries that are not safety-critical in nature. This is particularly so for large or complex projects whose losses, in the event of failure, can be substantial and likewise where the introduction of disruptive technologies are desired to achieve business goals.

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Appendices

Appendix A2.1 – 39 Technology Satisfaction Factors

39 Technology Satisfaction Factors Developed by Bailey and Pearson (1983)			
No	Key	Satisfaction Factor	Definition Summarised
1	Org	Top management involvement	Interest, enthusiasm, support or participation
2	Org	Organisational competition with *EDP	Systems in conflict for organisational resources
3	Org	Priorities determination	Policies for resource allocation for competing systems
4	Sup	Charge-back method of payment for services	Schedule of charges for assessing users (pro rata basis) for new IS
5	DP	Relationship with user and EDP staff	Manner of interaction, conduct, association
6	DP	Communication with user and EDP staff	Manner of information exchange
7	Sup	Technical competence of the EDP staff	Computer technology and expertise exhibited
8	Sup	Attitude of EDP staff	Willingness & commitment to achieve org. goals over their own
9	Sup	Schedule of products and services	Production of system outputs and services
10	Sup	Time required for new development	Elapsed time between users' request to implementation
11	TS	Processing of change requests	EDP staff response to user requests for changes systems/ services
12	TS	Vendor support	Type & quality of service to the user to maintain hard or software
13	TS	Response/ turnaround time	Elapsed time between user request and output
14	TS	Means of input/ output with EDP centre	Method for user inputs data to receive output from EDP centre
15	HSI	Convenience of access	Ease of use to access system capability
16	HSI	Accuracy	Correctness of the output information
17	Sup	Timeliness	Availability of output info at a suitable time for its use
18	HSI	Precision	Variability of output information to purported to measure
19	HSI	Reliability	Consistency and dependability of output information
20	HSI	Currency	Age of the output information
21	HSI	Completeness	Comprehensiveness of output info content
22	HSI	Format of output	Design, layout and display of data
23	HSI	Language	Vocabulary, syntax, grammatical rules used to interact with system
24	HSI	Volume of output	Amount of information conveyed to a user
25	HSI	Relevancy	Match between user needs & info/services provided
26	Org	Error recovery	Policies governing correction and rerun of incorrect system outputs
27	TC	Security of data	Safeguarding data from misappropriation, alteration or loss
28	HCI	Documentation	Documented description & instructions for use
29	HF	Expectations	Features user considers reasonable
30	HF	Understanding of systems	User understanding of how to use IS
31	TC	Perceived utility	User judgement about balance between cost & usefulness -benefit
32	HF	Confidence in the system	User certainty of system use
33	HF	Feeling of participation	User involvement with EDP staff - functioning of IS and services
34	HF	Feeling of control	User's personal power to regulate, direct or dominate the development, alteration and/or execution of the IS or services.
35	HF	Degree of training	Specialised instruction and practice required
36	HF	Job effects	Changes to user job freedom and job performance
37	Org	Org. Position of the EDP function	Hierarchical relationship of EDP function to overall org. structure

*EDP – Refers to the new *EDP unit* that was under investigation in this study.
Key: DP = Design Process, HSI – Human System Integration, HF = Human Factor, Org = Organisational Factors, Sup = Supplier Factor, TC = Technology Characteristic, TS = Technical Support

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Appendix A2.2 – TAM Construct Definitions Used in TAM

Construct	Definition
Attitude	Individual's positive or negative feeling about performing the target behavior (e.g. using a system).
Behavioural intention	The degree to which a person has formulated conscious plans to perform or not perform some specified future behavior.
Computer anxiety	The degree of an individual's apprehension, or even fear, when she/he is faced with the possibility of using computers.
Computer playfulness	The degree of cognitive spontaneity in microcomputer interactions.
Computer self-efficacy	The degree to which an individual believes that he or she has the ability to perform specific task/job using computer.
Effort expectancy	The degree of ease associated with the use of the system.
Experience	Opportunity to use a target technology and is typically operationalized as the passage of time from the initial use of a technology by an individual.
Facilitating conditions	The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system.
Habit	The extent to which people tend to perform behaviours automatically because of learning (automaticity)
Hedonic Motivation	'the fun or pleasure derived from using a technology
Image	The degree to which use of an innovation is perceived to enhance one's status in one's social system.
Job relevance	Individual's perception regarding the degree to which the target system is relevant to his or her job.
Objective usability	A comparison of systems based on the actual level (rather than perceptions) of effort required to complete specific tasks.
Output quality	The degree to which an individual believes that the system performs his or her job tasks well.
Performance expectancy	The degree to which an individual believes that using the system will help him or her to attain gains in job performance.
Perceived ease of use	See the definition of effort expectancy
Perceived enjoyment	The extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system use.

Construct	Definition
Perceived usefulness	See the definition of performance expectancy
Perception of external control	See the definition of facilitating conditions
Price Value	Consumers' cognitive trade-off between the perceived benefits of the applications and the monetary cost for using them.
Result demonstrability	Tangibility of the results of using the innovation.
Social influence	The degree to which an individual perceives that important others believe he or she should use the new system.
Subjective norm	Person's perception that most people who are important to him think he should or should not perform the behavior in question.
Voluntariness	The extent to which potential adopters perceive the adoption decision to be non-mandatory.

Reference

Venkatesh, V 2015, *Construct Definitions*, viewed 10 August 2015, http://www.vvenkatesh.com/it/organizations/theoretical_models.asp

Venkatesh, V, Thong, JY & Xu, X 2012, 'Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology', *MIS Quarterly*, vol. 36, no. 1, pp. 157-178.

Appendix A2.3 – Overview of Technology Acceptance Developments

The aim of technology acceptance models is to predict user adoption behaviour. Since its development the Technology Acceptance Model (TAM), has attracted a great deal of research interest from the Management of Information Systems (MIS) researcher community. Davis (1986, 1989) proposes that two main constructs (1) perceived usefulness (PU) and (2) perceived ease of use (PEOU) determine and predict an individual's intention to use a technology, as illustrated in Figure A1. Since this first iteration, TAM has been tested, extended, and redesigned to investigate the influence that preconditions (i.e. external variables) may have on the two determinants that influence an individual's behavioural intention. Factor analysis and regression are commonly conducted to determine the percentage of variance in behavioural intention. TAM authors offer that managers could use the results from TAM studies to predict likely acceptance by users, and to diagnose the reasons for reluctance to accept so that corrective action could be taken to increase acceptance and thus profitability for the organisation introducing the new technology.

While TAM models have their limitations, they can provide some insight into understanding the factors that may influence the pace and quality of end-user adoption, and thus contribute to the aim of this study. There are numerous TAM variations. Therefore a historical representation of models have been presented below.

The Technology Acceptance Model (TAM) (Davis 1986)

The Technology Acceptance Model (TAM) was first introduced by Fred Davis (1986) (Figure 2:6). Davis proposed that if an individual perceives that a technology has some utility and it seems easy to use, they are likely to accept the technology. The model is based on the Theory of Reasoned Action (Fishbein & Ajzen 1975) that proposes that behavioural intentions (BI) determine why a person comes to perform an actual behaviour (AB), and that the individual's behavioural intention is determined by their attitude (A) and subjective norm (SN) towards the particular behaviour (i.e. A + SN = BI → AB). A general consensus amongst TAM researchers is that the two constructs do determine behavioural intention (i.e. PU and PEOU) toward the use of the technology under consideration and that behavioural intention leads to actual usage.

Updated TAM (Davis, Bagozzi & Warshaw 1989)

The original model was refined in 1989 to include Behavioural Intention to Use (BI) as illustrated in Figure A2.3.1. A comparative study over a 14 week period, found that TAM accounted for 45% (study 1 – pre-use) and 57% (study 2 – 14 weeks later) of the variance in behavioural intentions of system users (Davis, Bagozzi & Warshaw 1989). Authors concluded that an individual's behaviour can be predicted with some confidence from their intentions.

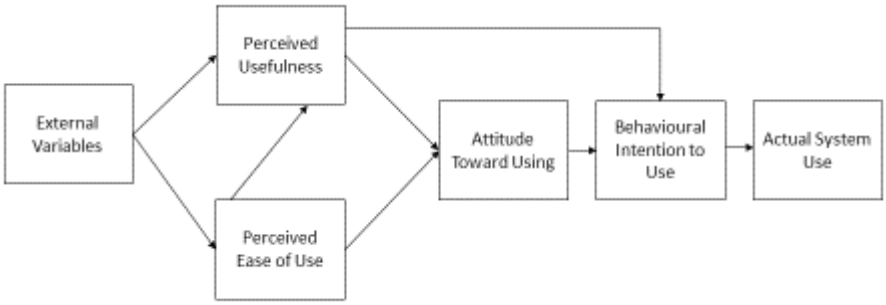

Figure A2.3.1 Technology Acceptance Model

Source: Davis (1989, p. 985)

Technology Acceptance Model 2 (TAM2) (Venkatesh & Davis 2000)

In 2000, the model was extended to include variables related to social influence and cognition. This extended model, named TAM2, was tested using longitudinal data over four different systems in 4 organisations, testing both voluntary and mandatory circumstances. Results accounted for 34-52% of variance in usage intentions. While results are fairly similar to those of TAM, subsequent studies using TAM2 were found lacking in consistency and clarity (Legris, Ingham & Collerette 2003).

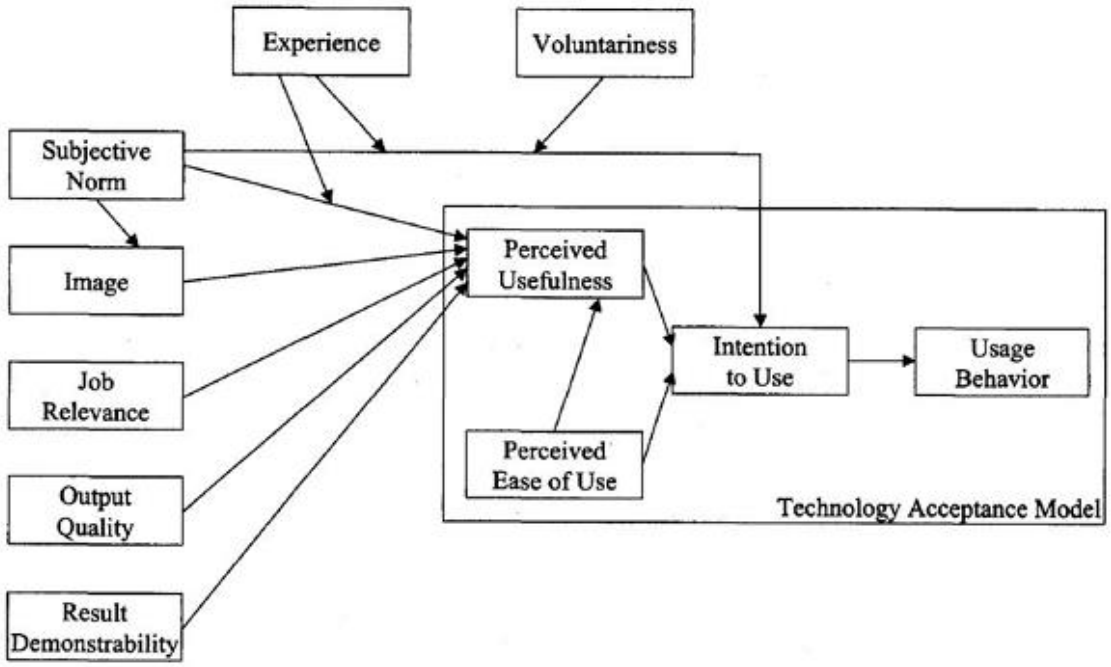

Figure A2.3.2 TAM2

Source: Venkatesh and Davis (2000, p. 188)

The Extended Technology Acceptance Model (Mathieson, Peacock & Chin 2001)

Mathieson, Peacock and Chin (2001) investigated the relationships between PU and PEOU as show in Figure A2.3.2, and added the influence of perceived resources.

Testing the TAM (Liaw & Huang 2003)

Liaw and Huang (2003) examined user perceptions of search engines. They extended the TAM model by reorganising the original two main constructs showing that PU was the primary predictor variable, influenced by PEOU and *perceived enjoyment*. Also, perceived enjoyment was found to be a predictor of PU. External variables added included: *experience with work processing packages*, *quality of search engines, internet response time and experience using operating systems*, as illustrated in Figure A2.3.3. Results from their regression analysis explained 67% of behavioural intention toward the use of search engines.

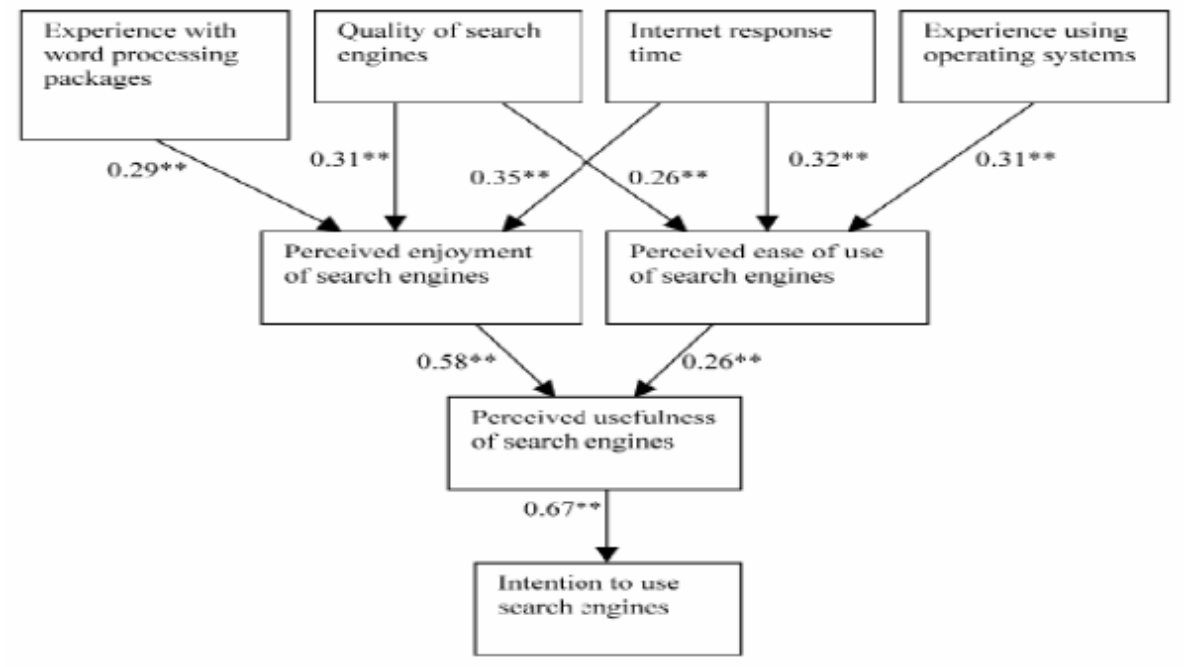

Figure A2.3.3 Testing the TAM

Source: Liaw and Huang (2003, p. 756)

Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003)

By 2003, quite a number of external variables had predictive power and thus TAM researchers united and formed the Unified Theory of Acceptance and Use of Technology (UTAUT). Eight models were examined, namely: TAM, the theory of reasoned action, TAM, theory of planned behaviour, the motivational model, innovation diffusion theory, social cognitive theory, the model of PC utilization and a model combining the technology adoption model.

Analysis across the eight models accounted for 17% to 53% of the variance in user intentions to use information technology. Subsequent analysis of the UTAUT on two new organisations found that the UTAUT accounted for 70% of the variance in user intentions. The UTAUT re-models and extends the TAM in three ways. Firstly, the names of the two original constructs have been changed from perceived usefulness to performance expectancy and perceived ease of use has been change to effort expectancy. Secondly, two constructs that directly influence behavioural intentions have been added, namely: social influence and facilitating conditions. Thirdly, moderating factors shown to influence the

predictive factors have been added, namely: age, gender, experience and voluntariness of use (Figure A2.3.4).

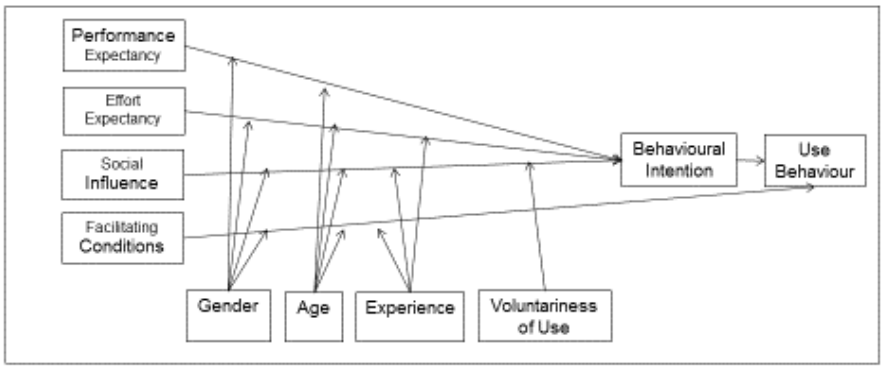

Figure A2.3.4 The Unified Theory of Acceptance and Use of Technology ATAUT

Source: Venkatesh et al. (2003, p. 445)

Incorporating Risk Factors into the TAM (2003)

Featherman and Pavlou (2003) extended TAM by including various risk factors, as illustrated in Figure A2.3.5. As with Liaw and Huang's model, this model posits that *usefulness* has the most predictor power. Perceived factors of risk included in the model, are: *financial, psychological*, *privacy*, *time* and *performance*. Ease of use influenced *performance risk* and *perceived risk* which in turn influenced *usefulness*. Study results reported that the model predicted 58% of adoption intention.

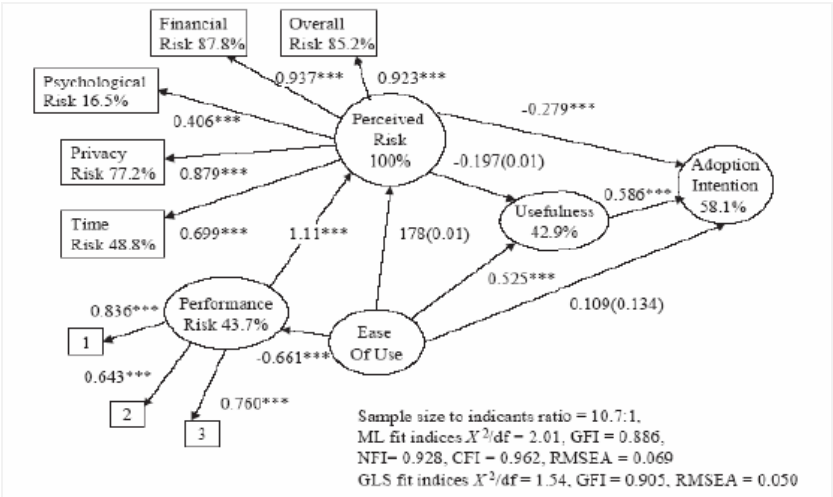

Figure A2.3.5 Incorporating Risk Factors into the TAM

Source: Featherman and Pavlou (2003, p. 458)

Theoretical Research Model – Extension of TAM (2004)

Seyal and Pijpers (2004) extend the TAM model and proposed the external variables to be *demographics*, *PC exposure*, *task-related* and *organisational factors*, as shown in Figure A2.3.6.

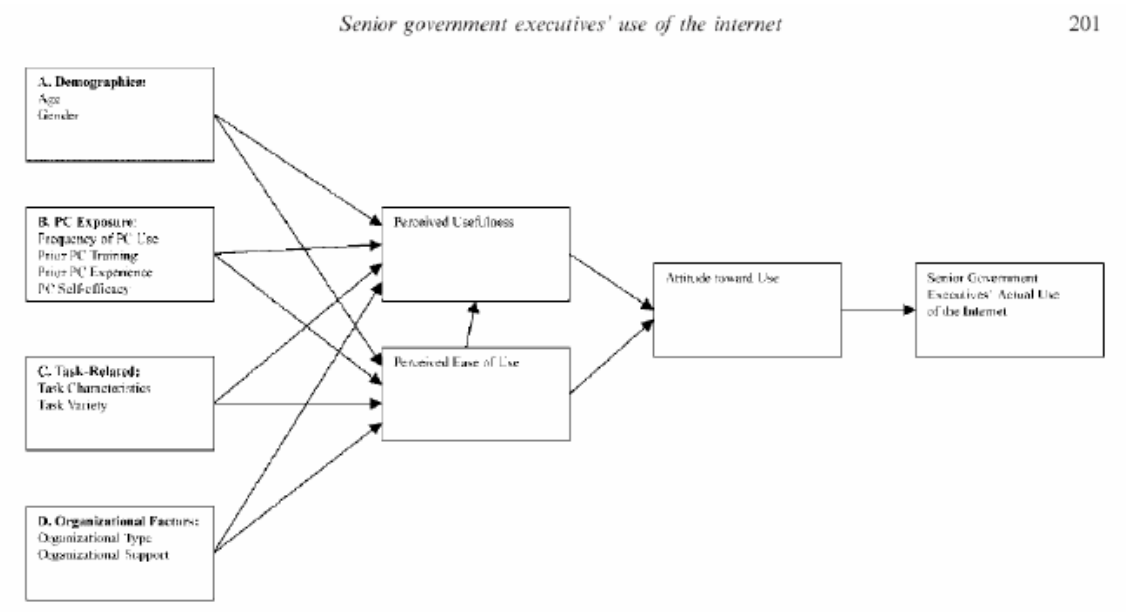

Figure A2.3.6 Theoretical Research Model - Extension of TAM

Source: Seyal and Pijpers (2004, p. 201)

Technology Acceptance Model 3 (TAM3) 2008

TAM3 presents a theoretical construct for organisational settings. The model shows that experience and the feeling of voluntariness has a moderating influence behavioural intention and an indirect influence on perceived ease of use, as shown in Figure 2.3.7.

A Qualitative Model of Technology Acceptance

van Ittersum and colleagues (2006) performed a literature review of TAM models and from this developed an impressive model that combined the contribution offered by all authors included in the review, as displayed in Figure A2.3.7.

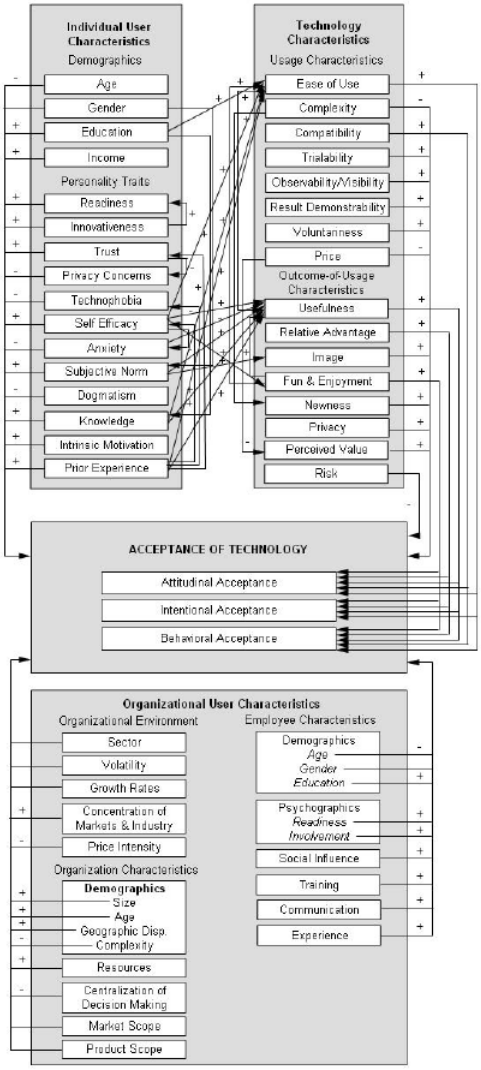

Figure A2.3.7 Qualitative Representation of all TAM models

Source: van Ittersum et al. (2006, p. 77)

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Appendix A2.4 – Human Factors-Related Standards for Control Systems

Standard	Application
AS 4024-2006, *Safety of machinery* Contains 35 Parts	Covers placement of equipment, reach zones, mental ability, perception and information processing. Part 1901 has a useful table that outlines function allocation for human and machine tasks. Part 1401 itemises tasks to perform during the design process. Unfortunately, topics associated with system complexity, such as team interactions, situational awareness and cognitive analyses are lacking.
AS IEC 62508-2011 *Guidance on human aspects of dependability*	Contains a useful list of human factors topics to address throughout the system life cycle. Contains a sample of HFATs to be used in conjunction with other engineering and technical activities.
ISO 26800:2011 *Ergonomics. General approach, principles and concepts*	Provides an introduction on how to design tasks, products, systems, organisations, services and environments compatible with human characteristics, needs, values and ability.
ISO 6385:2004 *Ergonomic principles in the design of work systems*	Integrates human factors practitioner activities with system developers to achieve compatible work systems.
ISO/TR 18529:2000 *Ergonomics of human-system interaction – Human-centred lifecycle process descriptions*	This standard complies with the information processing protocol outlined in ISO/IEC TR 15504.
ISO 9241 series on *Ergonomics of human-system interaction.*	Part 11 covers general office technologies. Users are cautioned that this part is not suitable for control technologies, due to the assumption that errors are recoverable. Part 210 provides guidance on human-centred design of interactive systems.
Standard ISO 11064:2000 – 2008 *Ergonomic design of control centres*	ISO 11064 was developed for industrial control rooms which includes railway control rooms. It provides a generic framework for applying human factors related requirements and recommendations to the entire design of control centres or to smaller parts.
AS/NZS ISO/IEC 25062:2006 *Software engineering – Software product quality requirements and evaluation (SQuaRE) – common industry format (CIF) for usability test reports*	Focuses on usable software development. Useful items include examples on decision making processes for purchasing, upgrading and automation and a report template for standardising methods and results of usability tests.
ISO 9921:2003 *Ergonomics. Assessment of speech communication*	Requirements for speech communication concerning verbal alerts, danger signals, information messages and general speech communication. Assessment methods are also described with examples.
ISO 20282-1:2006 *Ease of operation of everyday products. Design requirements for context of use and user characteristics*	Of interest to a control room setting is the information on user characteristics that may influence usability.

(Source: Crawford, Toft & Kift 2013, p. 531)

Reference

Crawford, EGC, Toft, Y & Kift, RL 2013, 'New control room technologies: human factors analytical tools for railway safety', *Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit*, vol. 227, no. 5, pp. 529-538.

Appendix A3.1 – Description of Mixed Methods Characteristics

Mixed methods procedures have four defining features, namely: timing (the sequence in which data collection occurs), weighting (priority assigned to qualitative and quantitative data sources), mixing (when is data mixed and how) and theorising. (Table A3.1.1 and 2)

Table A3.1.1 Defining characteristics of mixed methods procedures (developed from: Creswell 2003, 2009)

Term	Definition
Timing	When the qualitative and quantitative data collection takes place: concurrent (not sequential) or sequential (qualitative first, or quantitative first).
Weighting	The priority given to the methods: equal or skewed
Mixing	When and how the two methods are brought together. Mixing of methods can occur in one or more phases of the study including: during data collection, data analysis, and interpretation. Strategies used to mix the data types include: • not mixed – unique results that simply reside side by side to offer a broader picture • connected – occurs in two-phase studies, the second method follows-up the first • integrated – data is merged by transforming themes to counts for comparison analysis • embedded – the nesting of one method into the primary method to support analysis • triangulated – where a study uses two methods to confirm or validate findings
Theorising	Whether a theoretical perspective guides the study explicitly or implicitly

Mixed methods notation.

Table A3.1.2 Common notation used in mixed methods from the field (Creswell 2009)

Term	Definition
+	Indicates a simultaneous or concurrent form of data collection
→	Indicates a sequential form of data collection
Boxes □	Denotes the data collection type and analysis design
Capitalisation	Indicates a weight or priority placed on the data during analysis
Concurrent	Qualitative and quantitative data collection was conducted at the same time
Embedded	A method of mixing data whereby data is brought together during the analysis process
Qual	Qualitative data
Quan	Quantitative data
QUAN/qual	Indicates that qualitative methods are embedded within a quantitative design

References

Creswell, JW 2003, *Research design: qualitative, quantitative, and mixed methods approaches*, 2nd edn, Sage Publications, London.

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Appendix A3.2 – Description of Q methodology

Q methodology is a specialised mixed methods approach that uses a unique way to gather and analyse data. The process involves collecting data on a group of statements (or other items) on a particular topic that represent the sample (rather than participants) for the study. Participants are required to evaluate the statements as a collective group according to a Gaussian curve, rather than individually as is the case with r-technique (i.e. Pearson's product-moment coefficient) used in the first phase of the study to measure the linear correlation of two variables (Vincent 2005). *Q-technique* involves the data gathering procedure called the Q-sort; factor analysis is the *method*; while the *methodology* signifies the philosophical and conceptual framework that justifies the *technique* and *method* necessary to examine the phenomenon to be studied (Brown 1993).

The difference between Q-technique and the well-known R-technique, as associated with 'objective' investigation that uses the Pearson's product-moment correlation, is that Q examines the relationship between people rather than traits (Brown 1980; Stephenson 1935). Instead of evaluating a statement as a standalone variable, as is the case with the traditional Likert-scale question, Q studies require the participants to evaluate statements within the context of other statements and rank order them according to a forced quasi-normal Gaussian distribution, known as the Q-sorting process (Papworth & Walker 2008). In so doing, participant beliefs, and preferences emerge that represent their viewpoint on the topic under investigation (van Exel & de Graaf 2005).

The Q-technique of ranking Q-sorts in a quasi-Gaussian curve helps to guard against potentially misleading or confusing results. For instance, Gottschalk (2002) found that studies on Information Systems using Likert scale gave results that implied key issues were homogeneous amongst IT managers, and warned that such conclusions can be misleading.

Q studies follow a recognised series of steps and are concerned with three questions (Stricklin & Almeida 2010).

- What is the range of communicated ideas in a particular discourse?
- What are the prevalent variations in it?
- How do these variations logically relate to each other?

Step 1: Develop a concourse (sample)

The Q-sample, also known as a Q-set, is drawn from the communication that represents the debate surrounding the topic, known as the concourse (Stephenson 1972). The nature of the concourse depends upon the research question and thus can appear in a variety of forms such as: objects, sounds, images, words, etc. (Brown 1993). A number of ways can be used to established the concourse, namely: literature searches (Butler et al. 2014; Harvey et al. 2015), surveys, existing relevant Q sets, email correspondence with relevant agencies (Butler et al. 2014), focus groups (Dryzek & Holmes 2002), participant interviews (Butler et al. 2014; Yao et al. 2015), participant provision of a list of representative words or quotes (Barnes & Angle 2015; Watts & Stenner 2014), or any number of combinations (Barnes & Angle 2015; Jaffares & Skelcher 2011). However, the goal is to capture the manner in which the issue is expressed in the language that respondents relate to (Jaffares & Skelcher 2011). Hence, purposive interviews, focus groups and participant surveys are also very useful for this purpose. Concourses can amount to hundreds of statements or items. To reduce this number so that individuals can effectively sort the statements/items, a sample that preserves the diversity of the discourse, must be drawn (Fisher 1960).

Step 2: Establish the Q-Sample

The establishment of the Q-sample has been described as a critical step in Q methodology (Paige & Morin 2016). The literature has revealed three ways to approach Q-sample selection. The inductive, unstructured approach is used when no theory about the phenomenon exists, while a deductive, structured approach is adopted where pre-existing theory exists (Paige & Morin 2016). The third approach involves inductive and abductive thinking and utilises a semi-structured approach based on a mix of theory-led and thematic-led statements (Hurd & Brown 2005).

The inductive approach supports the interpretive epistemology of Q methodology (Jeffares 2014) which permits abductive reasoning during the research process (Schwartz-Shea & Yanow 2012). Abductive research logic allows research to be creative for the construction of novel explanations (Thagard & Shelley 1997). Use of abduction aims to follow rule-governed and replicable production of new and valid knowledge by making inferences from new and

existing theory (Charniak & McDermott 1985; Reichertz 2010). First taken up by Peirce (1998), abductive reasoning was described as the only truly knowledge-extending means for making inferences that sets it apart from the other forms of logic, namely deductive and inductive logic.

The size of the sample to be used in the study depends largely on the topic under investigation. Forty to 50 statements are considered representative of an average sample (van Exel & de Graaf 2005); while a manageable number of statements has been identified to fall between 30 and 60 statements (Jeffares & Skelcher 2011), but smaller (Spencer & Pisha 2015) or larger samples (Butler et al. 2014) are also possible. To reduce the Q-sample and to maintain the breadth of the topic under investigation, Dryzek and Berejikian (1993) developed a structured approach. The dimensions of the discourse are first identified and then a sampling of statements is chosen to reflect equal representation across the dimensions, and that at least one statement must be represented in each dimension.

Step 3: Select the participants

Participants of Q studies are typically purposively chosen to explore and characterise the attitudes and beliefs that exist within a given population. Therefore, as with case studies, the number of participants is less important than it may be for other forms of research (McKeown & Thomas 1988). The average number of participants engaged in Q-studies falls between 25 to 75 participants (Jaffares & Skelcher 2011); while others have found between 20 and 40 to be sufficient (Watts & Stenner 2012). However, larger samples have been reported. To identify general views, a recent study engaged 294 participants (van Exel et al. 2015). Q-studies do not claim generalisability to the wider population but openly acknowledge that further research would be needed to ascertain this type of information (Baker et al. 2010).

Step 4: Perform the Q-sort

The process of Q-sorting provides the participant a means for expressing their opinion by rank ordering statements according to a particular instruction, typically to order statements/items according to the topic under investigation from most to least characteristic of their viewpoint. The set distribution (i.e. quasi-Gaussian curve) forces the

participant to prioritise their choices (Rimm-Kaufman et al. 2006). Therefore, each participant will produce a unique Q-sort.

Sorting statements is often performed manually by sorting cards on a grid. Due to the sensitivity required to understand the feelings and thoughts of respondents, the Q community generally prefer face-to-face Q-sorting and interview processes (van Exel & de Graaf 2005). However, online administration of the Q-sort is becoming increasingly popular where participants are geographically dispersed and because the widespread use of the internet is rarely a limiting factor (Jeffares 2015; Reber, Kaufman & Cropp 2000). A recent study achieved representation of 10 countries using both manual and online solutions. Of these responses, 247 were received online (van Exel et al. 2015). However, ten percent of these were excluded from the study due to inadequate time spent on survey completion.

In addition to the sorting of statements, participants are generally required to provide demographic details and to complete an interview process. Those doing online sorts will generally be asked to justify and elaborate their statement selections at the extreme ends of the scale (i.e. most and least). Interview information is often gleaned during the Q-sorting process, for face-to-face participants who are manually sorting cards or shortly after the Q-sorting process. Researchers have reported that 40 statements took between 30 to 40 minutes (Kim & Lee 2015), while sorting 88 was reported to take 60 minutes (Butler et al. 2014), with a few additional minutes to complete interview questions.

A number of online and desktop applications exist for the administration of Q studies, namely: Attachment Q-Sorter, Flash Q, Hotspot, HtmlQ, nQue, POETQ, QPress, Q-Sorter, Q-sort touch, QSortware, RAP II, Web Q and The WebQSort Project. Some Q projects have reported using online instruments with success, involving: POETQ (Klijn et al. 2014; Dickinson et al. 2014); FlashQ (Braehler & Hackert 2007; Jaffares & Skelcher 2011); and Q-Assessor (Reber, Kaufman & Cropp 2000). Flash Q has been likened to a game of Solitaire. After piloting a number of online solutions (although not identified), FlashQ was found to be the most intuitive and easy to use (Jaffares & Skelcher 2011). However, FlashQ creators do not host the software. Rather, the researcher can download the program but needs to run it from their own or another sourced server (Braehler & Hackert 2007).

In support of online administrative solutions, Reber, Kaufman and Cropp (2000) conducted two validation studies to examine study reliability and validity between online (using Q-Assessor) and manual administration of Q-sorts and found no apparent differences. More recently, results from a pilot study showed that comparisons between manual and online administration of the Q-sort were similar ($p = 0.8$) (van Exel et al. 2015). However the actual online application used in the study was not identified.

Reported advantages of online Q study administration, include: it can be quicker for all involved (Jeffares & Skelcher 2011); respondents can complete the Q-sort in their own time; the novelty factor may increase response rates over the conventional mail based application (Jeffares & Skelcher 2011); and can reach geographically dispersed participation.

Step 5: Analysis and interpretation

The analysis of Q-sorts follows the original by-person formula developed by Stephenson (1935). Due to the assistance of software, the analysis of Q-sorts has become a purely technical and objective procedure (van Exel & de Graff 2005). Behind the scenes, a bivariate *N*N* correlation matrix is produced from pairwise comparisons made between Q-sorts, from which factors are extracted using Centroid factor analysis. Each Q-sort (participant's viewpoint) is assigned a factor loading score depending upon the degree to which the Q-sort associates with each factor. To help delineate cluster groups, the clusters are rotated either manually or using the VARIMAX technique. After rotation, the z scores of each Q sort is then synthesised to create an exemplar Q-sort for each factor. These are known as factor arrays (Watts & Stenner2012). The analysis above has described how viewpoints are converted to factors, clusters of similar views representing shared viewpoints (Brown 1993).

The formation of factors allows the researcher to examine relationships between people, as their common and disparate viewpoints become apparent (Brown 1980; Stephenson 1935). Once clusters of common viewpoints have emerged, they have to be interpreted to give them meaning. Viewpoints that load most highly on a particular factor represent that factor as an exemplar key informant (Farrimond, Joffe & Stenner 2010).

Interpretation involves both qualitative and quantitative data analyses. Qualitative data is gathered to help the researcher have more empathy of the individual's viewpoint (Brown

1980). Therefore, interview data is gathered in a variety of ways: face-to-face (via post study interviews and/or during the Q-sorting process), online (via open ended comment boxes), and through various forms of other correspondence, including: email, telephone, skype, etc.

Interpretation of the factor arrays (synthesised viewpoints) involves an examination of consensus, distinguishing and statements that the participant's indicated either most or least aligned with their own viewpoint, known as a gestalt process (Watts & Stenner 2012). The qualitative data collected is then used to enhance this interpretation for the development of accurate viewpoint narratives. The interviews are important to study's validity and specifically used to capture the respondents own subjectivity, and not that of the researcher (Ockwell 2008).

Hypotheses are tested against theory through observations and patterning within the data when interpretation is deductive. If the interpretation is inductive, the object of enquiry is led by the data and thus provides a description of the viewpoint through bottom-up logic. Abductive interpretation is used when theory is developed by examining the facts within the data, patterns and interrelationships. Abductive interpretation is used to grasp an explanation for new insights (Watts & Stenner 2012). Once interpretation has been undertaken, labels are assigned to each factor to reflect a descriptor for what was communicated within the viewpoint (McKeown 1990).

Therefore, Q methodology, provides a process to help reveal the more subtle nuances that provide additional understanding to why individuals might behave or make decisions the way they do, and thus their viewpoint on the matter.

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Appendix A3.3 – Survey: Adoption of New Technology in Control Rooms

Section 1 - Demographic information

Please answer the following questions or select the box that best describes you.

1. What country do you work in?

2. What industry do you work in?
   - Aviation
   - Railways
   - Power
   - Technology
   - Education
   - Other

   Other (please specify)

3. How many employees work in your organisation?
   - 1-4
   - 5-19
   - 20-150
   - More than 150
4. Which organisational structure best describes where you work?
   - Hierarchical
   - Linear/flat
   - Matrix
   - Networking
5. What is your gender?
   - Male
   - Female
6. What best describes your current work role?
   - Safety Professional
   - Supplier/ IT Developer/ Engineer (Builder)
   - Designer/Engineer (Architect)
   - Manager/ Approver of New Technology
   - Technical Support/ Technology Maintainer
   - Evaluator of New Technology (CPE, Ergonomist, OT, Physiotherapist)
   - Operator/ User of Complex Systems
   - Trainer/Educator
   - Other (If you indicated 'other' please enter an appropriate description of your work role)

7. What are your qualifications?

8. Have you ever worked as a control room operator?
   - Yes
   - No
9. What is your age?
   - Under 25 years
   - 25-35 years
   - 36-55 years
   - Over 55 years

Section 2 – Consultation and assessment tools

10. Please rate the level you agree with the following statements as they relate to implementing new technology

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It is important to consult and seek feedback from intended users	○	○	○	○	○
(Answer if applicable) If you have obtained feedback from the end user, the input was valuable		○	○	○	
It is important to perform a human factors/ergonomics assessment before implement a new technology	○	○	○	○	○

11. (Answer if applicable) If you use human factors/ergonomics analytical tools or methods when implementing or evaluating a new technology, please identify those you find most useful: (Be as specific as possible, e.g. Cognitive Reliability Analysis Method (CREAM), Management Oversight & Risk Tree (MORT), Strengths, Weaknesses, Opportunities, and Threats (SWOT), etc.

Section 3 – The risks associated with new technology and adoption

12. When a new technology is introduced into a workplace, what is the most important thing to do to minimise risks?

13. What is the most significant reason why a new technology may not be successfully adopted?

Section 4 – Implementing new technologies

14. These factors impact adoption of new technologies. Please rate your level of agreement.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1 The age of the employee	o	o	o	o	o
2 Employee computer abilities	o	o	o	o	o
3 Unlearning old habits or procedures	o	o	o	o	o
4 Employee openness to change	o	o	o	o	o
5 Level of task/job demand changes to employee's role	o	o	o	o	o
6 End user's need to understand why the new technology is introduced	o	o	o	o	o
7 Employee attitude	o	o	o	o	o
8 Level of workflow disruption	o	o	o	o	o
9 Influence from others (e.g. colleagues, superiors)	o	o	o	o	o
10 Employee fear of job loss (e.g. replaced by technology, unable to adapt)	o	o	o	o	o
11 Employee fear of reduced job satisfaction	o	o	o	o	o
12 Employee fear of reduced control of activity	o	o	o	o	o
13 Technology/co-worker support networks facilitated by management	o	o	o	o	o
14 Piloting the new technology before implementation	o	o	o	o	o
15 Shared decision-making between employees & management	o	o	o	o	o
16 Physical work environment (e.g. desks, chairs, screens, lighting)	o	o	o	o	o
17 Managerial structure of the organisation	o	o	o	o	o
18 The employee's experience of failed adoption of prior technologies	o	o	o	o	o
19 Managerial support of additional resources (e.g. time, training)	o	o	o	o	o
20 The new technology's ability to interact with existing systems	o	o	o	o	o
21 The gender of the employee	o	o	o	o	o

Thank you for your participation-

Appendix A3.4 – Interview Questions

Safe and Successful Adoption of New Technologies: Control Room Operators

Interview No._____ Organisation _____ Date _____

Demographic Questions

1. What is your gender?
2. What is your age?
3. What is your role?
4. Years in current or similar role?
5. What are your qualifications?

Interview questions and probing questions

1. Tell me about the technologies in your control room. How do they help your work process?
    - What do you control and how?
    - How does the technology help or hinder your ability to control?
2. In what way does your job rely on other people to do their job correctly?
3. When you suspect something major could go wrong, are you able to shut down the system?
    - Do you feel your technologies support you in your work?
    - Does management allow you the ability to exercise total control?
4. Describe what happens when new technologies are introduced into your organisation and who is involved?
    - What catalyses the introduction of a new technology?
    - Who is involved in: selection, development, implementation, review?
    - What preparatory steps are necessary to ensure successful adoption?
5. What factors do you think help or hinder the successful adoption of new technologies?
    - Product: compatibility, right idea, reliability…
    - Design processes: user and human factors involvement, communication
    - Local influences: co-workers, shift supervisors, shift design, workload, staff numbers…
    - Organisational factors: structure, policy and decision making, values, communication…
    - Implementation process – facilitating conditions, support, training, incentives, motivation
    - Feasibility
    - Resolution of uncertainty, fears, doubt
6. Final piece of advice – what would you tell someone intending to introduce a new technology?

    Request a statement of the results Yes/No **Email: _____**

Appendix A3.5 – Participant Recruitment

Paper-based survey invitation

CENTRE FOR RAILWAY ENGINEERING
Customer focused research and training

New Technology Adoption

CQUniversity AUSTRALIA

Seeking Research Participation

- ✓ Do you develop, design or engineer new technologies?
- ✓ Are you a manager who approves technology selections?
- ✓ Do you provide technical assistance to adjust and/or maintain technical systems?
- ✓ Are you a Human Factors/Ergonomic professional?
- ✓ Do you work in a complex operating environments?

If you answered **YES**, to one of the above questions, you can make a valuable contribution to my research. I am looking for the factors that impact upon the safe and successful adoption of new technologies particularly in complex operating environments, such as control rooms. Additionally, I seek the human factors/ergonomic analytical tools that have proven useful when new technology evaluations are made.

Your assistance is greatly appreciated and will improve understanding of a significant area of risk. Participation in this study is completely voluntary and names and organisations will not be disclosed. The study has been approved by the Human Research Ethics Committee of CQUniversity, Australia. If you have any concerns with this study, you can contact the CQU Office of Research on +61-7-49232607 or by email at *research-enquiries@cqu.edu.au*.

Elise Crawford researcher
+61-7-49309589
e.crawford@cqu.edu.au

Survey invitations for LinkedIn professional groups

Message No. 1 Example

Message from Elise Crawford

Hi

I'm a researcher looking for people who are rail experts and know the risks associated with new technology adoption in complex environments to complete my 5 – 10 minute survey. Your opinion matters. I think you'll find it interesting…

http://www.surveymonkey.com/s/638GY7C *(Name of survey appears hyperlinked)*

My project has ethical approval and is examining end-user adoption of new technologies when introduced into cognitively complex environments (control rooms/towers) of safety critical organisations. Your help is greatly appreciated.

Message Nos. 2 and 3 Example

If you haven't done my survey it's not too late. The survey will be closing in one week on the 18th of September. http://www.surveymonkey.com/s/638GY7C *(Name of survey appears hyperlinked)*

My project has ethical approval and is examining end-user adoption of new technologies when introduced into cognitively complex environments (control rooms/towers) of safety critical organisations.

Thanks to everyone who has already completed it and for your time.

Interview Request for Participation Letter

Elise Crawford (Research Student)
Centre for Rail Engineering, CQUniversity, Australia
Bruce Highway, Nth Rockhampton QLD 4702
PH: 07 4930 9589, Email: e.crawford@cqu.edu.au

To the Operations Manager Date

Request for participation: Determinants for safe and successful adoption of new technologies in control rooms

As a human factors research student, I am looking for industry participation. The aim of my research is to find ways to assist the safe and successful adoption of new technologies in control rooms. By interviewing the operators or their new technology support personnel, I hope to find common determinates that operators feel affect the safe and successful adoption of new technologies.

A maximum of six participants is sought and interviews will not exceed 30 minutes. Participation is voluntary and those who partake are free to withdraw at any time. Interviews will be conducted either in private, or in an appropriate place negotiated by the organisation.

Data will be collected via a voice recorder (consent permitting), transcribed and examined for common themes that operators consider important when adopting new technologies. Should a participant withdraw, all data collected to that point will be included in the research. Data collected will be stored confidentially for 5 years after the publication date of the last publication produced from this data, as required by CQUniversity, Australia. To maintain anonymity, no participant or participating organisation will be identified by name in the results. Participants will be identified by new technology stakeholder group only. In this case, control room operators.

Please contact the CQU Office of Research (tel 0749 23 2607 or email research-enquiries@cqu.edu.au) should there be any concerns about the nature and/or conduct of this research project. Should any adverse effect arise from the interview, please contact Lifelines' Crisis Counselling Service on: 13 1114.

Upon request, a completed plain English statement of research findings will be provided. If you would like to participate in this project please contact me via mail or email so that we can negotiate a suitable day and time.

I appreciate your consideration of this matter.

Yours truly,

Elise Crawford

Researcher

Interview ***preamble***

New technologies can bring a certain level of uncertainty and therefore risk when introduced into complex operating systems. To find solutions that can prevent technology failure, I am interested in the issues that have either a positive or negative effect on the successful adoption of new technologies.

Failed technologies can be said to be those that are rejected, not used to their full capabilities, adopted slowly, misused accidentally, and/or provoke human error that results eventually in an adverse event.

Conversely a successfully adopted technology would mean one that is adopted by its operators relatively smoothly, completely, quickly and easily, without hiccups or problems to work flow. Additionally, it incurred no unanticipated costs and operators did not experience frustration, anguish or stress.

Participant consent form

Consent Form: Determinants for safe and successful adoption of new technologies in control rooms

As a human factors research student, I am looking for industry participation. The aim of my research is to find ways to assist the safe and successful adoption of new technologies in control rooms. As the actual users of control room technologies, operators or their new technology support personnel can assist my research by sharing the issues they feel are important when adopting new technologies.

Interviews will be conducted either in private, or in an appropriate place negotiated by the organisation and will not exceed 30 minutes.

Data will be collected via a voice recorder (consent permitting), transcribed and examined for common themes that operators consider important when adopting new technologies. Should a participant withdraw, all data collected to that point will be included in the research. Data collected will be stored confidentially for 5 years as required by CQUniversity, Australia.

This interview is totally voluntary and you are free to withdraw at any time. Should an adverse effect arise from the interview, please contact lifelines' Crisis Counselling Service on: 13 1114.

Participant to sign and return to researcher. Please retain a photocopy for your own records.

I _____ (*print name*), of _____ (print *organisations' name*) agree to participate in the above research and acknowledge that my involvement is voluntary and that I am free to withdraw at any time.

Signature: _____ Date: _____

Interview Feedback Form

Interview Feedback Form:

Determinants for safe and successful adoption of new technologies in control rooms

Providing feedback ensures research is performed in accordance with ethical approval.

Please indicate yes or no for each statement.

Statement	**Yes**	**No**
The researcher asked for my consent to participate in this research.		
The researcher made it clear to me and my supervisor that my participation was totally voluntary and that I was free to withdraw at any time.		
The researcher made it clear that neither my name nor the name of the organisation for which I work, would be identifiable in the results.		
The researcher has asked for approval to use a digital voice recorder.		
All questions asked were related to my work.		
The researcher has given me an opportunity to request results from the research.		

Participant to sign and return to researcher.

I _____ (*print name*), of _____ (print *organisations' name*) agree to participate in the above research and acknowledge that my involvement is voluntary and that I am free to withdraw at any time.

Signature: _____ Date: _____

Appendix A3.6 – SPSS Codebook

(Coded according to rules outlined in Pallant (2005, p. 13)

Description of variable	SPSS variable name	Coding instructions
Identification number	ID	Participant identification number
Industry of work	Industry	Rail = 1; other transport = 2; process industries = 3; technology = 4; unspecified = 5
Employee numbers in your organisation	Size of org	1-4 = 1; 5-19 = 2; 20-150 = 3; >150 = 4
Organisational structure where you work	Org Structure	Hierarchical = 1, matrix = 2, networking = 3; linear = 4
Participants gender	Gender	Male = 1; female = 2
Work role	Role	Manager = 1; Designer = 2; Researcher = 3; Evaluator = 4; Safety = 5; End User = 6; Supplier = 7; Trainer/educator = 8.
Participants qualifications - grouped	Quals	Certs & Diploma = 1; Ass Degree = 2; Bachelor Degree = 3; Post Grad = 4; PhD = 5; Unspecified = 6
Whether ever worked as a control room operator	Ever a controller	Yes = 1; no = 2
Age group of participant	Age	<25 = 1; 25-35 = 2; 36-55 = 3; >55 = 4
Likert-scale questions – rate level of agreement	Agreement	Strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, strongly agree = 5
Q11 OE	HFAT used	Yes = 1; no = 2
Q 12: When a new technology is introduced into a workplace, what is the most important thing to do to minimise risks? **Themes identified**	Must do	CULTURE: Management = 1; communication = 2; or values = 3; change mgt = 4; DESIGN: approach = 5; planning = 6; buy-in = 7; consultation = 8; implementation = 9; TECH DESIGN: product = 10; fit for human = 11; test = 12; pilot = 13; user testing = 14; SUPPORT: management = 15; technical = 16; learning = 17; document = 17; user responsible = 19; FEASIBILITY: resources = 20; safety = 21; VALUE: user needs = 22; user gains = 23. (NO 18)
Q13 What is the most significant reason why a new technology many not be successfully adopted **Themes identified**	Why no adoption	CULTURE: Management = 1; communication = 2; or values = 3; change mgt = 4; DESIGN: approach = 5; planning = 6; buy-in = 7; consultation = 8; implementation = 9; TECH DESIGN: product (bugs, compatibility) = 10; fit for human = 11; test = 12; pilot = 13; user testing = 14; SUPPORT: management = 15; technical = 16; learning = 17; document = 17; user responsible = 19; FEASIBILITY: resources (time $ staff) = 20; safety = 21; VALUE: user needs = 22; user gains = 23. (NO 18)
Grouped variables		
Grouped according to years of work	Experience	Novice = 1, knowledge = 2, expert = 3 (1-2 = novice, 3-10 = knowledge, 11+ = expert)

Description of variable	SPSS variable name	Coding instructions
Work role – grouped to the 4 stakeholder groups	Role fix	Manager = 1; Designer/Supplier = 2; Evaluator = 3; End User = 4
Country of work - grouped	Country	1/AUS/NZ/SE Asia, S Korea, Japan, Singapore = 1; 1/USA, CA = 2; 1/W Europe & Israel = 3; Developing world = 4.

Appendix A3.7 – Interview Coding Iterations

First iteration of coding

Supports technology adoption	Hinders technology adoption
Culture	Culture
Change	Change
Communication	Communication
Teamwork	Teamwork
Management	Management
Leadership	Leadership
Conditions	Conditions
Shift work	Shift work
Workload	Workload
Stress	Stress
Morale & Motivation	Morale & Motivation
Design	Design
P Useful	P Useful
P Ease of use	P Ease of use
User-centred	User-centred
Function allocation	Function allocation
Equipment design	Equipment design
Workplace design	Workplace design
Task analysis	Task analysis
Job design	Jo design
Training	Training
Needs analysis	Needs analysis
Cost-effective	Cost-effective
Supv & appraisal	Supv & appraisal
Staffing	Staffing
Selection	Selection
Recruitment	Recruitment
Retention	Retention

Reference

Rail Safety and Standards Board 2008, *Good practice guide on cognitive and individual risk factors*, Rail Safety and Standards Board, London.

Second iteration of coding

Changes to first iteration	Supports or hinders technology adoption
Culture **Change** **Communication** ~~**Teamwork**~~ **Management** **Leadership** **Conditions** **Shift work** **Workload** **Stress** ~~**Morale & Motivation**~~ **Design** ~~**P Useful**~~ ~~**P Ease of use**~~ **User-centred** ~~**Function allocation**~~ **Equipment design** ~~**Workplace design**~~ ~~**Task analysis**~~ ~~**Job design**~~ **Training** **Needs analysis** ~~**Cost-effective**~~ ~~**Supv & appraisal**~~ **Staffing** **Selection** ~~**Recruitment**~~ ~~**Retention**~~	Organisational Culture • Change management • Communication • **Values: trust, transparency, accountability** • Management **commitment** • **Leadership** **Working** Conditions • Shift **design** • **Additional** Workload • **Increased** stress • **Communicate with trusted peers** • **Respected as domain experts** **Facilitating** Conditions • Training **(types, timing, frequency, who)** • **Management support** • **Technical support** • **Social support** Design • **Right idea** (useful, priority) • **Reliable technically** • **Compatible with existing technology** • **Compatible with work processes** • **Compatible with user (usability)** (ease of use) **Design process** • **Consult and involve end users** • **Site specific participation/ representation** • **Training development** • **Provide feedback to suggestions** • User-centred **(not human-centred)** • **Iterative** Staffing • Selection • **Expertise** • **Number** **Safety** **Resourcing** • **Staff** • **Finance** • **Time** • **Support post implementation**
Note: Codes crossed out were deleted. Codes in bold are those added	

Final code iteration: Factors that influence end-user adoption

1. Organisational culture
    a. Trust & honest
    b. Communication
    c. Leadership
    d. Accountability & transparency
    e. Commitment
2. Idea to concept
    a. Priority and useful
    b. Beneficial
    c. Compatible (user needs, existing technology, work processes)
3. Viability
    a. Safe
    b. Resourced (social, time, training, tech support, finance)
4. Design & Build Process
    a. Consult end users
    b. Agreement to design specifications
    c. Communication (vertical, horizontal frequency)
    d. Top-down and Bottom-up
    e. User advocate
    f. Local representative involved (end user)
    g. Training design and delivery (end user)
    h. Feedback from suggestions made
5. Product Outcome
    a. No surprises
    b. Meets a priority
    c. User needs and usability (including maintenance staff)
    d. Compatible with existing systems
    e. Compatible with work processes
    f. Supports task requirements
6. Implementation Process
    a. Planned
    b. Resourced during and continued after
    c. End-user involvement
    d. Pilot before deployment
    e. Training (timely, hands on, safe, real and site specific scenarios)
    f. Fix problems
    g. Expert technical support
    h. Ghost implementation

Appendix A3.8 – Phase Two Statement Lists

Pilot Q-set

Subtopic 1: Innovation and impact of new technology (includes risk & productivity)

1. The physical work environment can impact new technology adoption
2. The more job tasks change, due to new technology, the higher the level of risk
3. New technologies need to reflect the future direction of technology advancement
4. New technologies should enhance work performance
5. Avoid new technologies that complicate work tasks unnecessarily
6. Businesses will benefit from technologies that anticipate future trends

Subtopic 2: Safety

7. Unless something can be done safely, it should not be done at all
8. Potential technologies should be risk assessed prior selection or development
9. Business sustainability takes priority over safety concerns
10. When it comes to safety, reliable technologies are more important than the operator

Subtopic 3: Productivity

11. Standardising technologies across all sites will improve productivity
12. Stress can slow end-user adoption of new technology
13. End-user fatigue can slow new technology adoption
14. Greater productivity results when end-user preferences are incorporated into the design

Subtopic 4: User attributes and needs

15. A negative attitude toward a new technology can slow its adoption
16. A person's openness to change can assist new technology adoption
17. Safer outcomes result when Human Factors professionals are involved in new tech projects
18. Younger people adopt new technologies quicker than older people
19. End users do not need to be consulted when Human Factors professionals are involved
20. Fear that a new technology will reduce job satisfaction, will slow adoption
21. Unlearning old habits or procedures can slow adoption of new technology

Subtopic 5: Consultation and opportunity to evaluate impact

22. End users need to understand the purpose for the new technology
23. End users are not interested in participating in the design phase of new technologies
24. New technologies should be piloted before implementation
25. Errors are usually the fault of the operator, not the technology
26. When introducing new technology, managers must consult with the intended users

Subtopic 6: Design process – to meet user needs

27. End users need to be involved at the initial design phase of the new technology
28. End-user input during technology development reduces training requirements

29. End-user input into new technology selection and development is valuable
30. Managers and end users should reach a consensus when making new technology decisions
31. End users make unreasonable demands when they are involved in the design of new technology

Subtopic 7: Quality - attributes of the technology

32. New technologies must be able to interact with existing systems
33. New technologies need to be easy to use
34. To avoid problems, 'in-house' technical support must be consulted during the initial design phase
35. New technology needs to serve a functional purpose
36. Fine tuning the technology is not necessary as people are very adaptable
37. New technologies need to be customisable

Subtopic 8: Constraints

38. Selection and development of new technologies is influenced by budget constraints
39. Newly created technologies are safer than modifying 'off the shelf' or existing technologies
40. Meeting deadlines can impact the design quality of new technologies

Subtopic 9: Support

41. Online help menus built into software packages assist end users to adopt new technologies
42. Online training is as effective as hands-on learning prior to implementation
43. When selecting new technologies, consideration must be given to future manufacturer support
44. Increased staffing is required when a new technology is being implemented
45. User manuals for new technologies are easy to understand
46. On-the-job training is the best way to learn a new technology
47. During implementation, an 'expert' on the new technology must be available on site

Actual Q-Study questions

1. Q-Sort

Please rate the following statements according to your level of agreement:

1. When introducing new technologies, managers must consult with the intended users
2. Standardising technologies across all sites will improve productivity
3. End users make unreasonable demands when they are involved in the design of new technologies
4. Greater productivity results when end-user preferences are incorporated into the design
5. End users are not interested in participating in the design phase of new technologies
6. Newly created technologies are safer than modifying 'off the shelf' or existing technologies
7. End users do not need to be consulted when Human Factors professionals are involved in the design
8. End users need to be involved at the initial design phase of the new technology
9. To avoid problems, 'in-house' technical support must be consulted during the initial design phase
10. Meeting deadlines can impact the design quality of new technologies
11. Find tuning the technology is not necessary as people are very adaptable
12. Safer outcomes result when Human Factors professionals are involved in new technology projects
13. Online training is as effective as hands-on learning prior to implementation

14. During implementation, an 'expert' on the new technology must be available on site
15. Business sustainability takes priority over safety concerns
16. Unless something can be done safely, it should not be done at all
17. Businesses will benefit from technologies that anticipate future trends
18. The more job tasks change, due to new technology, the higher the level of risk

2. Interview question

Please comment on:

- the statement(s) that you most agreed with
- the statement(s) that you least agreed with
- and add any further comments if you wish:

Summary of Q-study elements

- Topic investigated: end-user involvement in new technology projects
- Concourse of 170 statements
- P set n = 64
- Q survey administered using Q-Assessor
  - Five demographic multiple choice questions
  - 18 statements to sort
  - Umbrella question: What contributes to the best outcome when introducing new control room technologies?
  - Q set N = (2)(9) = 18 (m = 1 replication each)
  - Sort distribution (+/-3), levels at 7, 5, 3, 3
  - Three interview questions using open-ended format
- Centroid factor analysis with Varimax rotation
- Statistical significance taken at $p<.01$.
- Preliminary viewpoint descriptions established based on:
  - Normalised Q sort factor loadings
  - Distinguishing statements
  - Participant interview comments
- Viewpoint refinement based on feedback provided by close scoring participants (via email)

Appendix A3.9 – Summary of Study Elements

Phase	Title	Participants	Instrument	Analysis	Equipment	Method
1	Stakeholder opinion compared with end-user experience	Control room technology stakeholders Controllers	Survey (Likert-scale and open-ended questions) Semi-structured interviews	Embed exploratory data with confirmatory data Multivariate Analysis Factor Analysis Multiple Regression Content Analysis Thematic Analysis	Survey Monkey SPSS Version 20 G*Power 3.1.9.2 Monte Carlo PCA for Parallel Analysis 2.3 QSR NVivo 9 Digital Voice Recorder Audacity 1.3.2 Beta	Mixed Methods
2	Viewpoints on end-user involvement	Control room technology stakeholders	Q Survey (Q Sort and Interview questions)	Exploration Factor Analysis Viewpoint confirmation	Q-Assessor	Q Methodology

Appendix A4.1 – Preparatory Analysis for Factor Analysis

As recommended by Tabachnick and Fidell (2001), the process used to find the best factor solution for this study is discussed. Preliminary analysis was conducted to determine how many items and factors to retain for rotation. With all 21 items included in the analysis, components (factors) were extracted using Principal Component Analysis (PCA) and six factors emerged with eigenvalues above 1 explaining 57.1% of the total variance of opinion. Eigenvalues and their representative percentages are displayed in Table A4.1.1 The Kaiser-Meye-Olkin (KMO=0.81) measure of sampling adequacy was above 0.6 and thus considered to be a good indication that the number of cases (i.e. participant responses) were adequate and thus appropriate for factor analysis. Also positive, the Bartlett's test of sphericity indicated significant correlations were achieved (df = 210, p <.01).

Table A4.1.1 Initial factor analysis eigenvalues

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Eigenvalues	5.111	1.850	1.601	1.318	1.092	1.011
Variance explained	24.34%	8.81%	7.62%	6.28	5.20%	4.81%

After the factors were extracted, they were rotated using the Varimax technique. Two of the six factors had the fewest items (variables) loading and many variables were loading on two factors. After a closer examination of the factors, two items (the age of the employee, the gender of the employee) were removed as they loaded together on a single factor and did not meet the three item minimum to retain a factor. A third item was removed (Influence from others, e.g. colleagues, superiors) due to dual loading and the potential ambiguity associated with the item. Analysis was repeated with the remaining 18 items, and rotated using the Varimax technique, resulting in a four factor solution resulted (KMO = .84, df = 153, p<.01) explaining close to 50% (49.6%) of the total variance. The Component Transformation Matrix (see Table A4.1.2) shows moderate correlations, and therefore Direct Oblimin was considered a more suitable rotational technique for the study.

Table A4.1.2 Component transformation matrix

Component	1	2	3	4
1	.577	.467	.537	.400
2	-.374	.861	-.345	-.001
3	-.481	-.190	.045	.855
4	-.544	.072	.768	-.330

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

Before, this analysis was conducted, reliability of the data had to be determined by checking the assumptions made about the data. The following assumptions were checked:

- *Sample size* – The sample size of 397 fell well above the recommended minimum of 150+ (Pallant 2005) and is considered to be a good sample size. According to Cromrey and Lee (1992), a sample of 300 cases is considered good and 500 very good. Furthermore the case to variable ratio of at least 5:1 was exceeding by achieving a ratio of 22:1 (397 cases to 18 variables).
- *Factorability of the correlation matrix* – visual inspection of the correlation matrix confirmed that the data was suitable for factor analysis with many correlations above the required r=.3 (see Appendix A4.3). The Bartlett's test of sphericity was proven statistically significant at p<.000, and met the p<.05 limit. The high Kaiser-Meyer-Olkin (KMO) score (KMO = .84) confirms that the data is suitable for factor analysis.
- *Linearity* – Linear relationships between factor variables was ascertained by spot checking scatterplots, as recommended by Tabachnick and Fidell (2001) (Figures A4.1.1, A4.1.2 and A4.1.3).
- *Outliers among cases* – Box plots revealed a number of outliers. These are discussed next in Appendix A4.2.

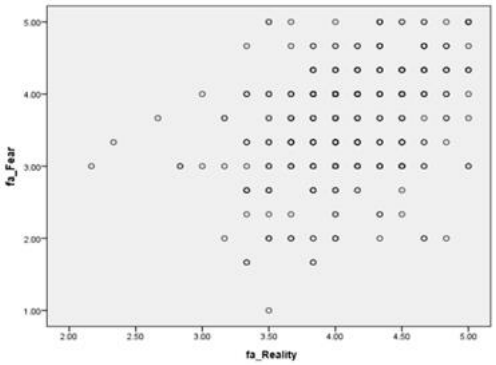

Figure A4.1.1 Scatterplots to check linearity (fear/reality)

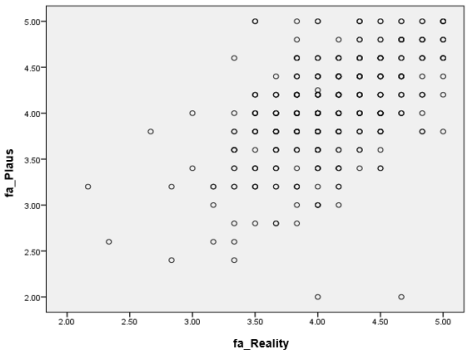

Figure A4.1.2 Scatter plots to check linearity (plausibility/reality)

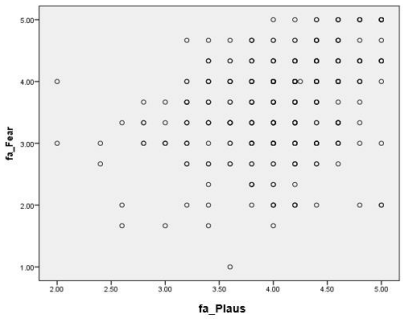

Figure A4.1.3 Scatter plots to check linearity (fear/plausibility)

References

Cromrey, AL & Lee, HB 1992, *A first course in factor analysis*, Erlbaum, Hillsdale, NJ.

Pallant, J 2005, *SPSS survival manual*, 2nd edn, Open University Press, New York.

Tabachnick, BG & Fidell, LS 2001, *Multivariate statistics*, 4th edn, Allyn & Bacon, Boston.

Appendix A4.2 – Outlier Test for Original Data Set

Box plots and associated mean and 5% trimmed mean scores

Box plots of 400 cases entered and 18 variables examined revealed a number of outliers. Examination of the means compared with 5% trimmed means showed no major fluctuations with any of the outliers. However, seven cases were identified as extreme outliers (8, 67, 82, 125, and 207) and were therefore removed from the study. All other outliers were retained in the study due to similarity with mean and trimmed mean scores. The box plots and mean scores tables for the factors extracted can be found in the following:

- State / Fear (Figure A4.2.1, Table A4.2.1)
- State / Reality (Figure A4.2.2, Table A4.2.2)
- State / Plausibility (Figure (A4.2.3, Table A4.2.3)

Notes: Boxplot key - O indicates an outlier, * indicates an extreme outlier

Notes: Means indicate the size of the outlier effect, similar scores indicate no great effect

Table A4.2.1 Mean Scores Trimmed

r_State x r_Fear		
	Mean	5% Trimmed
1.67	4.0625	4.0694
2.00	4.000	4.0139
2.33	3.8333	3.8565
2.67	4.0278	4.0309
***3.00**	4.0932	4.1085
***3.33**	4.1515	4.1587
***3.67**	4.1556	4.1914
***4.00**	4.2377	4.2391
***4.33**	4.4956	4.5236
4.56	4.4318	4.4369
5.00	4.6326	4.6599

*Scores with outlier cases

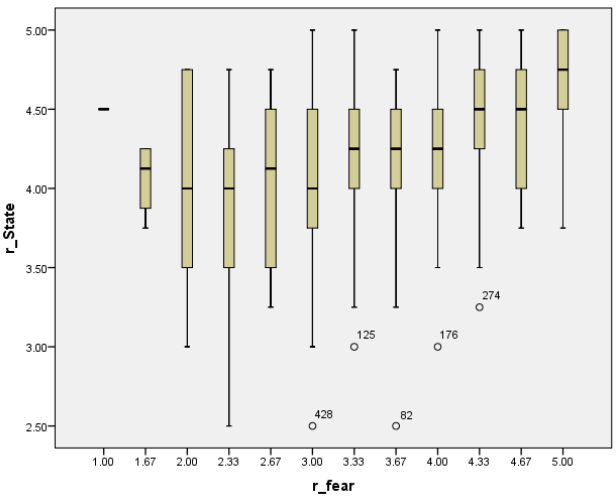

Figure A4.2.1 Box plot – State / Fear

Table A4.2.2 Mean Scores Trimmed

r_State x r_Reality		
	Mean	5% Trimmed
3.17	4.0625	4.0556
3.33	4.0833	4.0787
3.50	3.9091	3.9129
***3.67**	4.0403	4.0677
3.83	4.1667	4.1754
***4.00**	4.0864	4.1097
4.17	4.3525	4.3684
4.33	4.2885	4.2927
4.50	4.3295	4.3510
4.67	4.4167	4.4316
4.83	4.6176	4.6446
***5.00**	4.8186	4.8401

*Scores with outlier cases

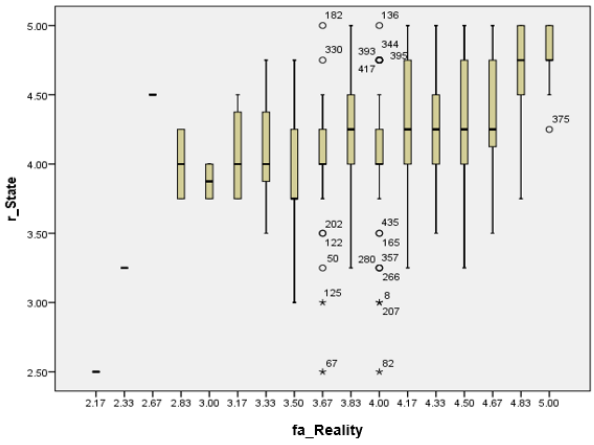

Figure A4.2.2 Box plot – State / Reality

Table A4.2.3 Mean Scores Trimmed

r_State x r_Plaus		
	Mean	5% Trimmed
2.00	4.1250	constant
2.60	3.6667	constant
2.80	4.2000	4.208
***3.00**	4.2000	4.2083
***3.20**	3.8824	3.9248
3.40	3.9405	3.9478
3.60	4.2396	4.2500
3.80	4.2448	4.2500
***4.00**	4.1478	4.1564
***4.20**	4.1604	4.1783
***4.40**	4.3250	4.3556
4.60	4.4797	4.4981
4.80	4.4881	4.5007
***5.00**	4.6625	4.7083

*Scores with outlier case

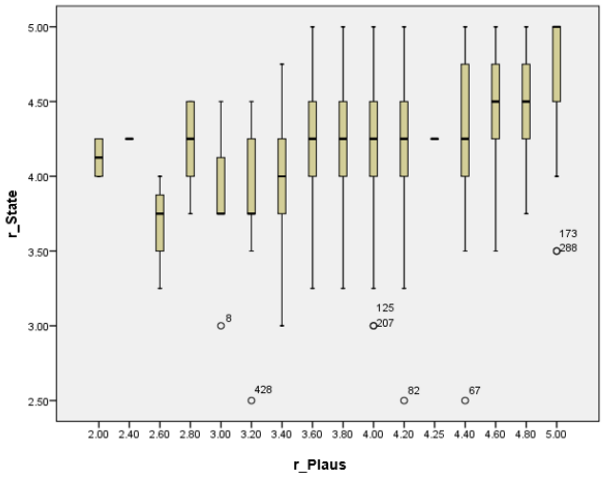

Figure A4.2.3 Box plot – State / Plausibility

Appendix A4.3 – Factor Analysis Correlation Matrix

		Computer ability	*Unlearning*	*Openness to change*	*Job Change*	*Understand why change*	*User Attitude*	*Workflow disruption*	*Fear job loss*	*Fear job satisfaction*	*Fear lost control*	*Support networks*	*Pilot test 1st*	*Share decisions worker and manager*	*Physical Environment*	*Management Structure*	*Prior tech failure*	*More resources*	*Tech interoperability*
Correlation	Computer ability	1.000																	
	Unlearning	.198	1.000																
	Openness to change	.203	.363	1.000															
	Job Change	.126	.218	.193	1.000														
	Understand why change	.075	.159	.219	.277	1.000													
	User Attitude	.250	.214	.410	.234	.319	1.000												
	Workflow disruption	.090	.202	.268	.306	.260	.308	1.000											
	Fear job loss	.042	.236	.215	.124	.308	.231	.277	1.000										
	Fear job satisfaction	.102	.174	.221	.239	.274	.262	.195	.447	1.000									
	Fear lost control	.043	.150	.184	.133	.250	.194	.221	.374	.585	1.000								
	Support networks	.109	.055	.064	.128	.226	.185	.140	.203	.238	.276	1.000							
	Pilot test 1st	.096	.073	.162	.330	.283	.265	.306	.080	.231	.180	.350	1.000						
	Share decisions worker and manager	.049	.161	.252	.248	.328	.237	.374	.151	.249	.224	.325	.453	1.000					
	Physical Environment	.074	.140	.175	.423	.175	.232	.227	.109	.248	.151	.209	.396	.364	1.000				
	Management Structure	.079	.122	.134	.285	.227	.124	.206	.200	.196	.186	.338	.211	.260	.212	1.000			
	Prior tech failure	.067	.180	.098	.249	.191	.182	.288	.251	.254	.326	.107	.153	.194	.192	.316	1.000		
	More resources	.078	.263	.219	.262	.303	.281	.299	.135	.142	.173	.264	.366	.279	.292	.256	.271	1.000	
	Tech interoperability	.174	.231	.146	.265	.185	.170	.303	.082	.064	.105	.146	.319	.236	.248	.187	.278	.413	1.000

[Factor Analysis: Principal component analysis with 400 cases and 18 variables] Correlations of 0.3 and greater have been highlighted in green.

Appendix A4.4 – Factor Aanalysis Correlation Tables

Three tables help to interpret the findings. The structure matrix (Table A4.4.1) displays the correlations between the variables and the factors and the pattern matrix (Table A4.4.2) contains the coefficients for the linear combination of the variables. Variables were suppressed to 0.3 to make it easier to see the significant factor loadings. TableA4.4.3 shows the low correlation values between each factor indicating four distinct factors.

Table A4.4.1 Structure Matrix

Variable	Component			
	1	2	3	4
Piloting the new technology before implementation	.781			.331
Shared decision-making between employees and management	.698			.310
Technology/co-worker support networks facilitated by management	.637	.349		
Physical environment (e.g. desks, chairs, screens, lighting)	.603			.393
End user's need to understand why the new technology is introduced	.450	.405	.314	
Employee fear of lost control of activity		.789		
Employee fear of reduced job satisfaction		.786		
Employee fear of job loss (e.g. replaced by technology, unable to adapt)		.733		
Employee openness to change			.752	
Employee attitude	.368		.674	
Unlearning old habits or procedures			.595	.434
Employee computer abilities			.560	
The new technology's ability to interact with existing systems				.698
The employee's experience of failed adoption of prior technologies		.437		.698
Managerial support of additional resources (e.g. time, training)	.442			.615
Level of task/job demand changes to employee's role	.428			.542
Level of workflow disruption	.354		.366	.524
Managerial structure of the organisation	.372	.329		.500

Extraction Method: Principal Component Analysis
Rotation Method: Oblimin with Kaiser Normalization

The structure matrix shown in Table A4.4.1 displays the significant correlations between the factors and the strength of their association. For instance, the variable 'End user's need to understand why the new technology is introduced' appears on three factors, and therefore

has an association with each of the three factors, namely: *Plausibility*, *Fears* and *technology adoption State*, but not with *Reality*. The associate is strongest (0.45) with *Plausibility*. Associations can be interpreted as:

- *Plausibility* (understanding starts with the creation of plausible meanings, and thus has a strong association with plausibility),
- *Fears* (a need for greater understanding acknowledges there is incomplete knowledge, and uncertainty has been found to evoke negative emotions), and
- Technology adoption *State* (One's state of technology adoption reflects a continuum of incomplete to complete understanding about the new technology, including skill level)

Similarly, the variable 'Level of workflow disruption' has an association with factors 1, 2 and 4, namely: *Plausibility, Fears*, and *Reality,* with the strongest (0.52) association with factor 4, *Reality*. Therefore, the associations for 'level of workflow disruption' can be interpreted as:

- *Plausibility* (A plausible meaning leads to expectations regarding anticipated level of disruption to work flow once implemented and used in situ),
- *Fears* (the level of disruption has been known to influence quality of work and therefore a concern that can evoke a negative emotional response), and
- *Reality* (level of workflow disruption can only fully be realised after the new technology is used in situ).

Table A4.4.2 Pattern Matrix[a]

Variable	Component			
	1	2	3	4
Piloting the new technology before implementation	.762			
Shared decision-making between employees and management	.643			
Technology/co-worker support networks facilitated by management	.635			
Physical environment (e.g. desks, chairs, screens, lighting)	.536			
End user's need to understand why the new technology is introduced	.327			
Employee fear of lost control of activity		.771		
Employee fear of reduced job satisfaction		.755		
Employee fear of job loss (e.g. replaced by technology, unable to adapt)		.723		

Variable	Component			
	1	2	3	4
Employee openness to change			.737	
Employee attitude			.626	
Employee computer abilities			.578	
Unlearning old habits or procedures			.540	.356
The employee's experience of failed adoption of prior technologies		.342		.720
The new technology's ability to interact with existing systems				.688
Managerial support of additional resources (e.g. time, training)				.515
Managerial structure of the organisation				.432
Level of task/job demand changes to employee's role				.431
Level of workflow disruption				.392

[a]Extraction Method: Principal Component Analysis
Rotation Method: Oblimin with Kaiser Normalization
[a]Rotation converged in 14 iterations

The pattern matrix in Table A4.4.2 shows the coefficients for the linear combination of variables (Institute for Digital Research and Education 2015). Furthermore, as is displayed by the Pattern Matrix, factor solution accepted produced the desirable simple structure (Brown 2001; Thurstone 1947). Each of the four factors have a number of strong loadings with all variables (survey items) loading substantially on one of the four factors.

Table A4.4.3 shows the low correlation values between each factor indicating four distinct factors that are not highly correlated to each other.

Table A4.4.3 Component correlation matrix

Component	1	2	3	4
1	1.000	.229	.194	.314
2	.229	1.000	.146	.222
3	.194	.146	1.000	.254
4	.314	.222	.254	1.000

Extraction Method: Principal Component Analysis
Rotation Method: Oblimin with Kaiser Normalization

Appendix A4.5 – Analysis of Survey Items for Reliability

Reliability testing was conducted to ensure the survey items reliably represented the factors. Internal consistency was checked to determine how closely the set of items align with each other. To examine internal consistency, the Cronbach alpha scores were examined. Cronbach alpha scores above 0.8 are considered highly consistent, whereas scores of 0.7 are considered acceptable for research purposes by (Nunnally 1978). Cronbach values for this study ranged between 0.73 and 0.60, in factor order: *Plausibility* (α = 0.70), *Fears* (α = 0.73), technology adoption *State* (α = 0.60), and *Reality* (α = 0.70). The factors are considered reliable according to Nunally's acceptance criteria for research purposes (i.e. α = 0.70) except for technology adoption State (α = 0.60). Lower Cronbach alpha scores of 0.6 and above have been considered acceptable for exploratory research (Arumugam, Ramachandran & Bhattacharyya 2014). Furthermore, Cronbach alpha values are sensitive to the number of items defining the factors. Low Cronbach alpha values of 0.5 are common with scales that have less than 10 items (Pallant 2005). Furthermore, use of a non-standardised questionnaire has also been identified to moderate Cronbach alpha scores (Nunnally 1978). Each of the factors in this study were defined by less than ten items, as illustrated in Table A4.5.1.

Table A4.5.1 Factors, associated survey items and Cronbach alpha

Component Number	Factor Name	N of items	Items	α
1	Plausibility	5	Shared decision-making between employees & management Piloting the new technology before implementation Physical work environment (e.g. desks, chairs, screens, lighting) Technology/co-worker support networks facilitated by management End user's need to understand why the new technology is introduced	.70
2	Fears	3	Employee fear of reduced job satisfaction Employee fear of reduced control of activity Employee fear of job loss (e.g. replaced by technology)	.73
3	State	4	Employee openness to change Employee attitude Unlearning old habits or procedures Employee computer ability	.60
4	Reality	6	Managerial support of additional resources (e.g. time, training) The new technology's ability to interact with existing systems Employee's experience of failed adoption of prior technologies Level of workflow disruption Level of task/job demand changes to employee's role Managerial structure of the organisation	.70

In consideration of the small number of items (less than 10) and their relatively high Cronbach scores it is safe to conclude that all 18 items are to be retained and while additional items could strengthen the Cronbach alpha scores, the current items are considered useful and reflective of the factors they define. Of the 18 survey items analysed, 05 items measure *Plausibility*, 03 measure *Fears*, 04 measure *State* and 06 measure *Reality.* Thus it can be concluded that construct validity was supported.

References

Arumugam, S, Ramachandran, K & Bhattacharyya, A 2014, 'Suitability screening test for air traffic controllers', *Global Journal of Human-Social Science*, vol. 14, no. 4, pp. 1-9.

Nunnally, JC 1978, *Psychometric theory*, McGaw-hill, New York, NY.

Pallant, J 2005, *SPSS survival manual*, 2nd edn, Open University Press, New York.

Appendix A4.6 – Tests for Factor Predictability

In preparation for Standard Multiple Regression Analysis, the factors were tested for factor predictability. . A three step process was used, as offered by Pallant (2005), to interpret the results. First assumptions were checked to ensure model integrity; secondly, the model was evaluated; and thirdly, the predictor variables were evaluated.

Step 1: Check assumptions

The achieved sample size of 417 for this analysis is much larger than the minimum 74 participants (cases) required for generalisability, as calculated using the formula provided by Tabachnick and Fidell (2001). Following this formula, we can confirm that the assumption on sample size for this study has not been violated. The calculations are as follows:

N = 50 + 8m (where m = number of independent variables)
*N = 50 + 8*3 (where m = 3 independent variables)*
N = 50 + 24
N = 74

To check that the independent variables have some relationship with the depended variable the correlations between factor variables is examined (see Table A4.6.1). This checks the assumption that multicollinearity (i.e. r = .9+) does not exist. Pearson correlation scores indicate acceptable correlations between independent variables (*Reality, r = .410, Fears r = .312* and *Plausibility, r = .336*) and the dependent variable (*technology adoption State),* show values in the acceptable range of above .3 and below .7 as recommended by Tabachnick and Fidell (2001). To be sure, the tolerance and variance inflation factor (VIF) values were checked by examining the collinearity diagnostics located in the Coefficients (see Table A4.6.1). The presence of multicollinearity is indicated when tolerance values are less than .10, or VIF values are above 10 (Pallant 2005). Tolerance scores did not fall below .10 and VIF scores are well below 10, indicating the multicollinearity assumption has not been violated. This test confirmed that variables have independent predictive power, and therefore all variables were retained.

Table A4.6.1 Regression Coefficients Table

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	2.304	.193		11.958	.000	1.926	2.683					
	fa_Fear	.101	.029	.166	3.443	.001	.043	.158	.312	.167	.151	.829	1.206
	fa_Plaus	.104	.046	.120	2.234	.026	.012	.195	.336	.109	.098	.666	1.502
	fa_Reality	.282	.053	.284	5.289	.000	.177	.387	.410	.252	.232	.667	1.500

a. Dependent Variable: fa_State

Assumptions of outliers, normality, linearity and homoscedasticity were checked by examining the normal probability plot (Figure A4.6.1), the histogram (Figure A4.6.2) and the residual scatterplot (Figure A4.6.3).

The normal probability plot for this study is indicative of a normal distribution illustrated by the reasonably straight diagonal with no observable outliers detected. For large sample sizes, as is the case for this study, it would not be considered uncommon for some outliers to be found, but less than 1% is considered desirable (Pallant 2005). The residual scatterplot (Figure A4.6.3) confirms homoscedasticity (i.e. equal statistical variance) required for valid regression analysis. The figure shows that most points fall between the recommended +3 and -3 distribution and that they congregate across the horizontal line around the centre point in a fairly rectangular manner indicating the desired homoscedasticity. The scatterplot shows that a few outlying cases exist. These may not be a problem, however, they were investigated further. To ensure that the data was appropriate for regression analysis, the Casewise Diagnostics Table was used to investigate outlier cases as recommended by Pallant (2005). This table identifies the individual cases so that they can each be examined. This table was not produced in the SPSS Analysis output indicating that the outlying cases were not negatively influencing the data for regression analysis.

Normality was further consolidated by confirming the continuity of the data by examining the histogram, as recommended by Witte and Witte (2007). The distribution of data fit the normal bell-curve of continuous probability, while the common boundaries between

adjacent bars confirmed that the assumption that the data is normally distributed and has not been violated (Figure A4.6.2). The histogram shows the predictive factor variables (y axis) *Plausibility*, *Fears* and *Reality* are plotted against the dependent factor variable (x axis) technology adoption *State*. The dense concentration of predictive factor variables shows that these variables have an impact on Adoption *State*. The highest bars on the graph indicate the greatest impact and these bars represent the impact of: *Reality* (*p*=.000), *Fears* (*p*=.001), and *Plausibility* (*p*=.026). Finally, the Cook's Distance values located in the Residuals Statistics Table (see Table A4.6.2) were examined. Cook's Distance values larger than one (1) indicate potential problems (Tabachnick & Fidell 2001). The maximum Cook's Distance value for this study was .09 and therefore the data is applicable for regression analysis. The above checks indicated that the data was suitable for regression analysis and that results are likely to predict the opinions of the study participants as a group.

Table A4.6.2 Residuals statistics

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.5490	4.7357	4.2498	.20632	417
Std. Predicted Value	-3.396	2.355	.000	1.000	417
Standard Error of Predicted Value	.020	.114	.037	.013	417
Adjusted Predicted Value	3.5818	4.7315	4.2495	.20625	417
Residual	-1.07473	.95303	.00000	.40234	417
Std. Residual	-2.662	2.360	.000	.996	417
Stud. Residual	-2.676	2.366	.000	1.002	417
Deleted Residual	-1.10214	.95785	.00026	.40663	417
Stud. Deleted Residual	-2.696	2.379	.000	1.004	417
Mahal. Distance	.058	32.390	2.993	3.303	417
Cook's Distance	.000	.090	.003	.006	417
Centered Leverage Value	.000	.078	.007	.008	417

a. Dependent Variable: fa_State

Although the data was found suitable for regression analysis, since there were some observed outlier cases, assumptions between variable pathways were checked and results are displayed in Table A4.6.3. The results revealed that the opinions of ten participants were found to be different from the group as a whole (N=417), representing 2% of the total cases.

No difference of opinion was found between combinations of variables. However, differences of opinion were found between six individual variables. Of the seven relationships between individual variables, the following differences of opinion were found: *Plausibility* on *State* (N=1), *Reality* on *State* (N=0), *Fear* on *State* (N=2), *Plausibility* on *Reality* (N=3), *Plausibility* on *Fear* (N=3), *Fear* on *Plausibility* (N=3) and *Reality* on *Fear* (N=2). This indicates that the predictive model between three individual pathways did not reflect the opinion of respondent 423, the opinions of respondents 162 and 361 are not predicted by two pathways, and the opinions of respondents 125, 172, 272, 134, 169, 276 and 355 fail to be predicted by one of the predictive pathways. However, in combination with other pathways, all opinions are accounted for and represent less than 1% of the total data. Examination of the Cook's Maximum Distance score showed that the outliers in this model did not have an undue effect on the model as a whole and this is supported by the absence of outliers when more than one predictive pathway is examined. Therefore, it has been confirmed that no assumptions were violated in this study. A summary of the results are displayed in Table A4.6.3.

Table A4.6.3 Summary of assumption violation check for moderator relationships

Moderator relationship	Tolerance	VIF	Cook's Distance	Histogram	P-P Plot	Scatterplot	Outlier Cases
Unviolated assumption levels	(>.10)	<10	Max. <1	Visual – normal bell-curve	Visual – Lt to Rt diagonal	Visual – rectangular horizontal	<1% of sample (417)
P → S	1.00	1.00	.056	yes	yes	yes	423
R → S	1.00	1.00	.137	yes	yes	yes	0
F → S	1.00	1.00	.054	yes	yes	yes	172, 423
P → R	1.00	1.00	.361	yes	yes	yes	162, 272, 423
P → F	1.00	1.00	.089	yes	yes	yes	134, 169, 361
F → P	1.00	1.00	.058	yes	yes	yes	125, 162, 355
F → R	1.00	1.00	.040	yes	yes	yes	276, 361
P, F → R			.241	yes	yes	yes	0
P	.867	1.153					
R	.867	1.153					
R, F → S			.109	yes	yes	yes	0
R	.868	1.152					
F	.868	1.152					

P, R, F→S			.090	yes	yes	yes	0
P	.666	1.502					
R	.667	1.500					
F	.829	1.206					

Notes: F = Fears, P = Plausibility, R = Reality, S = Technology Adoption State

Step 2: Evaluate the model

The R Squared value in the Regression Model Summary table (Table A4.6.4) identifies the amount of variance in the dependent variable (technology adoption *State*) that is explained by the predictor factors. Therefore, the three factors *Plausibility*, *Fear* and *Reality* explain 20.8 percent of the variance in technology adoption *State,* that is, the degree to which adoption is achieved along the technology adoption continuum. These findings are displayed in the Regression Model Summary in Table A4.6.4.

Table A4.6.4 Regression model summary

Model Summary[b]

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate	Change Statistics				
					R Squared Change	F Change	df1	df2	Sig. F Change
1	.456[a]	.208	.202	.40380	.208	36.202	3	413	.000

a. Predictors: (Constant), Reality, Fear, Plaus

b. Dependent Variable: State

The model of prediction has been proved to be statistically significant according to the ANOVA ($F(3,413) = 36.20$, $p < .001$). Therefore, the null hypothesis that predictor factors, *Plausibility*, *Fears* and *Reality* do not influence technology adoption *State* has been rejected and the alternative hypothesis that *Reality, Fears,* and *Plausibility* can be used to predict the users' state of adoption toward new technology has been accepted. Therefore, it can be concluded that the regression model explains 20.8% of the variance in factors that influence how the user comes to adopt new technology. As noted earlier, while relatively low, the new perspective has predictive power and thus shows promise for future studies.

Step 3: Evaluate the predictor variables

Assumptions have already been checked between predictor variables in Step 1. To determine which independent variables (*Reality*, *Fears* and *Plausibility*) contribute the most

to the prediction of the dependent variable (technology adoption *State*), the beta scores for standardised coefficients were examined. Beta scores allow fair comparisons between independent variables, as they have been converted to the same scale.

Results show that the largest single contributor to technology adoption *State* is *Reality* with a beta coefficient of 0.28. Therefore, when variance explained by all other variables in the model is controlled, *Reality* has the strongest *unique* contribution that explains technology adoption *State*. *Fears* account for the next highest *unique* contribution, with a beta score of 0.17; while *Plausibility* accounts for the least *unique* contribution with a beta score of 0.12. These results show that plausible meanings contribute less than reality of use toward an individual's actual adoption state. Furthermore, the results show that fears have a stronger influence on technology adoption state than plausible meanings, suggesting that high levels of uncertainty can lead to undesirable adoption decisions when fears have been evoked. Therefore, to guard against undesirable and potentially ill-informed decision-making, industrial uncertainty and fears should be addressed as soon as possible (Dekker 2014; Project Management Institute 2013).

References

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Appendix A4.7 – Path Analysis Statistics and Effect Sizes

Factor relationships	F	R	R-Square (Prediction %)			Beta ($^{\beta}$)	Effect size (f^2)
P→S	52.94***	.336	.113***	0.21	0.37	.336**	.13 Small
R →S	83.71***	.410	.168***	0.32	0.50	.410***	.20 Med.
F → S	44.83***	.312	.097***	0.13	0.25	.312***	.11 Small
P →R	180.28***	.550	.303***	.409	.549	.550***	.44 Large
P → F	63.64***	.365	.133***	.392	.648	.365***	.15 Med.
F → P	63.64***	.365	.133***	.193	.319	.365***	.15 Med.
F → R	62.99***	.363	.132***	.447	.741	.363***	.15 Med.
P, F→R	103.46***	.577	.333***				.50 Large
P				.346	.493	.482***	
F				.063	.166	.187***	
R, F→ S	51.31***	.446	.199***				.25 Med.
R				.247	.432	.341***	
F				.058	.171	.188***	
P, R→ S	47.14***	.431	.185***				.23 Med.
P				.047	.228	.159**	
R				.216	.424	.322***	
P, F→ S	37.85***	.393	.155***				.18 Med.
P				.140	.305	.257***	
F				.075	.191	.219***	
P, R & F → S	36.20***	.456	.208***				.26 Med.
P				.012	.195	.120*	
R				.177	.387	.284***	
F				.043	.158	.166***	

*p<.05, **p<.01, ***p<.001 (effect size .02 = small, .15 = medium, .35 = large, in accordance with Faul et al. 2007)

Notes: F = Fear, P = Plausibility, R = Reality, S = Technology Adoption State. Sample size 417

Appendix A4.8 – Factors that Influence End-User Adoption of New Control-Room Technology

Attribute	Help	Hinder
Organisational factors		
Values	Trustworthy, honest, open, accountable.	Secretive, dishonest and distanced.
Leadership	Mindful, collaborative, strong yet flexible, consistent, and open minded.	Hidden agendas, aloof, rigid, judgmental and inconsiderate of others.
Management	Committed, supportive, resolves conflict, and defers to those who know.	Low interest, looks for a quick win, lacks concern for others, inconsistent.
Communication	Clear, accurate, frequent, two-way, inclusive, encourages collaboration.	Selective, one way, unclear, inaccurate, incomplete or too much, imposing.
Change mgt.	Participative, full project scope, planned, and impact understood, resourced.	Ad hoc, poorly envisaged impact, high level of uncertainty, no contingency plan.
Viability		
Analysis	Participatory, thorough, risks assessed, safety assured, realistic.	Incomplete, lack of stakeholder input, rushed, impact not assessed.
Resources	Areas to be resourced are addressed: allowance for training, necessary support, staff, suitable timeframes.	Poor financial planning, lack of training, staffing, unrealistic deadlines.
Future proofing	Provisions for unexpected needs, failure.	Solution not researched, unsustainable.
Design process		
Approach	Iterative, participatory, human/user-centred; flexible, well executed.	Rigid, engineering-centred, lack of consideration of the end user.
Participants	All stakeholders	Development team and client
Planning	Dynamic, Risk register, requirements, problem definition continually updated.	Detailed and complied with plan, risks not identified, no business case/justification.
Development	Early involvement of human factors experts and end users to ensure user requirements are reflected in the problem definition and design outcome.	Lack of understanding and agreement on requirements and defining criteria, poor requirements management, and inappropriate end-user involvement.
Testing	Utilises end users to test that all user needs are met prior going 'live'.	Not tested prior implementation, and failure to verify user acceptance.
Product outcome		
Right idea	Caters for high priority end-user needs, helps end user to achieve desired goal.	Not fit for purpose, does not solve the problem it was designed to, wrong idea.
Functionality	Competent, reliable, robust, info is visible, system status is observable, understandable, accountable, directable, proactive control, automation/manual flexibility.	End user must adapt or work around to make it work, not intuitive. Has intrinsic defects, doesn't support the end user, inappropriate level of automation, lack of adequate situational awareness.
Beneficial	Improves work performance, solves problems, aids competence, time saver.	Adds to workload, requires copious learning, disrupts and changes workflow.
Compatible	Works with existing systems, people, processes and technology.	Not supported by existing infrastructure, and disrupts workflow.
Implementation		
Support	Resources for appropriate training (i.e. hands-on, classroom, simulations), Experts for unexpected issues that arise.	Not in plan, no management support, no ongoing technical support, and provides little (online) or no training for end users.
Technology transfer	Phased introduction, old system as a fallback in case of emergency.	Lack of support and users revert back to old system. No contingency plan.

Appendix A5.1 - Correlation Matrix Between Sorts

Correlation Matrix Between Sorts

SORTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
1	1124	100	64	67	48	60	79	67	45	40	62	67	62	14	71	64	64	43	76	79	57	64	88	62	62	71	76	67	81	69	64	69	40	67	62	48	52	69	57	40	40	69	55	74	67	74	55	55	48	64	38	76	74	79	60	74	60	69	64	71	67	71	55	10	40
2	1148	64	100	48	40	64	52	36	14	-2	48	43	43	5	43	43	40	36	33	45	43	48	76	48	45	55	52	33	52	55	48	50	57	57	45	21	-7	50	36	5	36	64	36	69	40	62	31	-2	26	45	5	60	40	55	50	74	67	64	52	38	57	64	14	2	24
3	1149	67	48	100	33	67	71	71	33	36	48	67	76	33	64	52	76	60	62	76	43	50	57	74	52	48	62	40	55	64	71	48	57	64	69	67	40	60	38	43	79	52	48	67	67	57	69	31	50	48	55	60	76	74	62	57	60	55	64	55	71	69	33	45	38
4	1150	48	40	33	100	38	55	38	0	36	55	50	50	5	60	40	17	43	40	50	55	62	52	17	62	40	57	21	40	74	38	38	26	57	60	40	31	52	45	38	43	36	40	52	48	67	60	50	50	52	19	60	52	57	43	50	79	52	45	62	52	48	57	12	62
5	1156	60	64	67	38	100	69	62	40	10	24	76	64	43	52	33	71	48	38	71	57	62	69	76	48	64	45	19	43	69	31	40	55	69	67	48	26	45	31	36	57	79	45	64	74	43	60	24	52	52	43	52	74	67	60	67	57	52	43	33	52	55	33	36	64
6	1157	79	52	71	55	69	100	81	48	40	57	79	64	33	81	55	71	64	64	86	52	81	74	76	74	76	83	50	57	83	69	52	55	74	62	69	48	57	43	57	57	60	62	90	74	71	83	45	60	76	55	62	81	71	76	79	67	76	74	74	74	71	50	19	50
7	1158	67	36	71	38	62	81	100	64	50	33	62	57	45	74	50	76	60	55	86	60	62	62	69	55	79	67	52	43	67	50	50	50	67	69	86	43	67	43	62	52	64	48	62	67	45	64	55	67	57	71	60	64	62	64	76	50	48	71	62	74	60	45	38	55
8	1162	45	14	33	0	40	48	64	100	7	-7	43	24	43	45	26	48	31	33	52	17	43	36	57	10	71	38	33	17	48	19	19	26	40	43	50	24	57	12	71	31	33	17	29	36	12	29	40	7	48	45	29	31	33	43	62	21	36	31	21	24	26	45	12	29
9	1165	40	-2	36	36	10	40	50	7	100	33	24	24	-2	43	12	38	-7	40	36	50	7	29	26	57	19	31	62	38	26	26	48	0	7	36	40	71	31	36	17	31	10	0	31	45	19	45	50	45	26	43	38	33	38	45	19	10	5	33	55	33	38	26	45	29
10	1166	62	48	48	55	24	57	33	-7	33	100	29	38	-2	38	43	40	55	57	45	48	48	67	38	71	31	79	60	69	45	67	71	57	50	33	19	50	36	74	5	29	31	60	67	43	86	55	31	55	45	12	67	55	38	43	36	64	64	69	81	76	83	36	-17	26
11	1170	67	43	67	50	76	79	62	43	24	29	100	55	43	81	55	69	55	67	69	55	81	60	71	60	69	55	33	57	74	57	45	31	76	69	69	36	50	33	60	60	64	52	71	76	55	69	48	48	83	57	50	83	79	67	69	60	57	52	40	48	48	60	21	55
12	1171	62	43	76	50	64	64	57	24	24	38	55	100	31	62	38	57	57	55	74	33	45	50	48	52	40	55	26	36	67	57	29	48	48	64	50	33	48	29	33	50	48	38	55	71	52	67	26	43	40	24	43	79	71	31	55	57	57	48	52	48	52	45	43	50
13	1172	14	5	33	5	43	33	45	43	-2	-2	43	31	100	52	24	62	62	33	55	43	29	17	52	29	48	19	29	5	24	21	31	26	45	50	62	14	21	29	62	24	21	14	31	57	21	19	26	48	38	43	14	40	31	12	36	19	31	55	29	14	33	50	0	67
14	1173	71	43	64	60	52	81	74	45	43	38	81	62	52	100	62	67	64	71	79	55	71	57	62	69	76	67	57	55	74	71	55	33	71	74	83	33	64	40	69	52	45	38	76	79	64	64	52	52	83	55	52	74	83	62	81	64	67	76	64	52	60	67	17	57
15	1174	64	43	52	40	33	55	50	26	12	43	55	38	24	62	100	55	48	55	64	45	74	50	26	36	67	74	31	57	60	64	48	33	60	57	50	29	48	62	43	36	50	36	45	45	55	45	45	33	48	45	52	60	67	36	55	48	48	64	57	62	45	45	17	29
16	1175	64	40	76	17	71	71	76	48	38	40	69	57	62	67	55	100	60	64	76	64	57	60	81	64	71	64	62	55	52	62	69	60	60	69	67	55	40	62	40	50	60	36	64	86	45	64	38	62	62	64	50	81	67	57	62	38	50	74	57	62	71	45	38	52
17	1176	43	36	60	43	48	64	60	31	-7	55	55	57	62	64	48	60	100	55	67	40	67	48	57	55	57	67	33	36	55	67	45	64	76	55	67	12	40	48	50	38	43	67	64	57	71	55	29	62	62	38	45	64	45	36	60	69	69	79	57	67	64	52	-12	52
18	1181	76	33	62	40	38	64	55	33	40	57	67	55	33	71	55	64	55	100	62	64	52	67	52	76	52	62	76	62	48	76	71	19	60	62	62	60	40	62	43	29	52	62	64	60	74	50	67	55	74	45	69	69	57	40	55	40	60	64	69	55	60	81	5	40
19	1182	79	45	76	50	71	86	86	52	36	45	69	74	55	79	64	76	67	62	100	62	69	71	69	57	76	74	45	55	79	55	52	48	76	74	74	50	64	50	67	55	64	55	71	76	64	67	57	69	55	60	67	79	76	57	71	60	64	74	76	71	67	57	26	71
20	1183	57	43	43	55	57	52	60	17	50	48	55	33	43	55	45	64	40	64	62	100	48	71	45	74	57	48	62	52	45	33	79	24	62	69	57	57	36	76	31	26	69	48	52	62	57	40	67	83	52	52	76	55	48	43	50	40	36	62	67	62	60	64	19	76
21	1184	64	48	50	62	62	81	62	43	7	48	81	45	29	71	74	57	67	52	69	48	100	62	52	55	81	81	24	55	83	60	43	50	79	60	57	29	50	50	55	45	62	60	69	62	64	74	45	45	79	48	52	76	67	62	74	71	67	62	55	67	52	55	7	48
22	1185	88	76	57	52	69	74	62	36	29	67	60	50	17	57	50	60	48	67	71	71	62	100	67	69	71	71	62	67	62	55	79	52	79	67	43	43	60	64	31	40	81	69	79	57	81	45	55	64	62	43	90	62	64	64	71	67	76	64	69	76	79	50	5	50
23	1187	62	48	74	17	76	76	69	57	26	38	71	48	52	62	26	81	57	52	69	45	52	67	100	57	67	55	52	48	55	55	60	62	71	62	60	38	50	33	50	67	52	48	79	71	52	57	31	52	67	62	55	67	62	79	64	52	67	62	45	57	74	33	19	45
24	1198	62	45	52	62	48	74	55	10	57	71	60	52	29	69	36	64	55	76	57	74	55	69	57	100	52	69	74	52	55	71	79	43	57	62	55	60	29	67	24	36	45	52	81	71	76	69	50	71	76	43	67	69	55	60	57	55	67	71	79	64	76	62	17	52
25	1199	71	55	48	40	64	76	79	71	19	31	69	40	48	76	67	71	57	52	76	57	81	71	67	52	100	74	50	48	71	52	60	52	76	71	67	29	62	52	62	40	67	40	67	67	52	52	52	48	76	62	60	62	69	67	88	57	67	69	55	62	60	55	17	52
26	1201	76	52	62	57	45	83	67	38	31	79	55	55	19	67	74	64	67	62	74	48	81	71	55	69	74	100	55	62	76	79	64	69	67	60	50	50	57	71	43	48	48	55	76	62	79	76	45	50	67	43	67	74	64	62	69	71	79	81	83	83	81	50	12	36
27	1202	67	33	40	21	19	50	52	33	62	60	33	26	29	57	31	62	33	76	45	62	24	62	52	74	50	55	100	60	24	60	86	29	36	45	45	60	40	67	24	14	31	29	57	55	57	31	50	50	60	36	60	43	40	43	50	26	48	69	69	48	71	55	-2	29
28	1203	81	52	55	40	43	57	43	17	38	69	57	36	5	55	57	55	36	62	55	52	55	67	48	52	48	62	60	100	55	52	67	29	52	33	26	50	48	57	14	26	48	43	60	60	64	50	33	40	55	17	57	64	62	52	52	50	40	55	62	60	64	38	-12	33
29	1205	69	55	64	74	69	83	67	48	26	45	74	67	24	74	60	52	55	48	79	45	83	62	55	55	71	76	24	55	100	52	33	45	69	64	55	38	64	36	60	62	50	43	71	67	62	83	40	38	67	36	57	74	74	69	79	76	64	55	64	64	57	55	26	60
30	1207	64	48	71	38	31	69	50	19	26	67	57	57	21	71	64	62	67	76	55	33	60	55	55	71	52	79	60	52	52	100	62	55	60	57	57	31	40	52	31	50	33	50	76	55	76	62	31	38	71	43	55	67	64	55	60	60	76	76	64	67	71	45	14	12
31	1214	69	50	48	38	40	52	50	19	48	71	45	29	31	55	48	69	45	71	52	79	43	79	60	79	60	64	86	67	33	62	100	48	62	64	43	57	40	86	19	31	52	45	64	62	71	36	57	69	62	50	79	55	55	55	50	48	60	74	71	67	83	52	5	45
32	1216	40	57	57	26	55	55	50	26	0	57	31	48	26	33	33	60	64	19	48	24	50	52	62	43	52	69	29	29	45	55	48	100	52	50	31	10	48	50	17	55	40	33	57	52	50	52	-2	38	38	29	40	55	45	48	52	69	67	67	40	67	79	5	19	21
33	1217	67	57	64	57	69	74	67	40	7	50	76	48	45	71	60	60	76	60	76	62	79	79	71	57	76	67	36	52	69	60	62	52	100	76	69	21	60	50	60	60	71	76	76	57	79	50	57	69	71	64	79	64	69	69	71	79	76	69	57	76	67	55	2	62
34	1223	62	45	69	60	67	62	69	43	36	33	69	64	50	74	57	69	55	62	74	69	60	67	62	62	71	60	45	33	64	57	64	50	76	100	74	40	67	60	62	71	62	38	57	71	57	52	67	62	62	71	74	69	81	57	64	67	64	64	55	60	64	64	50	67
35	1224	48	21	67	40	48	69	86	50	40	19	69	50	62	83	50	67	67	62	74	57	57	43	60	55	67	50	45	26	55	57	43	31	69	74	100	26	57	33	74	55	50	45	57	60	45	52	57	64	64	76	50	57	60	52	67	48	45	71	50	57	45	57	31	55
36	1225	52	-7	40	31	26	48	43	24	71	50	36	33	14	33	29	55	12	60	50	57	29	43	38	60	29	50	60	50	38	31	57	10	21	40	26	100	19	62	26	26	21	26	33	55	36	57	67	50	33	43	50	57	36	38	12	10	21	33	69	40	48	55	31	45
37	1227	69	50	60	52	45	57	67	57	31	36	50	48	21	64	48	40	40	40	64	36	50	60	50	29	62	57	40	48	64	40	40	48	60	67	57	19	100	36	67	64	45	26	48	48	50	38	43	29	45	36	60	48	69	50	69	74	55	60	45	52	60	40	14	38
38	1228	57	36	38	45	31	43	43	12	36	74	33	29	29	40	62	62	48	62	50	76	50	64	33	67	52	71	67	57	36	52	86	50	50	60	33	62	36	100	19	21	48	40	43	55	64	40	57	64	45	38	69	57	43	29	36	45	48	71	74	67	74	57	7	48
39	1229	40	5	43	38	36	57	62	71	17	5	60	33	62	69	43	40	50	43	67	31	55	31	50	24	62	43	24	14	60	31	19	17	60	62	74	26	67	19	100	55	24	29	40	43	36	38	60	31	52	57	38	43	50	40	52	45	48	50	40	29	31	64	7	55
40	1230	40	36	79	43	57	57	52	31	31	29	60	50	24	52	36	50	38	29	55	26	45	40	67	36	40	48	14	26	62	50	31	55	60	71	55	26	64	21	55	100	29	24	55	50	40	60	29	31	40	60	50	55	69	71	43	67	52	45	33	52	57	19	52	33
41	1234	69	64	52	36	79	60	64	33	10	31	64	48	21	45	50	60	43	52	64	69	62	81	52	45	67	48	31	48	50	33	52	40	71	62	50	21	45	48	24	29	100	67	52	50	50	36	45	62	48	48	69	60	55	43	64	48	45	45	36	64	45	38	21	48
42	1235	55	36	48	40	45	62	48	17	0	60	52	38	14	38	36	36	67	62	55	48	60	69	48	52	40	55	29	43	43	50	45	33	76	38	45	26	26	40	29	24	67	100	62	26	76	40	50	67	50	40	69	50	29	40	40	52	60	48	52	71	48	45	-19	36
43	1236	74	69	67	52	64	90	62	29	31	67	71	55	31	76	45	64	64	64	71	52	69	79	79	81	67	76	57	60	71	76	64	57	76	57	57	33	48	43	40	55	52	62	100	67	83	69	31	57	79	43	67	69	67	79	76	71	86	76	71	71	81	43	2	43
44	1237	67	40	67	48	74	74	67	36	45	43	76	71	57	79	45	86	57	60	76	62	62	57	71	71	67	62	55	60	67	55	62	52	57	71	60	55	48	55	43	50	50	26	67	100	50	74	38	60	69	45	43	90	81	55	64	55	55	67	60	48	69	55	33	69
45	1251	74	62	57	67	43	71	45	12	19	86	55	52	21	64	55	45	71	74	64	57	64	81	52	76	52	79	57	64	62	76	71	50	79	57	45	36	50	64	36	40	50	76	83	50	100	52	48	62	67	29	81	62	57	52	60	79	86	76	81	76	81	60	-19	45
46	1252	55	31	69	60	60	83	64	29	45	55	69	67	19	64	45	64	55	50	67	40	74	45	57	69	52	76	31	50	83	62	36	52	50	52	52	57	38	40	38	60	36	40	69	74	52	100	31	45	64	40	40	83	62	67	57	60	52	55	64	64	60	43	40	45
47	1253	55	-2	31	50	24	45	55	40	50	31	48	26	26	52	45	38	29	67	57	67	45	55	31	50	52	45	50	33	40	31	57	-2	57	67	57	67	43	57	60	29	45	50	31	38	48	31	100	62	48	69	71	43	45	38	31	29	36	38	60	45	33	76	19	57
48	1260	48	26	50	50	52	60	67	7	45	55	48	43	48	52	33	62	62	55	69	83	45	64	52	71	48	50	50	40	38	38	69	38	69	62	64	50	29	64	31	31	62	67	57	60	62	45	62	100	43	62	69	57	43	43	38	45	43	67	69	71	62	48	14	74
49	1268	64	45	48	52	52	76	57	48	26	45	83	40	38	83	48	62	62	74	55	52	79	62	67	76	76	67	60	55	67	71	62	38	71	62	64	33	45	45	52	40	48	50	79	69	67	64	48	43	100	48	52	69	64	69	79	62	71	64	52	50	60	69	0	43
50	1269	38	5	55	19	43	55	71	45	43	12	57	24	43	55	45	64	38	45	60	52	48	43	62	43	62	43	36	17	36	43	50	29	64	71	76	43	36	38	57	60	48	40	43	45	29	40	69	62	48	100	55	45	52	64	38	26	36	48	38	55	38	36	50	40
51	1275	76	60	60	60	52	62	60	29	38	67	50	43	14	52	52	50	45	69	67	76	52	90	55	67	60	67	60	57	57	55	79	40	79	74	50	50	60	69	38	50	69	69	67	43	81	40	71	69	52	55	100	50	57	62	57	64	67	62	74	81	74	57	14	52
52	1276	74	40	76	52	74	81	64	31	33	55	83	79	40	74	60	81	64	69	79	55	76	62	67	69	62	74	43	64	74	67	55	55	64	69	57	57	48	57	43	55	60	50	69	90	62	83	43	57	69	45	50	100	81	52	60	62	62	64	62	60	67	57	31	57
53	1300	79	55	74	57	67	71	62	33	38	38	79	71	31	83	67	67	45	57	76	48	67	64	62	55	69	64	40	62	74	64	55	45	69	81	60	36	69	43	50	69	55	29	67	81	57	62	45	43	64	52	57	81	100	64	69	69	64	60	52	52	62	45	40	50
54	1284	60	50	62	43	60	76	64	43	45	43	67	31	12	62	36	57	36	40	57	43	62	64	79	60	67	62	43	52	69	55	55	48	69	57	52	38	50	29	40	71	43	40	79	55	52	67	38	43	69	64	62	52	64	100	67	60	60	50	50	67	64	24	31	33
55	1281	74	74	57	50	67	79	76	62	19	36	69	55	36	81	55	62	60	55	71	50	74	71	64	57	88	69	50	52	79	60	50	52	71	64	67	12	69	36	52	43	64	40	76	64	60	57	31	38	79	38	57	60	69	67	100	69	69	69	52	62	62	50	12	45
56	1279	60	67	60	79	57	67	50	21	10	64	60	57	19	64	48	38	69	40	60	40	71	67	52	55	57	71	26	50	76	60	48	69	79	67	48	10	74	45	45	67	48	52	71	55	79	60	29	45	62	26	64	62	69	60	69	100	79	67	55	69	74	40	2	48
57	1295	69	64	55	52	52	76	48	36	5	64	57	57	31	67	48	50	69	60	64	36	67	76	67	67	67	79	48	40	64	76	60	67	76	64	45	21	55	48	48	52	45	60	86	55	86	52	36	43	71	36	67	62	64	60	69	79	100	71	64	62	79	50	-5	36
58	1280	64	52	64	45	43	74	71	31	33	69	52	48	55	76	64	74	79	64	74	62	62	64	62	71	69	81	69	55	55	76	74	67	69	64	71	33	60	71	50	45	45	48	76	67	76	55	38	67	64	48	62	64	60	50	69	67	71	100	79	76	86	50	0	48
59	1283	71	38	55	62	33	74	62	21	55	81	40	52	29	64

Appendix A5.2 – Factor Matrix with Defining Sorts

	ID	Pragmatist	Democrat	Traditionalist	Strategist
1	1124	0.58608	0.47647	0.19778	0.1914
2	1148	**0.75883**	0.15954	0.01299	-0.07592
3	1149	**0.63739**	0.24082	0.24748	0.49592
4	1150	0.41152	0.20866	0.08727	0.13548
5	1156	**0.62228**	-0.0331	0.36674	0.37955
6	1157	**0.69099**	0.35536	0.37979	0.28463
7	1158	0.40632	0.28137	0.57768	0.42054
8	1162	0.23596	-0.0284	**0.6611**	0.09899
9	1165	-0.06194	0.5229	0.08626	**0.62119**
10	1166	0.55017	**0.74894**	-0.23842	0.0225
11	1170	0.58554	0.09648	0.4907	0.2647
12	1171	0.52462	0.13506	0.23601	0.40918
13	1172	0.00548	0.13759	**0.80924**	0.08204
14	1173	0.49649	0.32673	0.60556	0.16589
15	1174	0.40954	0.27034	0.26944	0.1188
16	1175	0.41156	0.42401	0.50936	0.47733
17	1176	0.5372	0.29596	0.46762	-0.05117
18	1181	0.3157	**0.63613**	0.29866	0.10938
19	1182	0.50612	0.29861	0.4808	0.38759
20	1183	0.11747	0.57612	0.32172	0.26549
21	1184	**0.67466**	0.15096	0.37231	0.05056
22	1185	0.60404	0.51773	0.14448	0.0827
23	1187	0.58998	0.27666	0.49951	0.30525
24	1198	0.40862	**0.71478**	0.21816	0.18366
25	1199	0.51162	0.24879	**0.62989**	0.07512
26	1201	**0.65993**	0.51157	0.20222	0.13511
27	1202	0.12611	**0.87478**	0.31963	0.06792
28	1205	**0.69825**	0.0874	0.30042	0.27761
29	1207	**0.62416**	0.51021	0.23237	0.03521
30	1214	0.29351	**0.81722**	0.20213	0.09247
31	1216	**0.68773**	0.22156	0.15765	0.12136
32	1217	**0.64672**	0.24545	0.42851	0.0011
33	1223	0.40592	0.26311	0.51492	0.32472
34	1224	0.28475	0.23006	**0.72517**	0.25541
35	1225	-0.01481	0.60165	0.05909	**0.61005**
36	1227	0.49582	0.15152	0.37627	0.12153
37	1228	0.19792	**0.74983**	0.11625	0.12549
38	1229	0.22075	-0.00646	**0.72236**	0.091
39	1230	0.59198	-0.01943	0.26491	0.41522
40	1234	0.45151	0.19475	0.2235	0.1902
41	1235	0.50353	0.33439	0.08509	-0.05587
42	1236	**0.76386**	0.45557	0.28736	0.06674
43	1237	0.45774	0.32499	0.45976	0.49331
44	1251	**0.65321**	0.60661	0.0721	-0.14096
45	1252	0.60041	0.25737	0.20688	0.48853
46	1253	-0.04674	0.42861	0.36797	0.25729

	ID	Pragmatist	Democrat	Traditionalist	Strategist
47	1260	0.2061	0.51924	0.30695	0.29452
48	1268	0.52937	0.39788	0.53118	-0.04992
49	1269	0.16464	0.24515	**0.64041**	0.36485
50	1275	0.4325	0.56941	0.10839	0.12358
51	1277	0.59166	0.29701	0.31038	0.4555
52	1278	0.50253	0.48829	-0.01373	0.15462
53	1279	**0.81587**	0.172	0.15971	-0.04199
54	1280	0.51215	0.59908	0.45586	0.04376
55	1281	**0.65444**	0.21009	0.54769	-0.00565
56	1283	0.35336	**0.7654**	0.15724	0.19295
57	1284	**0.62569**	0.25551	0.23736	0.30226
58	1288	**0.62408**	0.48511	0.10166	0.20321
59	1295	**0.74661**	0.37314	0.3053	-0.12294
60	1300	0.60632	0.17319	0.34384	0.37956
61	1308	**0.62312**	**0.64555**	0.19025	0.16583
62	1346	0.10064	0.41672	0.55407	-0.02956
63	1361	0.01571	-0.06622	0.12195	**0.82468**
64	1400	0.13509	0.22683	0.46604	0.30494
Count		18	8	6	3
Eigenvalues		16.3632	11.1509	9.1688	5.0895
% Total Variance		25.5675	17.4233	14.3262	7.9523

Notes: Centroid Factor Analysis, VARIMAX rotation

Fuerntratt criterion: 2.58(1/√18) = .608 = p<0.01; 1.96(1/√18) = .462 = p<0.05 (Z = 2.58 = p<0.01 & Z = 1.96 = <0.05)