A systems perspective on safety leadership: Applications in the context of the mining industry

Sarah-Louise Donovan

Bachelor of Science (Psychology), Post Graduate Diploma (Psychology), Master of Science & Technology (Aviation), Diploma of Workplace Health & Safety

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Abstract

Safety leadership is recognised as a key safety-related concept in high-risk industries, such as mining. To date however, efforts to improve understanding of the concept of safety leadership, and its utility in supporting and enhancing safe performance across the industry have been limited. While a systems perspective is widely accepted as the dominant paradigm for understanding safety and performance within complex socio-technical systems, existing research has not examined safety leadership from this perspective. Further, examining safety leadership for improved understanding has not yet materialised as a focal area of interest in mining.

To address these gaps, this thesis aimed to examine safety leadership from a systems perspective in order to establish how mining work systems can best enhance the likelihood of appropriate and effective safety leadership to support safe performance. To achieve this aim, the body of research presented sought to; i) determine the utility of applying a systems perspective to conceptualise and analyse safety leadership; ii) expand understanding of safety leadership within a mining complex social-technical system, iii) identify factors that influence and interact with safety leadership across mining work systems to support safe performance, iv) demonstrate the utility in application of systems ergonomic methods to model safety leadership, and lastly; v) to develop a set of strategies for organisations to adopt to support appropriate and effective safety leadership.

To answer these research questions, a literature review and three studies were conducted. First, the utility of applying a systems perspective to study safety leadership was demonstrated through a case study examination of the Bingham Canyon Mine Highwall Failure incident (Study 1). Rasmussen's Risk Management Framework (RMF) and AcciMap Method were applied in conjunction with the Critical Decision Method (CDM) interview technique to examine safety leadership during the incident. Through testing of an adapted set of Rasmussen's predictions, safety leadership was established as a systems phenomenon. An expanded understanding of the safety leadership concept was also achieved, with an integral link established between decision-making and behaviour in the safety leadership context. Study 1 contributed to the identification of factors that influenced and supported effective safety leadership during the critical incident scenario, across the work system. Study 2 identified a further set of factors and interactions across the work system that influenced and supported effective safety leadership associated with regular safety-related task execution. Study 2 also provided a methodological contribution to the research through the development

and application of an extension to the CDM for improved examination of the behavioural component of safety leadership in association with decision-making. Last, Study 3 applied Cognitive Work Analysis (CWA) to develop a model of safety leadership that integrated the factors identified in Studies 1 and 2 to determine the core skill, rule and knowledge-based behaviours indicative of effective safety leadership across the work system during both normal and abnormal operational contexts. The output from Study 3 underpinned the development of a comprehensive systems-based competency framework for effective safety leadership development. A corresponding set of optimisation strategies are recommended for organisations in the industry to adopt to develop and enhance effective safety leadership to support safe system functioning.

Declaration

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

This thesis includes 4 original papers published in peer-reviewed journals. The core theme of the thesis is the application of systems-thinking to identify the factors that influence and support effective safety leadership decisions, behaviours and actions across a mining work system and the application of this knowledge to improve safety across the industry. The ideas, development and writing up of all the papers in this thesis have been the principal responsibility of myself, the student, working within the Monash University Accident Research Centre under the supervision of Associate Professor Sharon Newnam, Professor Timothy Horberry, Adjunct Professor Michael G. Lenné and Professor Paul M. Salmon of the University of the Sunshine Coast.

The inclusion of co-authors reflects the fact that the work has come from active collaboration between researchers and acknowledges the input into team-based research. With specific regard to chapters 2, 4, 5 and 7, which contain peer-reviewed journal articles, my contribution to the work has involved the following:

Thesis Chapter	Publication title	Publication status	Nature and extend of the student's contribution	Co-author names and extent of contribution	Co-authors Monash students?
2	Leading with style: a literature review of the influence of safety leadership on performance and outcomes	Published	85% primary author. Conceived idea to conduct a structured literature review, determine methodology for the review and criteria, conducted literature search, analysed results and was responsible for the initial drafting and subsequent editing of the paper.	Paul M. Salmon. 10% Guidance in interpretation and presentation of results. Provided critical review of the draft versions of the paper. Michael G. Lenné 5% guidance on interpretation and presentation of results. Provided critical review of draft versions of the paper.	No
4	Safety leadership and systems-thinking: application and evaluation of a Risk Management Framework in the mining industry	Published	80% primary author. Conceived idea of adapting methodology to examine safety leadership. Conducted analysis and application of methodology to the case study. Responsible for the initial drafting and editing of the paper.	Paul M. Salmon. 10% input into AcciMap review, including interpretation presentation of results. Provided critical review of the draft versions of the paper. Michael G. Lenné 5% guidance on interpretation and presentation of results. Provided critical review of draft versions of the paper. Timothy Horberry 5% guidance on interpretation and presentation of results.	No
5	Ending on a positive: examining the role of safety leadership decisions, behaviours and actions in a safety critical situation	Published	80% primary author. Conceived the idea to apply to the critical incident case study. Developed and applied the methodology. Collated and analysed the results. Responsible for the initial drafting and subsequent editing of the paper.	Paul M. Salmon. 10% input into review, including interpretation of presentation of results. Provided critical review of the draft versions of the paper. Michael G. Lenné 5% guidance on interpretation and presentation of results. Provided critical review of draft versions of the paper. Timothy Horberry 5% guidance on interpretation and	No

Thesis Chapter	Publication title	Publication status	Nature and extend of the student's contribution	Co-author names and extent of contribution	Co-authors Monash students?
				presentation of results.	
7	All in a day's work: towards improved understanding of safety leadership during regular safety-related tasks in mining	Published	80% primary author. Conceived the idea to apply to methodology in a normal operational setting. Developed and applied the methodology. Collated and analysed the results. Responsible for the initial drafting and subsequent editing of the paper.	Paul M. Salmon. 10% input into review, including interpretation of presentation of results. Provided critical review of the draft versions of the paper. Michael G. Lenné 5% guidance on interpretation and presentation of results. Provided critical review of draft versions of the paper. Timothy Horberry 5% guidance on interpretation and presentation of results	No

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

Student signature: SIGNATURE REMOVED Date: 7 January 2021

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author, I have consulted with the responsible author to agree on the respective contributions of the authors.

Main Supervisor signature: SIGNATURE REMOVED Date: 7 January 2021

Acknowledgements

To describe the path to completion of this research program as merely a journey, would be an understatement. It has been an epic adventure, crossing multiple continents, traversing mountains and canyons, navigating roads and trails, and with a finishing line that often appeared as a mirage in the distance. Yet, here I am. I finally made it. And I am incredibly grateful to the many people who have assisted me along the way to achieve this goal.

Firstly, I could not have done it without the support from my fantastic supervisory team. Associate Professor Sharon Newnam, thanks for stepping in to help guide me through the final months, days and hours. I appreciate your care and assistance in helping me pull together the finished product, something of which I am very proud. Thank you to Professor Timothy Horberry for helping me stay the course. Your ability to keep me focused and on track when at times, the end seemed so far out of reach, has been key to me crossing the finishing line. Professor Paul Salmon, thank you for allowing me the freedom pursue a program of research that interests me, for generously sharing your knowledge, and opening my eyes to the power of systems-thinking. And Adjunct Professor Mike Lenné, you've been there with me since day one. Thank you for always asking the hard questions, challenging me to think, and for your ever-present support and encouragement. As the inaugural recipient of the Thomas Triggs Memorial Scholarship, I am grateful we were able to honour Tom's legacy as a team, and in delivering this research program, contribute something of which I hope Tom would be proud.

This research would not have been possible if it weren't for the many participants who generously shared their time, knowledge and experience to this program. I never cease to be amazed by the generosity of people who participate in research and I hope that our combined efforts will lead to genuine improvements in safety. In particular, I'd like to extend my sincere thanks to those incredibly inspiring leaders at Rio Tinto's Kennecott Utah Copper who generously volunteered their time and knowledge to support this research. I will be forever grateful for your contribution towards the betterment of safety and am immensely proud to share the learnings of this research program with the world.

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This thesis is dedicated to those in the mining industry, whose daily leadership through decisions, behaviours and actions provide a significant contribution to ensuring the safety of their respective operations, and the safety of those individuals and teams in their care.

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Abbreviations

AL	Authentic Leadership
CDM	Critical Decision Method
CDM-SL	Critical Decision Method - Safety Leadership
CAT	Contextual Activity Template
CTA	Control Task Analysis
CWA	Cognitive Work Analysis
DL	Decision Ladder
EAST	Event Analysis of Systemic Teamwork
EBT	Evidence Based Training
EL	Empowering Leadership
FRAM	Functional Resonance Analysis Method
HFACS	Human Factors Analysis Classification System
HFE	Human Factors and Ergonomics
KBB	Knowledge-Based Behaviours
KPI	Key Performance Indicator
LMX	Leader-Member Exchange
MSHA	Mine Safety and Health Administration (USA)
NET-HARMS	Networked Hazard Analysis and Risk Management System
PPAA	Physical Processes and Actor Activities
QMI	Queensland Mines Inspectorate
RBB	Rule-Based Behaviours
RMF	Risk Management Framework
RTW	Return To Work

SBB	Skill-Based Behaviours
SOP	Standard Operating Procedure
SME	Subject Matter Expert
SMS	Safety Management System
SRK	Skills, Rules and Knowledge
STAMP	Systems Theoretical Accident Modelling Processes
TRFL	Transformational Leadership
TRSL	Transactional Leadership
VI	Vertical Integration
WCA	Worker Competency Analysis
WDA	Work Domain Analysis

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Publications arising from this thesis

The following peer-reviewed journal articles are included in body of thesis:

1. **Donovan, S.-L., Salmon, P. M., & Lenné, M. G.** (2016) Leading with style: a literature review of the influence of safety leadership on performance and outcomes. *Theoretical Issues in Ergonomics Science*, 17:4, 423-442.
2. **Donovan, S.-L., Salmon, P. M., Lenné, M. G., & Horberry, T.** (2017) Safety leadership and systems-thinking: application and evaluation of a Risk Management Framework in the mining industry. *Ergonomics*, Vol 60(10): 1336-1350.
3. **Donovan, S.-L., Salmon, P. M., Horberry, T., & Lenné, M. G.** (2018) Ending on a positive: Examining the role of safety leadership decisions, behaviours and actions in a critical incident scenario. *Applied Ergonomics*, *66*, 139-150.
4. **Donovan, S.-L., Salmon, P. M., Horberry, T., & Lenné, M. G.** (2020) All in a day's work: towards improved understanding of safety leadership during regular safety-related tasks in mining. *Human Factors Ergonomics in Manufacturing and Service Industries*.

1 Introduction

"… Meaningful interaction with an environment depends upon the existence of a set of invariate constraints in the relationships among events in the environment and between human actions and their effects." (Rasmussen, 1983)

The technical and human aspects of managing safety within complex socio-technical systems has received increasing attention over the past several decades (Griffin & Talati, 2014). Research has advanced knowledge of a range of factors associated with improvements in safety (Christian, Bradley, Wallace, & Burke, 2009). One such factor is safety leadership, which is recognised as the pivotal link between the safety of individuals and teams and the overall safety of an organisational system (Griffin & Talati, 2014).

Complex organisational systems comprise a large number of social and technical factors that interact to create the conditions for successful, or unsuccessful performance (Righi & Saurin, 2015; Walker, Stanton, Salmon, & Jenkins, 2008). Examples of such systems exist within aviation (Harris & Stanton, 2010), transport (Larsson, Dekker, & Tingvall, 2010; Salmon, McClure, & Stanton, 2012) and mining (Horberry & Cooke, 2010). Contemporary thinking in ergonomics suggests that for such systems to maintain safe performance, they require the ability to adapt and respond to uncertainty and changing circumstance in meaningful ways (Hollnagel, 2004, 2009; Righi & Saurin, 2015). A key component of this adaptive capacity (Rasmussen, 1997; Vicente, 1999) relates to safety leadership and its ability to support adaptive and safe performance under both normal and abnormal operational contexts.

In order to appreciate the capacity of safety leadership to support safe and successful performance, it is important to understand the decisions, behaviours and actions leaders make in the context of the system in which they occur. These attributes collectively represent safety leadership. Understanding the factors that influence and interact with safety leadership across complex organisational systems to support safe performance, is central to this thesis.

1.1 Safety leadership research: the status quo

Leadership is typically characterised by a leader's behaviours and the relationships they form with followers (Zaccaro & Horn, 2003). Not surprisingly, the relative success of a leader is often judged by their ability to influence followers towards the accomplishment of a common goal (Chemers, 1997). This characterisation remains dominant across a range of domains, including the education (Vecchio, Justin, & Pearce, 2010), finance and information technology sectors (Carmeli & Schaubroeck, 2006). Within this, understanding how leadership style and behaviour influence the performance of subordinate individuals and teams has been the historical research focus (Dinh et al., 2014; Zaccaro & Klimoski, 2001).

Leadership style and behaviour has also been linked to improvements in safety performance and outcomes (Flin & Yule, 2004; Hofmann & Morgeson, 1999; Kelloway, Mullen, & Francis, 2006; Michael, Guo, Wiedenbeck, & Ray, 2006; Zohar, 2002) however, conceptual and methodological limitations relating to safety leadership research exist. Over the last several decades, there has been a shift in the safety science research to a systems perspective to examine safety within complex socio-technical systems (Leveson, 2004; Rasmussen, 1997). As a consequence of this, there is now widespread acceptance that safety is an emergent property of the overall system of work; that is, it is a product of the decisions, behaviours and actions of actors across all levels of the work system, up to and including, regulatory bodies and government (Rasmussen, 1997). Indeed, the very notion of complex socio-technical systems is underpinned by a systems perspective (Dekker, 2011; Hollnagel, 2014; Leveson, 2012; Rasmussen, 1997) that recognises that the emergent nature of interactions between social and technical factors across work systems can have a profound effect on performance in both a desired (Hollnagel, 2004, 2009) and undesired way (Reason, 1997). Thus, applying a systems perspective to study safety-related concepts is important in the modern era, given the complexity of operations in high-risk domains where reductionist approaches are no longer considered suitable (Dekker, 2011; Read, Salmon, Lenné, & Stanton, 2015; Walker, Stanton, Salmon, Jenkins, & Rafferty, 2010).

With a systems perspective emerging strongly as the contemporary approach for studying and understanding safety within complex organisational systems (Alper & Karsh, 2009; Carayon et al., 2015; Dekker, 2011; Nayak & Waterson, 2016; Read, Salmon, & Lenné, 2013; Salmon, Walker, Read, Goode, & Stanton, 2017; Walker et al., 2008), it is important to examine safety leadership from this perspective. However, it is not clear whether this has yet occurred. Indeed, advocates for systems-thinking (Leveson, 2004; Rasmussen, 1997; Reason, 1997) acknowledge safety leadership is an important factor that supports safety within complex socio-technical systems, yet despite this, there is little evidence safety leadership has been examined using the frameworks, methods and models that promote its importance (Akselsson, Jacobsson, Botjesson, Ek, & Enander, 2012; Zohar, 2002). It is therefore not clear what factors across work systems either facilitate or inhibit safety leadership, which represents a significant gap in the knowledge base. As such, organisations in high-risk industries are no closer to understanding the factors that underpin and influence safety leadership across work systems in order to optimise its effectiveness. Thus, the problem of what creates 'good' and more importantly, effective safety leadership for different levels of leadership (i.e., frontline supervisors, team leaders, managers, senior and executive leaders) remains an outstanding challenge to researchers and practitioners (Glendon & Clarke, 2015). This is the central research gap being addressed in this thesis.

1.2 The application domain: the mining industry

The mining industry is characteristic of a high-risk, complex socio-technical system (Grote, 2012). It is selected as the domain of interest for the current research due to the safety critical nature of operations and the corresponding potential for both small-scale occupational incidents, as well as large-scale organisational accidents with the potential for significant loss of life (Grote, 2012).

Research has shown that mining workers are routinely exposed to a more hazardous work environment when compared with workers in other high-risk industries (Lenné, Salmon, Liu, & Trotter, 2012). Indeed, a hazard database published and maintained by the Queensland Mines Inspectorate (QMI) in Australia lists over sixty high-risk hazards associated with mining activities, including for example, interaction with mobile plant and equipment, exposure to high-voltage electricity and potential for entrapment (QMI website accessed 27th September 2020). Such hazards pose significant safety risks to mining workers, the outcomes of which are unfortunately reflected in work, health and safety serious injury and fatality statistics both in Australia (*Work-related Traumatic Injury Fatalities, Safework Australia*, 2016) and abroad (Mining Safety & Health Administration (MSHA) website accessed 27th September 2020).

In recent years, mining research has begun to explore the benefits of applying a systems perspective to help analyse and solve the problem of safety (Demir, Abou-Jaoude, & Kumral, 2017; Li, Sari, & Kumral, 2019; Xiao, Horberry, & Cliff, 2015). However, the majority of mining safety research to date continues to focus primarily on identifying failures at the operational level, with factors such as equipment and the work environment showing relationships with injury severity and fatality potential (Lenné et al., 2012). For instance, an analysis of fatalities and injuries involving mining equipment found off-road haulage to be a major factor in fatal injuries (Groves, Kecojevic, & Komljenovic, 2007). A similar analysis examined equipment-related fatal accidents and identified that interactions with trucks, conveyors and front-end-loaders accounted for 40% of worker fatalities in US mining operations between 1995-2005 (Kecojevic, Komljenovic, Groves, & Radomsky, 2007). Overhead powerlines have also been identified as a major causal factor in fatal electrical accidents (Cawley, 2003), suggesting design of the work environment also plays a role in the potential for exposure to fatal injury.

While identifying factors that contribute to incidents is important, it is also important to identify and understand factors that act as preventative safety measures. For example, existing research highlights safety culture and other organisational influences as important in determining positive safety outcomes (Alper & Karsh, 2009; Lenné et al., 2012; Paul & Maiti, 2008). The implications of such are twofold; first, in line with a systems perspective, this research points to factors which exist across mining systems that have the capacity to influence safe performance. Second, this research implies a need to focus on identifying positive performance shaping factors that support and maintain safe functioning (Hollnagel, 2014), rather than purely focusing on factors associated with failure.

Safety leadership is acknowledged as the critical link between the safety of individuals and teams at an operational level, and the overall safety of complex organisational systems (Griffin & Talati, 2014). With an established ability to influence performance and outcomes in a positive way, it represents a key concept that demands further examination specifically in a mining context. In other high-risk industries (e.g., nuclear power generation, manufacturing and oil and gas, etc.), safety leadership has been linked to improvements in compliance, communications and reductions in incidents and injuries (de Koster, Stam, & Balk, 2011; de Souza Costa Neves Cavazotte, Pereira Duarte, & Calvão Gobbo, 2013; Eid et al., 2004; Martinez-Corcoles, Schobel, Gracia, Tomas, & Peiro, 2012). However, safety leadership in mining has received less attention (Du & Sun, 2012; Du & Zhao, 2011). There exists a clear imperative to seek improvements in safety performance within the industry, and an associated inherent need to identify positive performance characteristics that can assist in that regard. The mining industry therefore presents as a key domain on which to focus research efforts. Moreover, moving beyond conventional approaches (Clarke, 2013) to explore and describe the influence of safety leadership on safety represents an opportunity to progress existing theory and practice. Importantly, it also provides an opportunity to enhance safety leadership by helping to understanding and optimising the systems around it.

1.3 Overall aim and research questions

Safety leadership is recognised as a key safety-related concept that necessitates exploration in the mining context. Without an understanding of the factors and interrelationships that underpin safety leadership across a mining work system, practical applications designed to support or enhance appropriate and effective safety leadership are unlikely to succeed. Thus, a significant research gap exists, which prevents understanding of the true capabilities of safety leadership in supporting and enhancing safety within the industry. Accordingly, the overall aim of this research was:

To examine safety leadership from a systems perspective, in order to establish how mining work systems can best enhance the likelihood of appropriate and effective safety leadership to support safe performance.

To achieve this aim, the following research questions have been addressed within this thesis:

RQ 1: Has safety leadership been conceptualised and analysed from a systems perspective and, if not, is this perspective appropriate?

RQ 2: Can the application of a systems perspective expand understanding of safety leadership within a complex socio-technical mining system?

RQ 3: What factors influence safety leadership within a complex socio-technical mining system and how do these factors interact?

RQ 4: Can systems-based ergonomics methods be used to develop a useful model of safety leadership?

RQ 5: How can organisations in the mining industry support appropriate and effective safety leadership?

1.4 Methods and approaches

An overview of the key research activities, research question and associated methods to be applied throughout this thesis is presented in Figure 1.

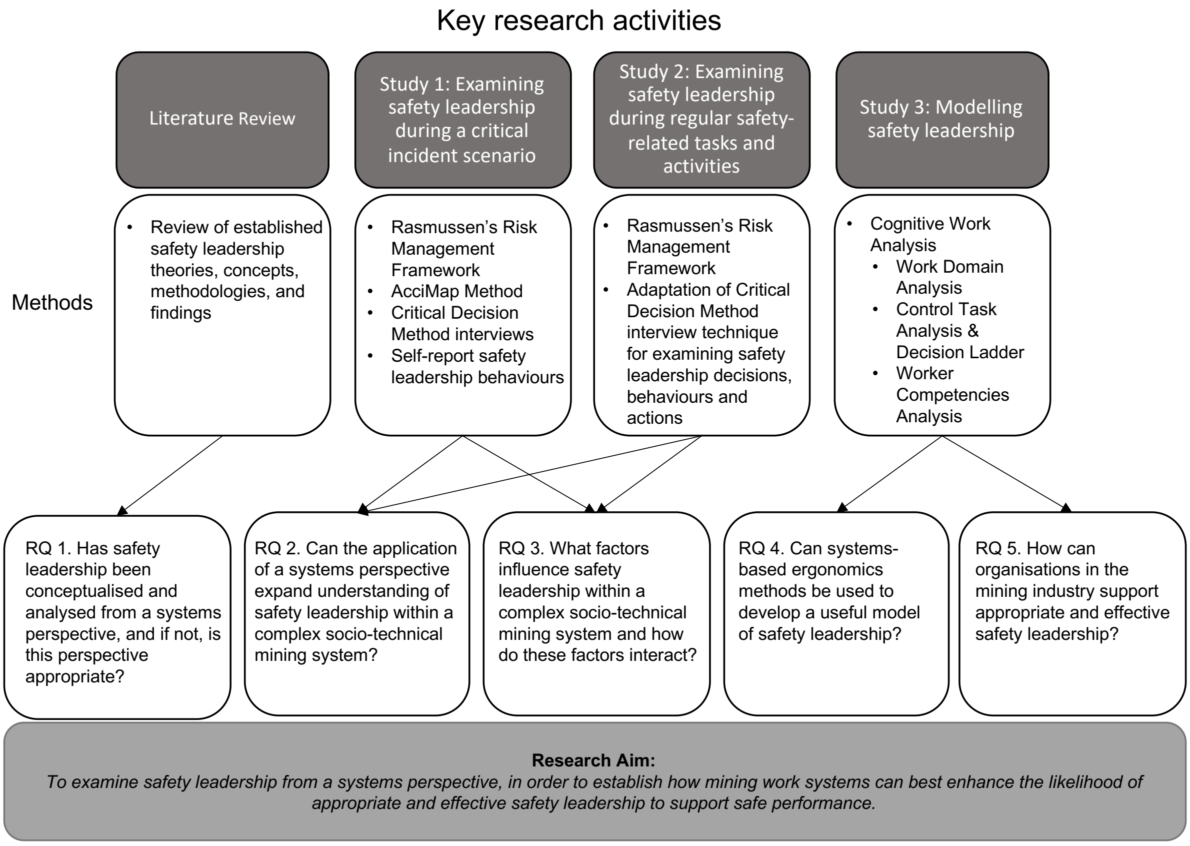

Figure 1 Literature review, key research activities, methods and questions answered

1.5 Structure of the thesis

In order to provide a logical sequence and progression towards achievement of the stated aim and answering the research questions, the thesis is structured as follows:

Chapter 1 - Introduction

The current chapter introduces the research topic, provides background to the research and outlines the need for improved understanding of safety leadership. The domain of application is also introduced, the aims and research questions are presented, and sets out the structure of the thesis to come.

Chapter 2 - Review of the safety leadership literature

Chapter 2 presents the findings from a review of the literature on safety leadership. It describes what is currently known about safety leadership, the links between different leadership styles and behaviours, and their respective influence on safe performance and outcomes. Chapter 2 also identifies gaps in the current knowledge base and the extent to which safety leadership has been examined from a systems perspective. An improved definition of safety leadership is proposed that reflects an integrated and systems-based underpinning.

Chapter 3 – Review and selection of a systems-thinking methodology for studying safety leadership

Chapter 3 presents the findings from a review of various systems-thinking frameworks, models and methods to determine their potential suitability to examine safety leadership, and subsequently sets out a methodology for studying safety leadership from a systems perspective.

Chapter 4 – Evaluating the suitability of Rasmussen's Risk Management Framework, AcciMap Method and the Critical Decision Method for examining safety leadership

This chapter presents the first set of findings from Study 1 that involved the application of three of the frameworks and methods identified in Chapter 3 to study safety leadership. Rasmussen's RMF (Rasmussen, 1997), the AcciMap Method (Rasmussen, 1997) and the CDM (Klein, Calderwood, & MacGregor, 1989) are applied to examine safety leadership during a mining critical incident scenario. This chapter describes the utility of examining safety leadership from a systems perspective and found safety leadership met Rasmussen's tenets for systems phenomena.

Chapter 5 – Examining safety leadership decisions, behaviours and actions during a critical incident scenario

Chapter 5 describes a further set of findings derived from Study 1 in which Rasmussen's RMF, AcciMap Method and the CDM were applied in conjunction with a self-reporting approach to identifying effective safety leadership behaviours during the same critical incident. This chapter identifies the factors that influenced safety leadership decisions, behaviours and actions across the work system to maintain safety during the incident. Chapter 5 also highlights a need to extend the CDM to support examination of leadership behaviour in association with decision-making. It also describes the need for further in-depth qualitative research to understand the factors that influence safety leadership under normal operational conditions.

Chapter 6 – Developing a methodological extension of the Critical Decision Method to support improved identification of effective safety leadership behaviours

The previous chapter identified a need to extend the CDM to better support examination of the behavioural component of safety leadership. Chapter 6 describes the development of an extension to the CDM to support improved examination of safety leadership behaviour as associated with decision-making across a mining work system. The methodological extension is developed for integration into a standard CDM interview to improve understanding of the relationship between safety leadership decision-making and behaviour as an integrated concept. This chapter outlines pilot testing and refinement of the extended method ahead of its application in Chapter 7 to examine safety leadership decisions, behaviours and actions during regular safety-related tasks that support every day safe functioning.

Chapter 7 – Examining safety leadership decision-making and behaviour during regular safety-related tasks

Chapter 7 describes Study 2, which involved the application of the modified CDM described in Chapter 6. This modified CDM was used to examine safety leadership during regular safety-related tasks in a mining work system under normal operating conditions. The findings highlight the need to consolidate the findings and factors identified in Studies 1 and 2 and proposes the use of Cognitive Work Analysis (CWA) to achieve this aim, to support movement towards the design of strategies to enhance effective safety leadership across mining work systems.

Chapter 8 – Applying Cognitive Work Analysis to develop a model of safety leadership to support the development of strategies to enhance performance

Chapter 8 describes Study 3 in which three phases of CWA are applied to develop a model of safety leadership (Work Domain Analysis; WDA), conduct a Control Task Analysis (CTA) and Worker Competencies Analysis (WCA) to identify the core safety leadership Skills, Rules and Knowledge (SRK)-based behaviours required across the work system to support safe performance. The findings highlight the need to develop a systems-based competency framework that defines the core safety leadership competencies required across each level of the work system, which can be developed in leaders to support safe system functioning.

Chapter 9 – Development of a systems-based competency framework for effective safety leadership development

Chapter 9 introduces a systems-based competency framework for safety leadership development across mining work systems. The framework aligns with Rasmussen's RMF and provides a consolidated perspective of the identified factors and attributes that influence and interact with safety leadership to support safe performance. The framework defines five core competencies, with underpinning behavioural indicators indicative of effective safety leadership practices required across the work system to support safe and successful performance.

Chapter 10 – Discussion, recommendations and conclusions

In the final chapter, the theoretical, methodological and practical implications of the research are discussed. A set of outcome recommendations are presented, which provide the basis for targeted improvements in safety leadership in line with the principles of the systems-based theory applied, and the optimisation strategies presented in Chapter 8. Implications for practical implementation within the mining industry are discussed and avenues for further research are recommended.

2 Review of the safety leadership literature

Donovan, S.-L., Salmon, P. M., & Lenné, M. G. (2016) Leading with style: a literature review of the influence of safety leadership on performance and outcomes. *Theoretical Issues in Ergonomics Science*, 17:4, 423-442.

2.1 Introduction

This chapter presents the results of a review of the literature that aimed to determine what is known regarding the influence of safety leadership on performance and outcomes in high-risk industries. The review was conducted to identify; the current knowledge state regarding safety leadership; the links between different leadership styles and behaviours and their influence on performance and outcomes; where gaps exist in the current knowledge base, and; to determine the extent to which a systems perspective has been previously applied to examine safety leadership. A systems perspective is widely acknowledged as the dominant safety paradigm however, it is not clear this perspective has translated to underpin research examining safety leadership.

This chapter reviews how safety leadership has been conceptualised, how it is considered to influence safety performance and outcomes, and how (if at all) it relates to other factors, addressing Research Question 1:

> RQ 1: Has safety leadership been conceptualised and analysed from a systems perspective and, if not, is this perspective appropriate?

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Leading with style: a literature review of the influence of safety leadership on performance and outcomes

Sarah-Louise Donovan[a], Paul M. Salmon[b] and Michael G. Lenné[c]

[a]Monash University Accident Research Centre, Monash University, Clayton, Australia; [b]The Centre for Human Factors and Sociotechnical Systems, Faculty of Arts and Business, University of the Sunshine Coast, Maroochydore, Australia; [c]Monash University Accident Research Centre, Monash University, Clayton, Australia

ABSTRACT

Leadership is increasingly being recognised as a key factor in supporting performance across a range of domains. Over the past two decades, a body of research has emerged with a focus on examining different safety leadership styles, with general support established for a positive influence on a range of performance and outcome variables. Despite this, findings to date can be considered limited, with the concepts and methodologies applied limiting advancement in understanding. This article aims to review the literature targeting the influence of safety leadership on performance and outcomes in high-risk industries to determine the extent to which systems-thinking is evident. The review identifies a number of limitations relating to current methodological and conceptual approaches used, highlighting considerable gaps in understanding within the current knowledge base. In conclusion, the application of systems-thinking is proposed to support both methodological and conceptual advancement of the study of safety leadership in high-risk industries.

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Support is growing for the positive contribution safety leadership plays in supporting safe performance, and the prevention of incidents and injuries in high-risk industries. However, the present article contends that limitations associated with current popular methodological approaches for examining safety leadership may prevent a full understanding of safety leadership, the factors underpinning it, and how it interacts with other behaviours. Current research points towards a lack of systems-thinking not only in relation to safety leadership methods, but also the corresponding theory and the concepts studied. As such, how safety leadership emerges and supports safety and risk management across work systems may not yet be fully understood. A systems approach is proposed, which will provide a new framework through which to study and examine safety leadership, which will in turn lead to new research, and corresponding implications for practice.

1. Introduction

Leadership is increasingly being recognised as a key factor in supporting successful performance across a range of domains (Carmeli and Schaubroeck 2006; O'Dea and Flin 2001).

CONTACT Sarah-Louise Donovan sarah-louise.donovan@monash.edu

Defined as a process of social influence in which a person can enlist the aid and support of others in the accomplishment of a common goal (Chemers 1997), the characteristics that underlie different approaches to leadership manifest as both broad and varied. As such, corresponding theory and research has expanded over the past two decades, with the examination of different styles and attributes as linked to the achievement of a variety of desirable performance and outcome measures emerging as a key area of focus (e.g., Vecchio, Justin, and Pearce 2010, Reid et al. 2014).

With this in mind, understanding the influence leadership has on performance and outcomes becomes particularly important when considered within the context of safety. With support growing for the positive contribution leadership plays in supporting safety performance and the prevention of incidents and injuries (Mullen and Kelloway 2009; Zohar 2002), understanding and characterising this contribution offers some important opportunities to enhance the traditional component approaches to safety and risk management (Dekker 2011).

In line with this, a body of research has emerged with a focus on understanding how different styles of leadership influence safety performance and outcomes in high-risk industries. Considered high risk due to the potential for either major accidents or smaller scale incidents and occupational accidents (Grote 2012), to date, much of the research in this area has been applied within the manufacturing and construction industries (Conchie 2013; Flin and Yule 2004; Hofmann and Morgeson 1999; Michael et al. 2006; Zohar 2002). General support has been established for different leadership styles as having a measurable influence on a range of safety performance and outcome variables (Christian et al. 2009; Nahrgang, Morgeson, and Hofmann 2011; Zohar and Tenne-Gazit 2008). For example, the literature points to links between Transformational and Transactional Leadership, and follower safety participation and compliance (Akselsson et al. 2012; Clarke and Ward 2006; Lu and Yang 2010). Furthermore, links have also been established for Authentic Leadership (AL) and Empowering Leadership (EL) practices as influencing those same variables (de Souza Costa Neves Cavazotte, Pereira Duarte, and Calvão Gobbo 2013; Martínez-Córcoles et al. 2011). The aforementioned leadership styles have also demonstrated positive links with safety climate (Hystad, Bartone, and Eid 2013; Martínez-Córcoles et al. 2011; Zohar 2002), with a Leader−Member Exchange (LMX) relationship and style also identified as providing a positive influence (Yagil and Luria 2010).

While these findings provide some insight into the role different leadership styles play in supporting improvements in safety, they also raise some questions regarding the current state of knowledge surrounding safety leadership in high-risk industries. Currently, there appears to be little consensus regarding what styles of leadership are most influential, with the degree of overlap in findings suggesting convergence of styles, rather than different styles representing discrete and separate constructs within the context of safety. In addition, research has not yet reached a conclusive standpoint regarding the definition of performance and outcome variables within the safety context. Some clarification has been provided in terms of conceptualising performance as a metric for safety-related behaviours (Christian et al. 2009; Neal and Griffin 2006), and outcomes as tangible events or results (Zohar 2002) however, the terms and concepts are still used interchangeably within the existing literature. This has important implications for safety leadership research in terms of conceptualisation and measurement of its influence, particularly with regard to understanding its contribution as a preventative safety element and potential lead performance indicator.

Perhaps most significantly however, research to date has tended to largely focus on the influence of leadership at the 'sharp end' (i.e., worker and frontline-supervisory level), with limited exploration within the context of the broader organisational (e.g., Zohar and Luria 2005), or work system as a whole. Furthermore, these relationships have largely been examined through the use of surveys and questionnaires as the predominant data capture method, with minimal exploration of additional factors and elements across organisational systems (i.e., procedures, policies, systems and processes) that may also provide important influence. Moreover, these approaches further restrict understanding of how different leadership styles at different levels within an organisational and work system shape desirable performance and outcomes; an important emerging piece of the puzzle (Carmeli and Schaubroeck 2006; Reid et al. 2014). These are considered significant limitations. Over the past two decades, the safety science research has seen an important shift to a systems approach when considering safety and safety management (Rasmussen 1997). In doing so, there is now widespread acceptance that safety and safety compromising incidents are emergent properties of the overall system of work (e.g., Jenkins et al. 2008; Leveson et al. 2009; Naikar 2006; Rasmussen 1997; Stanton 2014; Underwood and Waterson 2013; Underwood and Waterson 2014), that is accidents are caused by the decisions, behaviours and actions of actors across all levels of the work system, up to and including regulatory bodies and government. By extension, the decisions, behaviours and actions that characterise safety leadership thus become important emergent properties in the prevention of incidents and injuries, the influence of which should be considered within the context of the wider work system as whole, and not just contained to within an organisational system.

It is contended, therefore, that limitations associated with popular methodological approaches for examining safety leadership may prevent a full understanding of safety leadership, the factors underpinning it, and how it interacts with other behaviours. Current research points towards a lack of systems-thinking not only in relation to safety leadership methods, but also the corresponding theory and the concepts studied. As such, how safety leadership emerges and supports safety and risk management may not yet be fully understood.

The aim of the current article was thus to critically review the literature targeting the influence of safety leadership on performance and outcomes in high-risk industries to determine the extent to which systems-thinking is evident within the literature. A concurrent aim was to provide a way forward for methodological and conceptual advancement regarding the study of safety leadership. The review identified limitations regarding the current body of knowledge relating to the conceptualisation and measurement of safety leadership, safety performance and outcome variables, the current approach to methodological design, and the resulting impact on the applicability of findings. Future directions related to safety leadership are then discussed, with a new conceptual and methodological position proposed.

2. Methodology

Electronic library catalogue systems were searched including PsycINFO, Social Science Citation Index, OneFile, Scopus, ScienceDirect, SafetyLit, IngentaConnect, MedLine and Wiley

Online Library. An initial considerable list of search terms were used which included: 'safety leadership, 'leadership', 'style', 'safety', 'systems-thinking', 'systems-approach, 'systems', 'performance' and 'outcome', with the subject filter of 'safety' being applied. The list of search terms was subsequently refined with 'systems-thinking', 'systems-approach' and 'systems' removed which yielded the greatest number of hits. The search was refined further to focus on articles published in English between January 1993 and December 2013, and yielded 267 total hits. The title, abstract and keywords for each article were then screened, with the following eligibility criteria applied to permit inclusion in the final list for review. First, articles that did not focus on high-risk industries were excluded. As such, articles outlining research in the education, financial or food safety sectors were excluded from the list as they did not meet the definition of a high-risk industry (Grote 2012) applied for this review. Second, articles had to demonstrate original research, either qualitative, quantitative, theoretical or methodological in nature, thus excluding items such as book reviews, technical reports, letters and editorials as they were not considered practical for inclusion in the current review. Finally, safety leadership needed to be the key focus of the research, and not a secondary variable of interest. Review of the full text articles was then undertaken and articles that failed one or more of the selection criteria were rejected. The process identified thirty-five articles. Data was extracted from the thirty-five articles relating to the leadership style examined, the key findings in relation to the performance and outcome variables measured, and the methodological design adopted.

A critical review of the articles is presented in Section 3. The review presents the findings in relation to the examination of leadership style, conceptual performance and outcome variables measured, and the focus of methodological design.

3. Review findings

3.1. Safety leadership styles

Five prominent leadership styles emerged as studied within the context of safety as having a positive influence safety performance and outcomes, specifically Transformational Leadership (TRFL), Transactional Leadership (TRSL), LMX, EL and AL. Each style is defined and characterised within the literature as having a range of dimensions, attributes and underpinning behaviours, based on a mix of social-exchange focused interactions, person and task-focused interactions, as well as neo-charismatic-based and follower-centric interactions (Arnold et al. 2000; Burns 1978; Graen, and Uhl-Bien 1995; Walumbwa et al. 2008).

Figure 1 provides an overview of the key attributes and behaviours underpinning each of the five leadership styles identified within the review (adapted from Arnold et al. 2000; Avolio, Bass, and Jung 1999; Graen and Uhl-Bien 1995; Barling, Loughlin, and Kelloway 2002).

Twenty studies reviewed (57.1%) focused on examining TRFL and TRSL (Akselsson et al. 2012; Bahn 2013; Clarke 2013; Clarke and Ward 2006; Conchie 2013; Conchie and Donald 2009; Conchie, Taylor, and Donald 2012; Conchie, Moon, and Duncan 2013; Dahl and Olsen 2013; Du and Sun 2012; Hoffmeister et al. 2013; Kapp 2011; de Koster, Stam, and Balk 2011; Lu and Yang 2010; Noruzy et al. 2013; Wu et al. 2011; Zahari and Shurbagi 2012; Zohar 2002; Zohar and Tenne-Gazit 2008; Zohar and Luria 2010), with 11 of those studies (31.4%) conducted within the manufacturing and construction industries. Of the remaining studies, a comparatively lesser number examined LMX (Credo et al. 2010; Hofmann and

Transformational Leadership	**Idealised Influence:** Leader demonstrates determination to maintain a safe working environment, and behaves in a way that displays commitment to a safe work place. **Inspirational Motivation:** Leader talks about his/ her values and beliefs of the importance of safety, providing continuous encouragement to others to do their jobs safely. **Intellectual Stimulation:** Leader suggests new ways of doing tasks more safely, and encourages team members to express ideas and opinions about safety at work. **Individualised Consideration:** Leader listens to individual concerns about safety on the job and actively spends time demonstrating to team members the safest way to complete tasks.
Transactional Leadership	**Contingent Reward:** Leader expresses satisfaction when team members perform jobs safely and ensures that appropriate recognition is received for achieving safety targets. **Management by Exception:** Leader only intervenes to provide corrective direction when team members do not meet acceptable performance levels.
Leader-Member Exchange	**Trust:** Leader develops effective working relationships with team members, recognising and developing followers' potential. Leader demonstrates confidence in team members' capabilities. **Obligation:** Leader demonstrates understanding of team members job problems and needs, and uses their power positively to help followers solve problems in their work. **Respect:** Leader demonstrates satisfaction with team members so they 'know where they stand'.
Empowering Leadership	**Leading by Example:** Leader sets high performance standards and a good example by the way he/ she behaves. **Participative Decision Making:** Leader encourages team members to express ideas and suggestions, giving all followers the chance to voice their opinions. Leader listens to suggestions and ideas and uses them to inform decisions that affect the work group. **Coaching:** Leader fosters collaboration between team members, encourages exchange of information, and group problem solving. Leader suggests ways to improve team performance and praises teams when they perform well. **Informing:** Leader explains company decisions and goals, and how the team fits into the company. Leader clearly explains own decisions and actions, and rules and expectations to the work group. **Showing Concern/ Interacting with the Team:** Leader takes the time to discuss team members' concerns patiently, and shows concerns for members well-being. Leader treats team members with honesty and fairness.
Authentic Leadership	**Self-Awareness:** Leader seeks feedback to improve their interactions with others and demonstrates ability to accurately describe how others view his/ her capabilities. **Relational Transparency:** Leader says exactly what he/ she means and is willing to admit mistakes when made. **Internalised Moral Perspective:** Leader demonstrates beliefs that are consistent with actions and makes decisions based on his/ her core beliefs. **Balanced Processing:** Leader solicits views that challenge his/ her deeply held positions and carefully listens to different points of view before coming to conclusions.

Figure 1. Attributes and behaviours of leadership styles identified.

Morgeson 1999; Kath, Marks, and Ranney 2010; Luria and Morag 2011; Michael et al. 2006; Yagil and Luria 2010), EL (Hechanova-Alampay and Beehr 2001; Martínez-Córcoles et al. 2011; Martínez-Córcoles et al. 2012a, Martínez-Córcoles et al. 2012b; Torner 2011) and AL (de Souza Costa Neves Cavazotte, Pereira Duarte, and Calvão Gobbo 2013; Eid et al. 2012; Hystad, Bartone, and Eid 2013; Nielsen et al. 2013) across a range of industries (e.g., process industry, nuclear power generation and rail). Notably, the review only revealed one study to be conducted in the mining sector, with no research identified in the aviation sector.

The majority focus on examining TRFL and TRSL within the literature reviewed is considered a notable limitation to advancing understanding. Restricting the research to focus largely on these two leadership styles neglects consideration of potential additional leadership styles (Dinh et al. 2014; Dionne et al. 2014) which may yield greater insight and stronger links between leadership style and improved performance and outcomes. Furthermore, in comparing the underpinning behaviours and attributes of each leadership style examined, it becomes evident that considerable overlap exists. While each style is cited as measuring empirically distinct constructs, the similarities evident between behaviours and attributes raises important questions regarding convergence of leadership styles within the context of safety. For example, the EL model shows considerable overlap with TRFL across a number of dimensions, with the EL dimension *Leading by Example* demonstrating similarity with that of TRFLs *Idealized Influence*. Further questions emerge regarding empirical distinction when reviewing the AL literature (Walumbwa et al. 2008). A high degree of overlap with TRFL is acknowledged (Eid et al. 2012), with AL also emphasising personal and social identification processes (Avolio et al. 2004; Gardner et al. 2005; Walumbwa, et al. 2010), thus providing evidence of further overlap with the core underpinnings of the LMX theory.

The limited leadership styles researched, coupled with the high degree of overlap in behavioural attributes between styles raises an important question regarding whether these leadership styles are in fact conceptually distinct. Further examination of the behaviours and attributes that underpin the individual styles is required to determine whether each is indeed comprised of separate and distinct constructs, as measurable within the context of safety.

3.2. Influence of leadership on safety performance and outcomes

Seventy-two performance and outcome variables were extracted from the studies reviewed. Of that, the five leadership styles were reported to have a positive influence over forty-five variables, with safety climate emerging as the most frequently studied variable across all leadership styles ($n = 12$ studies). Safety compliance ($n = 7$ studies) and safety participation ($n = 6$ studies) also emerged as prominent. The remaining variables identified comprised a disparate mix of both individual and group performance variables, which reflected a seemingly arbitrary approach to the selection of variable of interest.

The following section presents the findings of the review in terms of leadership style and reported links with the performance and outcome variables identified.

3.2.1. Transformational and transactional leadership

TRFL and TRSL were the most frequently researched leadership styles, with TRSL practices only researched in conjunction with TRFL, and not in isolation. Figure 2 provides an overview of the positive links identified between TRFL, TRSL and a range of performance and outcome variables. Safety climate emerged as the most frequently studied variable ($n = 8$ studies) for both leadership styles, with safety participation and safety compliance also emerging as prominent ($n = 3$ studies).

The review identified TRFL practices to demonstrate positive links over a range of variables, for example, trust (Conchie 2013; Conchie and Donald 2009; Conchie, Taylor, and Donald 2012), as well as safety compliance and participation (Clarke and Ward 2006; Dahl and Olsen 2013; Lu and Yang 2010). TRFL and TRSL practices were also positively linked to wider contextual factors such as organisational culture (Zahari and Shurbagi 2012), innovation and performance (Noruzy et al. 2013).

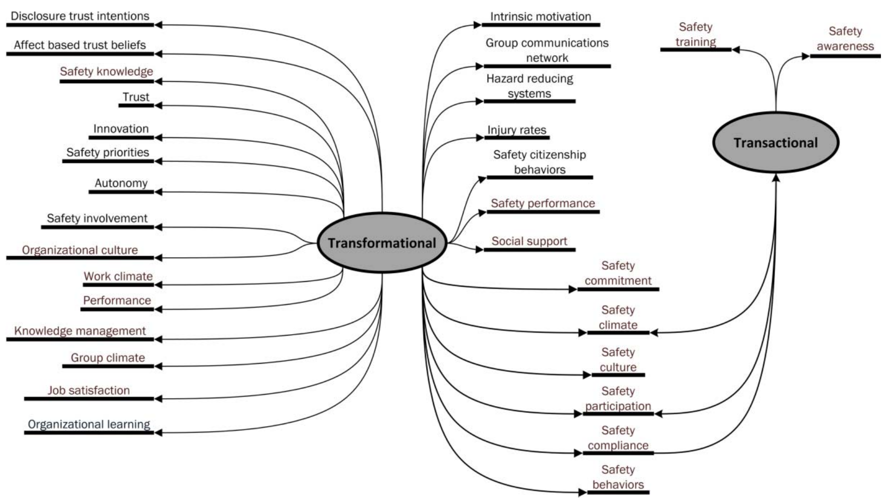

Figure 2. Overview of TRFL and TRSL influence on safety performance and outcome variables.

A prominent focus of the literature is the link between leadership style and safety climate. A product of organisational interactions, safety culture is shaped by people in the structures and social relations within and outside an organisation, giving rise to shared values, attitudes and behaviours related to safety (Richter and Koch 2004). Safety climate, by comparison, is a temporal state measure of safety culture, and refers to the perceived state of safety at a particular place, at a particular time. A range of studies reviewed revealed TRFL and TRSL practices as positively influencing safety climate (e.g., Clarke 2013; de Koster, Stam, and Balk 2011; Du and Sun 2012; Kapp 2011; Wu et al. 2011; Zohar 2002), however, these findings are also considered limited. The links reported are judged to be tenuous, as no standard approach or questionnaire was used to measure TRFL and TRSL, nor safety climate across the studies reviewed, rather a range of instruments were adopted. As such, the variability in instruments used and underlying concepts measured calls into question the strength of the links identified. It is thus contended measuring the influence of TRFL and TRSL on safety climate provides little benefit in defining a tangible contribution these leadership styles play in supporting improved climate.

While the findings reviewed provide general support for TRFL and TRSL practices as having a positive influence on safety, they are considered limited for a number of reasons. First, the disparate nature of the performance and outcome variables studied raises questions regarding the strength of each of the identified links. The literature suggests an arbitrary approach has been taken towards the identification of the individual and performance and outcome variables examined. As such, a conclusive position regarding the influence of TRFL and TRSL practices on the range of variables studied cannot be reliably inferred.

Importantly, the TRFL and TRSL research to date has overlooked integration of important systems-thinking concepts such as vertical integration. Integrating systems-thinking concepts would not only bring safety leadership research in line with contemporary safety research, applying such concepts may provide greater insight into the range of factors within the work system as a whole that influence performance, and thus provide improved understanding of how TRFL and TRSL positively contribute to safety.

3.2.2. Leader–Member Exchange

Six studies reviewed reported a positive relationship between LMX and a range of variables, with Figure 3 providing an overview of the links identified.

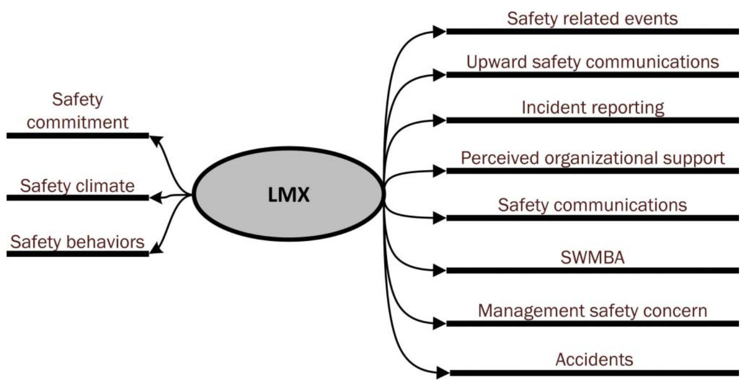

Figure 3. Overview of LMX influence on safety performance and outcome variables.

General support was established for the premise of higher quality LMX relationships as having a positive influence on performance and outcomes. Higher quality LMX relationships were shown to have a positive influence on safety communications and commitment (Hofmann and Morgeson 1999), whilst reducing accidents and safety related events (Michael et al. 2006). Moreover, the role of wider contextual variables such as perceived organisational support and ethics were shown to influence the relationship between LMX and individual employees' safety knowledge and behaviours (Credo et al. 2010; Luria and Morag 2011).

Similarly to that of TRFL and TRSL, LMX was also positively linked to safety climate, with Kath, Marks, and Ranney (2010) investigating specific facets of safety climate most predictive of employees' willingness to engage in upward safety communication (Kath, Marks, and Ranney 2010). In doing do, findings replicated Hofmann and Morgeson's (1999) finding that higher quality LMXs are positively linked to safety communications.

While the LMX research suggests some support for this leadership style in facilitating improved communications and commitment, similarly to the TRFL and TRSL literature, the reported links are considered limited as the concepts measured were highly variable in application. The measures employed varied across studies, thus the strength of the reported links is questionable, and the corresponding nature of the influence of LMX, unclear.

3.2.3. Empowering Leadership

EL was also found to have a positive influence with Figure 4 providing an overview of the linkages reported. Safety participation emerged as the most frequently studied variable ($n = 2$ studies).

Similarly to that of TRFL and TRSL, EL has been linked to safety participation and compliance, thus raising questions regarding the strength of each relationship and also, the separation of each leadership style in measuring these performance variables. In 2012, Martínez-Córcoles et al. (2012a) linked EL to safety participation and compliance, and reducing risky behaviours (Martínez-Córcoles et al. 2012a). In a separate study, Martínez-Córcoles et al. (2012b) also found a relationship between EL and safety participation, however, this was identified as being mediated by collaborative team learning. This finding provided a level of contradiction with previous findings given that the population sample was judged to be the same for both studies. In addition, the relationship between EL and collaborative team learning was partially mediated by the promotion of dialogue and open communication (Martínez-Córcoles et al. 2012b).

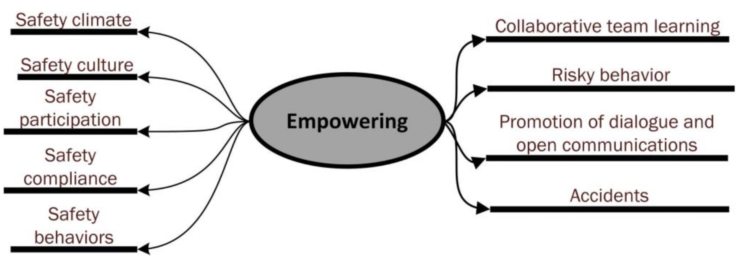

Figure 4. Overview of EL influence on safety performance and outcome variables.

Two articles reviewed explored EL with regard to influencing safety climate and culture. Torner (2011) reviewed research on organisational psychological concepts found to contribute to organisational performance and suggested an EL style may promote an enhanced safety climate (Torner 2011). More recently, Martínez-Córcoles, et al. (2011) found an empirical link with EL behaviours generating higher safety climate among employees when the safety culture was strong, which in turn predicted employee safety behaviours (Martínez-Córcoles et al. 2011). These findings further contribute to the lack of clarity around which leadership style is considered most effective in influencing safety climate.

3.2.4. Authentic Leadership

Research relating to AL is in its infancy, with only four studies identified and included in the review. Figure 5 provides an overview of the performance and outcome variables examined, with safety climate again emerging as the most frequently studied variable.

In 2012, Eid et al. (2012) proposed a theoretical model linking safety climate and the subsequent performance variables of participation and compliance, however did not specifically explore the nature of the link. Moreover, while Nielsen et al. (2013) established a direct negative relationship between AL and risk perception, this relationship was studied in isolation (Nielsen et al. 2013).

More recently, an empirical link was established supporting a positive relationship between AL and safety participation, compliance, and perception of justice (de Souza Costa Neves Cavazotte, Pereira Duarte, and Calvão Gobbo 2013). The findings from this study are important as they are comparable to those outlined relating to TRFL, TRSL, EL and safety compliance and participation. Using the same questionnaire to measure safety participation and compliance for all studies (Neal and Griffin 2006), AL, TRFL, TRSL and EL practices were all shown to have a positive influence. This agreement between findings suggests further research is required in order to establish whether each leadership style is comprised of the same or empirically distinct constructs, or, which style is considered the most beneficial in regard to influencing participation and compliance.

A positive relationship has also been established between AL and safety climate (Eid et al. 2012; Hystad, Bartone, and Eid 2013; Nielsen et al. 2013). Eid et al. (2012) proposed a theoretical model linking AL to safety climate, which was subsequently empirically tested by Hystad, Bartone, and Eid (2013) and Nielsen et al. (2013). A positive relationship was identified (Hystad, Bartone, and Eid 2013; Nielsen et al. 2013), as well as an indirect effect via psychological capital (Eid et al. 2012; Hystad, Bartone, and Eid 2013). Additionally, Hystad, Bartone, and Eid (2013) established a negative relationship between

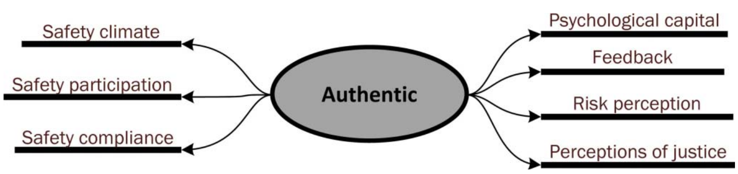

Figure 5. Overview of AL influence on safety performance and outcome variables.

AL and individual risk perception, while consistent with Nielsen et al. (2013), also suggesting safety climate displays a mediating role.

The findings from this group of studies add to the mounting concern regarding the significant overlap in findings identified across each leadership style examined. Further, the limited number of studies tend to focus on variables at the individual or team level, demonstrating a clear lack of inclusion of important safety related concepts, such as systems-thinking, to help understand systemic influences that may come into play when considering safety leadership.

3.2.5. Consolidated findings

Figure 6 provides an overview of the thirty-five studies reviewed, and the positive linkages reported in the literature reviewed between each leadership style and the performance and outcome variables measured. TRFL was the most frequently studied leadership style, with safety climate identified as the most prominently studied variable across all leadership styles. The leadership styles of TRSL, LMX, EL and AL were studied to a lesser degree, with positive influences reported over a comparatively fewer number of performance and outcome variables.

Figure 6 demonstrates the disparate approach taken to researching the influence of safety leadership on performance and outcomes within high-risk industries to date. While the leadership styles examined provide support for a positive influence over the range of concepts and variables studied, the arbitrary nature of the variables selected, and their resulting impact in terms of tangible improvements in safety, is highly questionable.

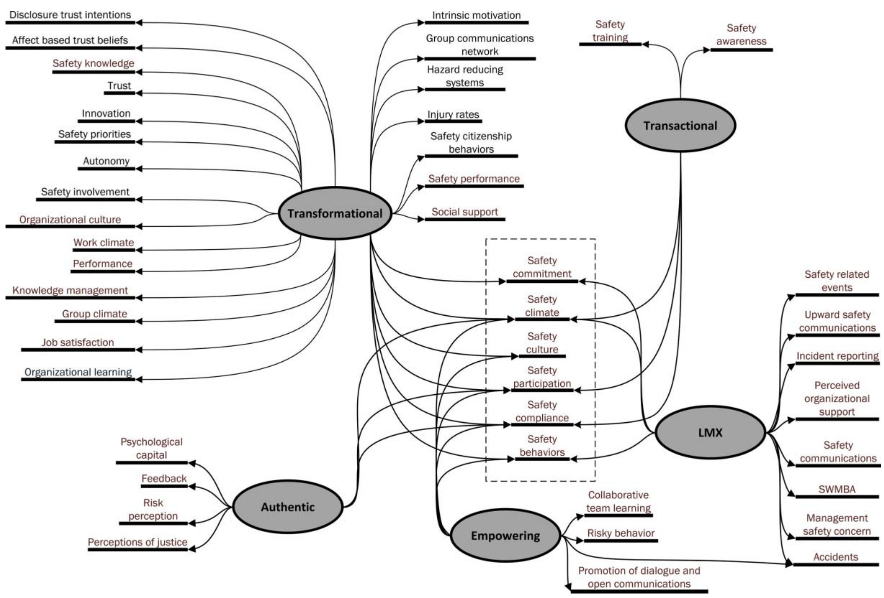

Figure 6. Consolidated overview of linkages between leadership style and safety performance and outcome variables.

Furthermore, the ill-defined nature of many of the variables studied, such as 'perceptions of justice' and 'autonomy', make definitive and enduring relationships hard to establish.

The considerable overlap in findings is concerning, with common influence identified the variables of; safety behaviours, safety commitment, safety participation, safety compliance, safety climate and safety culture. While not unsurprising given the overlap between attributes and behaviours of each leadership style, the concern surrounding these findings is compounded when considering the robustness of the variables studied as actual and definitive measures of performance or outcomes. With safety climate, safety participation and compliance emerging as the most frequently studied variables, the extent to which these are considered the panacea to safety improvement, and therefore focus of safety leadership research to date, is a considerable limitation. The focus on measuring these variables solely within the organisational context falls short of keeping up with contemporary approaches to studying and understanding safety within complex socio-technical system, such as applying systems-thinking. As such, the link between safety leadership, compliance, participation and climate outside of the organisational context is not well established, with a further lack of understanding of other factors outside of the organisational context that may influence performance and outcomes. As such, the current understanding surrounding the true contribution of safety leadership to improved safety performance and outcomes is considered elementary at best. Furthermore, the only commonality established across the studies examining these variables relates to the measurement instruments for safety participation and safety compliance (Neal and Griffin 2006), with the remaining variables all measured using different scales and instruments. As such, the strength of the identified relationships is questionable, and therefore their gravitas in terms of supporting safety improvement, largely unconvincing.

3.3. Methodological design

A key aspect of the literature reviewed relates to the methodologies used to assess safety leadership and its relationships with performance and outcomes. The review revealed questionnaires and surveys to be the predominant data collection method for both the measurement of safety leadership and also, the performance and outcome variables.

Regarding safety leadership measurement, the majority of studies reviewed (approximately 71%) used of a number of established, and yet also at times, purposely developed questionnaires as the sole data capture technique. Few of the studies reviewed supplemented that approach with supporting or objective data collection techniques, such as focus groups (Conchie, Moon, and Duncan 2013), interviews (Bahn 2013) observational assessments (Luria and Morag 2011; Zohar 2002; Zohar and Luria 2010) or even review and integration of historical safety incident data (Hechanova-Alampay and Beehr 2001; Hofmann and Morgeson 1999; Zohar 2002).

The questionnaires used are not without their flaws, with those used tending to take a 'one up' focus, with the frontline worker-immediate supervisor dyad as the key relationship examined. As such, the findings from approximately 75% of the studies reviewed were based purely on follower ratings of leader behaviours, with a noticeable absence of leader self-rating measures incorporated into the methodological design.

The focus on the frontline worker-supervisor dyad alone is considered a clear limitation, as it neglects to consider the context of the broader organisational and work system as a whole, and the corresponding potential influence different leadership styles at different leader levels may have on safety performance and outcomes. Only four studies examined leader influence at a higher dyad level (Hofmann and Morgeson 1999; Noruzy et al. 2013; Yagil and Luria 2010; Zohar 2002), and even then these studies restricted examination to one leader-follower level. Further, no studies were identified that examined the influence of safety leadership within a regulatory context, or at higher governmental levels.

Similarly, the effectiveness of the data capture methods used to examine performance and outcomes is also open to question. With the exception of the common instruments used to examine safety participation and compliance (Neal and Griffin 2006), the majority of studies opted for a range of both established and purposely constructed questionnaires. The inconsistency in measurement scales used across the variables examined makes meaningful comparison of results problematic, which further compounds the ability to draw definitive conclusions regarding the influence of each leadership style on the variables measured. As such, currently little conclusion can be drawn regarding which styles of leadership are considered most effective in supporting improvement in the performance and outcomes measured.

However, the most significant limitation of the studies reviewed, and a key conclusion of the current review, relates to the lack of systems-thinking methods, approaches and concepts applied to the examination of safety leadership. With systems-thinking now considered the dominant approach to understanding safety and safety management within complex socio-technical systems (e.g., Leveson 2004; Rasmussen 1997), this presents a key gap in knowledge and understanding.

Integrating systems-thinking methods and concepts, for example, by applying Rasmussen's Risk Management Framework (Rasmussen 1997) to the examination of safety leadership, would provide a framework for methodological and conceptual advancement to support improved understanding of the influence of safety leadership across the whole work system. Further, it would facilitate exploration of systems-thinking concepts and variables, such as vertical integration and the distribution of control, which have been demonstrated to support safety. Figure 7 demonstrates provides a diagrammatic representation of the methodological design of the studies reviewed, and demonstrates the lack of application of systems-thinking and examination of the influence of safety leadership across the work system as a whole. This points to a significant gap in understanding the influence of safety leadership across all levels of a work system.

4. Discussion

The aim of the article was to critically review the literature examining the influence of safety leadership on performance and outcomes in high-risk industries to determine the extent to which systems-thinking is evident within the literature. The review identified a number of limitations relating to the methodological and conceptual approaches used to examine safety leadership, and in doing so, highlighted considerable gaps in understanding with the current knowledge base. A way forward for methodological and conceptual advancement regarding the study of safety leadership is proposed.

Five leadership styles were identified as examined with reference to their influence on safety performance and outcomes in high-risk industries; TRFL, TRSL, LMX, EL and AL.

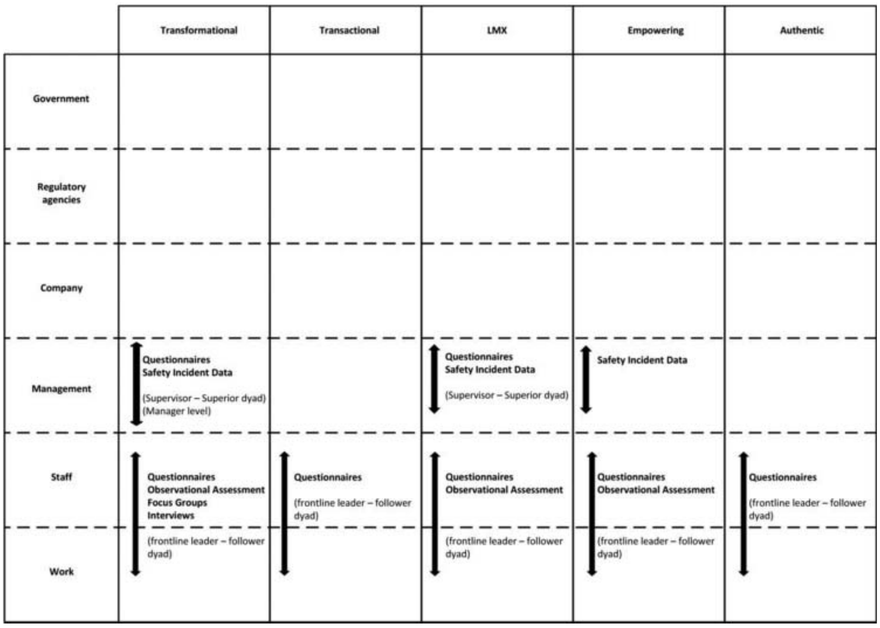

Figure 7. Overview of leadership style, method of assessment and work system level examined mapped on Rasmussen's Risk Management Framework.

In comparing the review findings, it quickly becomes apparent there is significant overlap between the different leadership styles and attributes studied. This raises important questions not only regarding the discrete measurement of each leadership style, but also their specific contribution to the performance and outcome variables measured. Further research is therefore required to determine whether the constructs and attributes of the five leadership styles identified are empirically distinct within the context of safety. Such examination would either clearly establish empirical distinction and thus, insight into what styles and attributes are considered the most influential, or determine whether the leadership styles and attributes examined potentially all contribute to measurement of a higher form of leadership style specific to the context of safety.

In connection with the overlap in leadership attributes, a considerable limitation identified lies in the conceptualisation of the safety performance and safety outcome variables examined. The seemingly arbitrary nature of the variables studied, and their reported impact in terms of tangible improvements in safety, is highly questionable. This becomes concerning when considering the reported influence of multiple leadership styles on the variables of safety behaviours, safety commitment, safety participation, safety compliance, safety climate and safety culture (e.g., Clarke and Ward 2006; de Souza Costa Neves Cavazotte, Pereira Duarte, and Calvão Gobbo 2013; Eid et al. 2012; Hoffmeister et al. 2013; Kapp 2011; Martínez-Córcoles et al. 2012a; Zohar 2002). While an overlap in findings is not surprising given the identified similarities in leadership styles, the concern surrounding these findings is heighted when considering the reported tangible benefits these performance and outcome variables provide to safety improvement. Furthermore, the focus on examining safety climate, safety participation and compliance, and the extent to which these are considered the most important safety related concepts over which safety leadership has an influence, is nothing short of alarming. Such a focus does not reflect incorporation of wider, more robust and tangible safety performance and outcome variables, thus rendering the importance of these findings questionable. In addition, no strong relationship was identified between safety leadership practices and accident causation, which raises further concerns regarding the contribution of the current research base. The focus on measuring these variables as the 'magic bullet' for improvements in safety performance therefore falls far short of keeping up with contemporary approaches to studying and understanding safety within complex socio-technical systems.

A key conclusion of the review relates to the limited methodological approaches used to examine safety leadership and corresponding performance and outcomes variables. The predominant data collection method used was questionnaires, which along with the variability in specific scales used, highlights a significant gap. While it is acknowledged many of the leadership measurement scales used were validated, well established measures (Arnold et al. 2000; Avolio, Bass, and Jung 1999; Barling, Loughlin, and Kelloway 2002; Graen and Uhl-Bien 1995; Walumbwa et al. 2008), they primarily adopted a single-level, one-directional approach in which followers are asked to rate their immediate leader, thus providing a limited level of analysis with regard to potential higher-level influences and safety leadership practices at different levels within a work system (i.e., consideration of high level company influences, as well as potential regulatory and governmental influences).

Significantly, the review also revealed a preference for existing research to view safety leadership as having a mostly proximal, but at times, inconsistent effect on the safety performance and outcomes measured. The majority of studies identified purely examined the relationship between frontline workers and their immediate supervisor or leader. This is considered a clear limitation. It is widely acknowledged that leadership is a complex and multi-faceted construct, yet even so, few studies considered multi-level and more distal influences of leadership on performance and outcomes, for example at the supervisory-managerial level and above (Noruzy et al. 2013; Yagil and Luria 2010; Zohar 2002), while fewer still (Akselsson et al. 2012) integrated more widely used safety-related concepts to examine and understand variables that may influence and interact to impact performance and outcomes at different organisational levels.

In short, research to date fails to look at safety leadership within the context of the broader work system as a whole. This limitation presents as a significant gap in the current body of knowledge. With systems-thinking now considered the dominant approach to understanding safety and safety management within complex socio-technical systems (Leveson 2004; Rasmussen 1997), applying systems-based methodologies and concepts is considered fundamental to advancing understanding of the role safety leadership plays in influencing safety performance and outcomes in high-risk industries.

5. Leading the way?

While the research reviewed does indicate safety leadership is important, the current understanding surrounding its true contribution to improved safety performance and outcomes can be considered elementary at best.

The results of the current review revealed a number of conclusions regarding the current state of knowledge surrounding the influence of safety leadership on performance and outcomes in high-risk industries. The key finding from the current review is that safety leadership has not been examined from a systems perspective. This is the dominant approach to accident causation, and is emerging strongly as an important paradigm for safety science issues such as injury prevention (e.g., Salmon et al. 2014) and manual handling (Goode et al. 2014). In order to realise its potential contribution to safety, a paradigm shift is required both in the way in which safety leadership is considered and studied. This involves applying systems-thinking. Over the past two decades, safety science research has seen a significant shift towards systems-thinking when examining safety-related concepts (Dekker 2011; Leveson 2004; Rasmussen 1997; Reason 1997). Notably, the review reveals that safety leadership is yet to be examined through a systems-thinking lens.

As with other safety-related concepts, there is scope to apply systems-thinking models (e.g., Rasmussen 1997) and methods (e.g., Leveson 2004) to safety leadership. Such an approach would engender two important features of safety leadership. First, an appropriate leadership style alone will not guarantee safe performance, rather, many other factors across the overall work system will interact with, and shape leadership style. Second, an important line of inquiry is to examine leadership across the different levels of the work system, including frontline staff, supervisors, managers, CEOs etc. It is notable from this review that both dimensions have not yet been examined. As such, it is argued that future research agendas should incorporate multi-level, systems-thinking approaches to the methodological design and exploration of safety leadership across all levels of a work system, up to and including regulatory and government bodies. Moreover, they should include examination of systems-thinking concepts, such as vertical integration and distribution of control, to better understand systemic influences which may impact on safety leadership.

It is, therefore, argued that the application of systems-thinking is key to the advancement of research into the influence of safety leadership on safety performance and safety outcomes in high-risk industries. As safety depends on the activities of individuals (human and non-human) at every level of the system, and on the specific interactions between these actors and levels (Vicente and Christoffersen 2006; Woo and Vicente 2003), it is of critical importance to examine the influence of safety leadership within the broader context of the work system of safety. Whilst the existing literature provides some support for the influence different leadership styles have on safety performance and outcomes, it does not shed any light on the influence of leadership styles at different levels of the overall work system. Further, it does not comprehensively identify what important systems-thinking concepts such as decisions, actions, policies, and vertical integration influence leadership style, and its impact. It is therefore concluded that these are critical knowledge gaps that require further exploration.

As such, future research endeavours should apply systems-thinking models and methods (e.g., Leveson 2004; Rasmussen 1997) to the examination of safety leadership, as well as incorporate systems-thinking concepts such as vertical integration and migration of work practices. For example, applying methods and frameworks such as Rasmussen's Risk Management Framework and AcciMap would facilitate examination of safety leadership across multiple levels within a work system. Supported by the application of knowledge elicitation techniques, such as for example the Critical Decision Method, such an approach would support examination of interactions between human and non-human actors, and understanding of systemic influencing factors that shape safety leadership performance to support and maintain safety. Applying such approaches will go a long way to advancing understanding of the true contribution safety leadership plays in positively influencing safety performance and outcomes in high-risk industries.

While the current review is considered comprehensive, it is important to acknowledge that studies examining safety leadership within the context of medical or health-care settings were not included. Such articles were excluded for the following reasons; firstly, the articles did not meet the definition of high-risk industry outlined by Grote (2012) applied for this review, secondly the body of literature identified relating to health-care or the medical sector was considered substantial enough to warrant a dedicated review within its own right, and thirdly, two literature review articles were also identified (Kunzle, Kolbe, and Grote 2010; Schmutz, Manser, and Mahajan 2013) which provided an already comprehensive perspective on the influence of leadership within the medical sector. As such, it is suggested a separate and updated specific review be undertaken for that of literature relating to the health-care and medical sectors, whereby cross comparison can be conducted with the findings of the current review.

6. Conclusion

The current review concluded a significant opportunity exists to advance understanding of the influence of safety leadership on performance and outcomes through the application of systems-thinking. Applying a systems-based approach to future research agendas would seek to close the identified gaps by broadening the conceptual and methodological approaches used to examine safety leadership across all levels within a work system. Doing so would provide insight into the less examined proximal and distal system influences which determine a range of effects on safety performance and outcomes. Further, such approaches would permit examination of the presence of a range of leadership styles across multiple levels of the system of safety, and their influence on key system performance and outcome measures. The findings of this review should be taken into account when developing future research endeavours to examine the influence of safety leadership on performance and outcomes in high-risk industries.

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About the authors

Sarah-Louise Donovan is a PhD candidate at the Monash University Accident Research Centre at Monash University in Melbourne. She received a postgraduate diploma in psychology from Monash University in 2005, having previously obtained a Bachelor of Science from the University of Melbourne, and a Master of Science and Technology from the University of New South Wales.

Paul M. Salmon holds the chair in human factors and is the creator and director of the Centre for Human Factors and Sociotechnical Systems at the University of the Sunshine Coast. He currently holds an Australian Research Council Future Fellowship applying systems thinking theory and methods in safety critical systems.

Michael G. Lenné is an adjunct professor with the Monash University Accident Research Centre at Monash University in Melbourne. He was awarded a PhD degree in experimental psychology/human factors from Monash University in 1998.

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2.2 Discussion

The aim of this chapter was to review the safety leadership literature to identify what is currently known about safety leadership, what gaps exist in the current knowledge base, and determine the extent to which a systems perspective has been previously applied to examine safety leadership. With a systems perspective widely acknowledged as the dominant safety paradigm, the review identified safety leadership has not been examined from a systems perspective.

2.2.1 Defining Safety Leadership

An important consideration to emerge from the review, and crucial for the direction of this thesis, relates to the need to redefine leadership in the safety context. Existing definitions of leadership applied in the safety context (e.g., Chemers, 1997) are considered inadequate to describe the emergent, complex and adaptive nature of the concept to support safe performance within high-risk, complex organisational systems. In order to provide a strong foundation for defining what constitutes good and effective safety leadership (Glendon & Clarke, 2015), a clear definition must be articulated, and one which encompasses the multi-faceted nature of the safety leadership concept. Thus, an integrated and systems-based definition of safety leadership is proposed that is consistent with a systems perspective. Accordingly, safety leadership is defined as:

"Safety leadership comprises the emergent decisions, behaviours and actions of actors across all levels within a work system, which combine and interact to support achievement of the common goal of safe performance".

Describing and focusing on an integrated definition of safety leadership is important for the following reasons. First, defining safety leadership in this manner can help illustrate the limitations of current theory, in terms of broadening understanding of safety leadership beyond the influence of leadership style on follower performance alone. Second, it provides alignment with contemporary thinking in ergonomics regarding the importance of considering safety leadership from a systems perspective. This can assist in the development of a more comprehensive agenda for future research with direct relevance to organisational practice (Langley, Smallman, Tsoukas, & Van De Ven, 2013). Third, it recognises the underpinning premise of systems-thinking, which relates to understanding the combined decisions, behaviours and actions of actors across all levels within a work system, which interact to influence performance (Rasmussen, 1997). The research presented in this thesis will apply this definition of safety leadership to improve understanding of the combined effect of decisions, behaviours and actions of actors across work systems, and how these elements emerge and interact to support safe performance.

2.3 Conclusion

The aim of this chapter was to determine what is known regarding the influence of safety leadership on performance and outcomes in high-risk industries and examine the extent to which systems-thinking has been applied to study safety leadership. Overall, it was concluded that safety leadership is not well understood from a systems perspective. There is little evidence of systems-thinking having been applied to its examination and hence, little understanding and development of appropriate systems-based interventions to support improved performance across high-risk, complex organisational systems. The findings provide evidence of key gaps in the literature in relation to the current methodological and conceptual approaches used to define and study safety leadership, which it is contended limit current understanding. In a first step to address these shortcomings, an integrated definition of safety leadership was proposed for application throughout this research. The definition reflects the underpinning premise of a systems perspective, to focus on understanding the decisions, behaviours and actions of actors across all levels within a work system, which interact to influence safe performance.

In order to identify a suitable methodology to support examination of safety leadership from a systems perspective, the following chapter describes a review of available ergonomics frameworks, models and methods. It outlines the subsequent selection and justification of the systems-thinking methodology that was applied and evaluated throughout this thesis.

3 Review and selection of a systems-thinking methodology for studying safety leadership

3.1 Introduction

The findings from the literature review presented in Chapter 2 confirmed that a systems perspective has not yet been applied to examine safety leadership. With systems-thinking considered the dominant paradigm for understanding safety and performance within complex socio-technical systems (Dekker, 2011; Hollnagel, 2004; Salmon, Goode, et al., 2017; Salmon et al., 2020), a clear research imperative exists. This involves applying systems theory-based frameworks, models and methods to analyse, understand and ultimately optimise safety leadership.

Various systems analysis methods have been applied in safety science research to study factors implicated in safety within complex organisational systems. Approaches such as the Functional Resonance Analysis Method (FRAM; Hollnagel, 2012), AcciMap (Rasmussen, 1997), CWA (Vicente, 1999), and Event Analysis of Systemic Teamwork (EAST; Stanton, 2013) have been applied to study and optimise road user behaviour (Read et al., 2018; Salmon, Lenné, Walker, Stanton, & Filtness, 2014; Stanton & Bessell, 2014) to assist in guideline development in health care settings (Clay-Williams, Hounsgaard, & Hollnagel, 2015; Hollnagel, 2012), and to explore activity allocation and the impact of automation on decision-making and behaviour in military systems (Jenkins, Stanton, Salmon, & Walker, 2008; Jenkins, Stanton, Salmon, Walker, & Young, 2008; Naikar, 2006).

With a variety of systems-thinking analysis approaches available to draw from, it is important to identify a suitable methodology for application in the safety leadership context. Accordingly, the aim of this chapter was to identify, review and analyse the strengths and weaknesses of various systems-thinking frameworks, models and methods, with a view to identifying a suitable methodology to support the examination of safety leadership across a mining work system.

3.2 Identification of systems-thinking frameworks, models and methods

Leveraging the findings from the literature review, a review was conducted of the available systems-thinking frameworks, models and methods that could potentially be applied to support the examination of safety leadership decisions, behaviours and actions across a mining work system.

A structured search of relevant databases, journals and the reference lists of publications was undertaken to identify journal articles, conference papers, books and chapters describing systems-thinking analysis approaches and their application within the context of safety. Databases in which the top ergonomics and safety science publications are held were searched and included: Science Direct and websites of publishers Taylor and Francis, Sage and Springer link. Keywords used in the search included the following in combination: 'systems-thinking', 'methods', 'analysis', specifically in the subject of 'safety', and covered both title of the publication and the abstract. Two-hundred and fifty-eight items were returned from the database search. Within the two-hundred and fifty-eight items, a total of thirty-nine analysis approaches were identified as having been applied and included frameworks, models and methods. The frameworks, models and methods were applied across eighteen domains, with healthcare the most frequently referenced domain.

Each of the thirty-nine analysis approaches was evaluated against a set of criteria developed to reflect the research questions to be answered within this thesis. The evaluation criteria are outlined in Table 1. The evaluation criteria were developed and applied to determine the suitability of each analysis approach with reference to; capturing data across a work system, the ability of the approach to examine safety leadership in line with the definition proposed in Chapter 2 and the extent to which the analysis approach was able to identify and represent positive performance shaping factors across a work system.

Table 1. Criteria for evaluating systems-thinking approaches to align with stated research questions

CRITERIA	DESCRIPTION
1	The ability of the framework, model or method to capture data and be able to represent data across system levels in relation to influencing factors, relationships and interactions between actors and performance characteristics.
2	The ability of the framework, model of method to examine safety leadership in line with the definition applied for this research (Chapter 2), that is, in terms of the "*emergent decisions, behaviours and actions of actors across all levels within a work system, which combine and interact to support achievement of the common goal of safe performance*".
3	The ability of the framework, model or method to describe and represent factors across a work system, which support and assist performance in a positive manner.

Each of the thirty-nine frameworks, models and methods were rated by the primary analyst as either Low, Medium or High based on the number of evaluation criteria met in Table 1 (Low = 1 criteria, Medium = 2 criteria, High = All 3 criteria). An inter-reliability analysis was conducted by a second analyst with experience in coding human factors and ergonomics

(HFE) data, with a percentage agreement in rating of 82.37% achieved. Disagreements regarding the number of criteria met were resolved through discussion between the analysts. A total of thirteen 13 frameworks, models and methods were identified and agreed upon as potentially suitable to examine safety leadership from a systems perspective.

Using an adapted approach to that taken by (Salmon et al., 2011) a table was constructed to outline the thirteen frameworks, models and methods reviewed. Table 2 provides a summary description of the analysis approach, reference domains where it has been applied, the type of approach, the relative strengths and weaknesses and number of criteria met as per Table 1.

It is important to note that some known frameworks, models and methods considered as systems-thinking analysis approaches are not presented in Table 2 . A number of methods known to be applied to examine complex systems did not appear in the initial search of relevant databases. For example, System Dynamics (Forrester, 1961), which is used to understand non-linear behaviour in complex systems did not appear in the search. Similarly, Hierarchical Task Analysis (Stanton, 2013), which is also utilised to study patterns of work and processes within complex systems did not appear. An explanation is that these methods may be associated with different keywords within the literature to the keywords applied in the present search. Further, a number of analysis approaches for studying behaviour in complex systems have emerged post review, for example NETworked Hazard Analysis and Risk Management System (NET-HARMS), which is used to identify risks across work systems (Dallat, Salmon, & Goode, 2017). As such, these methods have not been evaluated in the current context to determine their utility to study safety leadership from a systems perspective.

Table 2. Overview of systems-thinking frameworks, models and methods suitable for application to examine safety leadership

#	METHOD	AUTHOR/S	DESCRIPTION	PROMINENT APPLICATION DOMAIN	TYPE OF ANALYSIS	STRENGTHS	WEAKNESSES	RESEARCH CRITERIA MET IN TABLE 2	SUITABILITY FOR MINING APPLICATION
1	AcciMap Method	Rasmussen, (1997)	An accident analysis methodology used to graphically represent the causal and contributory factors involved in an incident. The technique enables development of a multi-layered diagram, which spans immediate causes, to remote causal and contributory factors (i.e., at a governmental or societal level). The method allows capture of preconditions and actions in the causal or contributory chain of events.	Aviation and Rail transport	Accident Analysis	• Underpinned by a generic framework, which considers multiple work system levels • Supports identification of relationships and links between factors • Does not use a taxonomy of errors, which enables flexibility in application to a range of contexts • Technique can be learned with minimal training	• Data capture intensive • Considerable time required to develop an AcciMap	1, 2 & 3	High
2	Cognitive Work Analysis (CWA)	Vicente (1999)	A framework and functional analysis method that defines the goals, constraints and affordances in a domain that constitutes a cognitive problem space. CWA incudes 5 levels of analysis; WDA, CTA, Strategies Analysis, Social Organisation and Cooperation Analysis and WCA, with each level focusing on different constraints which affect performance.	Rail Transport	System Design and Analysis	• Underpinned by a framework, which considers multiple system levels • Supports identification of relationships and links between factors • Does not use a taxonomy of errors, which enables flexibility in application to a range of contexts • Modest training required to become proficient	• Data capture intensive • Considerable time required develop outputs • Time required to train/ learn application of the method	1, 2 & 3	High
3	Critical Decision Method (CDM)	Klein, Calderwood, & Macgregor (1989)	A semi-structured, retrospective interview technique, which uses a set of cognitive probes to examine incidents that require expert judgement or decision-making. A naturalistic decision-making approach, it is used to elicit expert knowledge, strategies and cues attended to inform decision-making.	Aviation, rail and road transport, led outdoor activities	Analysis of cognitive processes	• Useful for gathering data on the factors, which input to and influence decision-making during accident scenarios • Well established as a method in application in complex socio-technical systems • Demonstrates high reliability	• Quality of data obtained is highly dependent upon the skill of the interviewer • Extent to which verbal interview responses reflect exactly the cognitive processes employed by decision makers during task performance is questionable • Very time consuming to apply and analyse data	1, 2 & 3	High
4	Event Analysis of Systemic Teamwork (EAST)	Stanton, 2013	EAST provides an integrated suite of HFE methods for analysing activity in collaborative systems. The underpinning the premise of EAST is that collaborative activity can be meaningfully described via a 'network of networks' focusing on three interlinked perspectives: task, social and propositional networks, which underlie collaborative activity.	Road Safety	Accident Analysis	• Very comprehensive and activities are analysed from various perspectives • The analysis provides compelling views of collaborative activities • A number of HFE concepts are examined, including situation awareness, decision-making, teamwork and communications	• Very time-consuming approach, when undertaken in full • High training time associated with the use of various methods • A high level of access to the domain, task and SMEs is required	1, 2 & 3	High
5	Functional Resonance Analysis Method (FRAM)	Hollnagel, 2012	FRAM is a method to retrospectively, or prospectively analyse how work activities take place, in order to produce a model or representation of how work is done. FRAM is based on	Health care and patient safety	System Design and Analysis	• Provides a way to develop an overall understanding of how complex socio-technical systems work • Emphasises a comprehensive view, rather than decomposition into	• Very time-consuming to apply • Difficult to apply, particularly for analysts with familiarity in application of simple methods, such as Root Cause Analysis	1, 2 & 3	High

#	METHOD	AUTHOR/S	DESCRIPTION	PROMINENT APPLICATION DOMAIN	TYPE OF ANALYSIS	STRENGTHS	WEAKNESSES	RESEARCH CRITERIA MET IN TABLE 2	SUITABILITY FOR MINING APPLICATION
			four principles to describe the functions involved in work: the equivalence of failures and successes, the central role of approximate adjustments, the reality of emergence and functional resonance as a complement to causality. The output can be used for specific types of analysis, whether to determine how something went wrong, to look for possible bottlenecks or hazards, to check the feasibility of proposed solutions or interventions, or to simply understand how an activity takes place.			individual components • Does not include a model of any system • Does not include assumptions about specific or typical cause and effect relationships	• Qualitative in nature • Requires imagination. The method guides the analyst and provides them with clues on 'where to look', but not with the answers		
6	Human Factors Analysis and Classification System (HFACS)	Wiegmann & Shappell, (2003)	HFACS is an accident analysis model, developed with the intent to provide a taxonomy of failure modes and unsafe acts within Reason's Swiss cheese model. It uses four levels; unsafe acts; preconditions for unsafe acts; unsafe supervision; and organisational influences. Each level contains different categories of failures, along with their own taxonomy of failure modes.	Aviation, health care and patient safety	Accident Analysis	• Provides taxonomies of failure modes across multiple system levels • Generic to be applied across a range of domains for accident analysis purposes • High reliability • Sound underpinning theory	• Developed for aviation, which limits application of taxonomies for other domains • Does not consider failures outside of the organisation involved • Highly dependent on the quality of data available	1	Low
7	Human Factors Engineering principles	Human Factors Society (1957)	The application of knowledge from a range of disciplines such as psychology, engineering, anthropometry. The discipline of HFE is concerned with the 'fit' between people, equipment and their environment and accounts for human capabilities and limitations in seeking to ensure that tasks, functions, information and the environment are designed to support the end-user.	Aviation, health care and patient safety	System Design and Analysis	• A broad range of principles and concepts, which can be applied in conjunction with additional methods to yield insight into behaviour • Facilitates a comprehensive approach to understanding research problem	• Principles and concepts in isolation do not yield insight into the interactions between elements • Highly time consuming in application • High level of training and competence required to apply principles correctly in order to optimise results or output	1, 2 & 3	High
8	Interviews (existing method used to examine safety leadership)	Nil	A common research technique whereby information is exchanged between two or more individuals in a question-answer style approach. Interviews can be used to gain insight into 'first person' cognitive processes associated with the variable or factors of interest.	Broad application across a range of domains	Trait/ Variable analysis	• Can capture a lot of information, on many variables • Can be applied immediately, with little preparation required	• High level of training and competence assurance required to get best results • Potential issues with analyst bias, requiring inter-rater reliability to be performed to overcome	1, 2 & 3	High

#	METHOD	AUTHOR/S	DESCRIPTION	PROMINENT APPLICATION DOMAIN	TYPE OF ANALYSIS	STRENGTHS	WEAKNESSES	RESEARCH CRITERIA MET IN TABLE 2	SUITABILITY FOR MINING APPLICATION
9	Observation (existing method used to examine safety leadership)	Nil	A common research technique involving the active acquisition of information from a primary source. Observations can be qualitative, or quantitative in nature.	Broad application across a range of domains	Trait/ Variable analysis	• Trained assessor observations of cues can yield insight into multiple factors and systems issues	• Observational data is often highly subjective • High level of training and competence assurance required for validity in observations • Potential issues with analyst bias, requiring inter-rater reliability to be performed to overcome	1, 2 & 3	High
10	Questionnaires (existing method used to examine safety leadership)	Various (dependent on content)	A research instrument consisting of a series of questions for the purpose of gathering information from a target group of respondents. Questionnaires are commonly applied in a research setting to gather information on specific variables, themes or demographics in order to identify and analyse links, similarities or indeed, differences between population groups of interest.	Broad application across a range of domains	Trait/ Variable analysis	• Can capture a lot of information, on many variables • Easy to administer	• Validity and reliability of constructs is often questionable • In depth knowledge of statistical analysis techniques to ensure accurate analysis of data	1, 2 & 3	High
11	Rasmussen's Risk Management Framework (RMF)	Rasmussen, (1997)	Rasmussen's Risk Management Framework is based on the premise that accidents are shaped by the decisions, behaviours and actions of actors across work systems. The framework describes 6 levels; Government, Regulators, Company, Management, Staff and Work involved in production and safety management. According to the framework, for systems to function safely, 'vertical integration' is required whereby decisions made at the higher system levels should be promulgated down and be reflected in the decisions and actions occurring at the lower levels (i.e. staff work levels) and information at the lower levels regarding the system's status needs to transfer up the hierarchy to inform the decisions and actions occurring at the higher levels.	Led outdoor activities, sports injury prevention	Accident Analysis	• Considers both discrete and system-wide factors involved in an incident • Does not utilise a taxonomy of failures • The output is visual and easily interpreted • Considers contributory factors across multiple levels, including external factors	• Very time-consuming to apply • The quality of the analysis produced is entirely dependent upon the quality of the input data • Potential issues with analyst hindsight, requiring inter-rater reliability to be performed to overcome	1, 2 & 3	High
12	Swiss Cheese Model	Reason (1990)	The Swiss Cheese model describes the interaction between system-wide latent conditions and unsafe acts made by human operators and their contribution to accidents. The model describes how latent conditions reside across all levels of an organisational system, rather than focusing on the	Aviation, Rail transport	Accident Analysis	• Generic framework, which can be applied across a range of domains for accident analysis purposes • Considers contributory factors across multiple levels • Considers both discrete and system-wide factors involved in an incident • Can be applied with minimal training	• Focuses on latent conditions and failures present within system • Considerable time required to develop outputs	1 & 2	Medium

#	METHOD	AUTHOR/S	DESCRIPTION	PROMINENT APPLICATION DOMAIN	TYPE OF ANALYSIS	STRENGTHS	WEAKNESSES	RESEARCH CRITERIA MET IN TABLE 2	SUITABILITY FOR MINING APPLICATION
			frontline or 'sharp end' in isolation. According to the model, each organisational level has defences, which are designed to prevent the occurrence of incidents. Weaknesses in these defences, create 'windows of opportunity' for accident trajectories to breach the defences and cause an accident.			• A detailed taxonomy of failure modes is provided for each level within the model			
13	Systems Theoretical Accident Modelling and Processes (STAMP) and associated methods	Leveson (2004)	The STAMP method is an accident analysis method, which holds that that accidents are a control problem and occur when component failures, external disturbances and/or inappropriate interactions between systems components are not controlled, which enables safety constraints to be violated. The model describes various forms of control, including managerial, organisational, physical, operational and manufacturing-based controls.	Military, Rail transport, Mining	Accident Analysis	• Based on control theory • Considers loss of control across the overall multiple levels within work systems • Can be applied for accident analysis across a range of domains	• Limited guidance available to support analysts in conducting STAMP analyses • The method is complex to apply, considering constraints, control structure, structural and behavioural dynamics	1 & 2	Medium

3.3 Selection of systems-thinking framework, model and methods for examining safety leadership

Ten of the thirteen frameworks, models and methods presented in Table 2 were rated as highly suitable to examine safety leadership from a systems perspective, that is; having met all three criteria defined in Table 1. From these ten methods, four analysis approaches were subsequently selected for actual application throughout this thesis. The four analysis approaches selected were; Rasmussen's RMF, AcciMap Method, the CDM interview technique and CWA. The justification for selection of each of the four approaches is outlined below.

3.3.1 Rasmussen's Risk Management Framework (RMF)

The methodology applied throughout this research required a consistent underpinning theoretical framework. Rasmussen's RMF was selected as this framework as it is generic and does not use a taxonomy of failures as with some other frameworks. This makes it flexible in application to identify and examine factors associated with both positive and negative performance across work systems. The framework was confirmed as appropriate in the literature review presented in Chapter 2 and was therefore deemed most suitable to apply as a 'first of type' approach to underpin the examination of safety leadership across a mining work system.

3.3.2 AcciMap Method

The AcciMap Method is directly associated with Rasmussen's RMF and is also generic in nature, making its application transferrable across multiple domains. The method is capable of supporting identification and exploration of relationships and links between factors across a work system, including contributory factors and influences external to an organisation (i.e., at the regulatory and governmental level). In addition to its use in accident analysis, it has been used to analyse many other behaviours outside of accident scenarios, for example, including distraction (Young & Salmon, 2015), improvisation (Trotter, Salmon, & Lenné, 2014) and near misses (Thoroman, Goode, Salmon, & Wooley, 2019).

3.3.3 Critical Decision Method (CDM)

The CDM (Klein et al., 1989) interview technique was selected for application as it facilitates gathering of specific information relating to the cognitive components of decision-making, and factors that influence decision-making. Although it is primarily used to explore decision-making following an incident, the technique is flexible enough to be applied to a normal performance scenario using the same interview questions and probes. Thus, the CDM interview technique was capable of gathering information and inputs associated with decision-making relevant to safety leadership in both normal and abnormal operational contexts.

3.3.4 Cognitive Work Analysis (CWA)

CWA (Vicente, 1999) is a systems analysis and design framework, with its primary application being to analyse complex socio-technical systems to inform system design or redesign activities (Cornelissen, Salmon, Stanton, & McClure, 2015; Jenkins, Stanton, Salmon, Walker, et al., 2008; Read et al., 2015; Stanton & Bessell, 2014). It is capable of modelling entire systems as well as the constraints that influence decision-making and behaviours. It also specifically allocates behaviours to different actors across the systems, which is important for safety leadership.

While the CWA framework itself comprises five phases of analysis (Vicente, 1999), only three phases will be applied in the present research. Specifically, WDA, CTA and WCA was applied. The remaining two phases (Strategies Analysis and Social Organisation and Co-operation Analysis) will not be applied in the present research, as it was felt that the analysis output from the three phases referenced will provide sufficient depth to achieve the study's intent regarding modelling safety leadership to support subsequent development of a safety leadership competency framework. Detail regarding each of the three phases to be applied are provided below.

3.3.4.1 Phase 1 – Work Domain Analysis (WDA)

WDA was applied to develop a model of safety leadership within a mining work system. The aim of the WDA conducted in this research was to describe the purposes of the safety leadership system and the constraints imposed on the actions of any actor performing activities within the system (Vicente, 1999). This was achieved by describing the system at the following five conceptual levels using the abstraction hierarchy method:

1. **Functional purpose** – The highest level describes the overall purposes of the safety leadership system and the external constraints imposed on its functions;
2. **Values and priority measures** – This level describes the criteria that stakeholders use for measuring progress towards the functional purposes of safety leadership;

3. **Purpose-related functions** – This level describes the purpose-related functions of the safety leadership system that are necessary for achieving the functional purposes;
4. **Object-related processes** – This level describes the functional capabilities and limitations of objects within the system that enable the purpose-related functions; and
5. **Physical objects** – This level describes the physical objects within the system that are used to undertake the purpose-related functions.

Within the abstraction hierarchy model, means-ends relationships are established to link 'nodes' across the five levels of abstraction. Every node in the abstraction hierarchy is the 'end' that is achieved by all of the linked nodes below it and also the 'means' by which all of the linked nodes above it are achieved.

In recent years, elements of CWA including WDA have been applied at a high level to examine mining operations and organisations (Demir et al., 2017; Li et al., 2019; Xiao et al., 2015), however these studies did not include examination of, nor focus on, safety leadership. Thus, application of this systems-thinking analysis technique in the current context is novel.

3.3.4.2 Phase 2 – Control Task Analysis (CTA) and Decision Ladder (DL)

The second phase of the CWA framework is used to facilitate identification and decomposition of specific control tasks through the use of the Contextual Activity Template. This phase provides a more context-specific description of the tasks that are undertaken within the work domain. To conduct the CTA, a Contextual Activity Template (CAT) is populated which maps the control tasks undertaken by individuals, teams, non-human agents and organisations within the system against the functional purposes of the work system as described in the WDA. Typically, the work or task situation is represented along a horizontal axis, while the functions derived from the abstraction hierarchy of the WDA are shown along the vertical axis. Mapping the control tasks in this way allows constraints associated with recurring classes of tasks and events to be identified. An example of a generic CAT is provided in Figure 2.

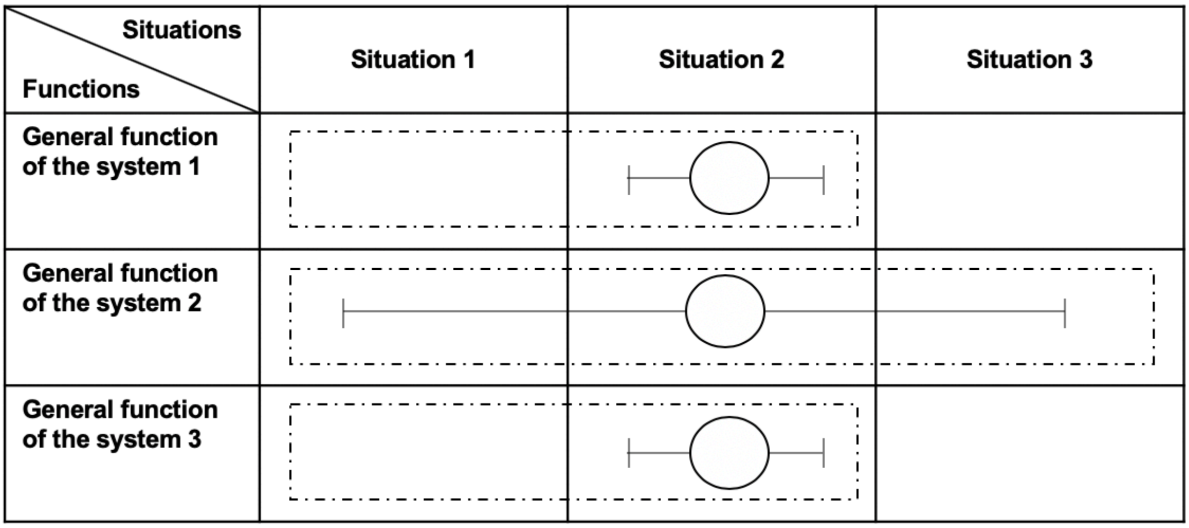

Figure 2. Generic CAT

The work and task situations are shown in columns, with the circles and bars showing the extent to which the function typically occurs within the situations identified. The dotted boxes indicate all of the work situations in which a work function can occur, as opposed to typically occur. In doing so, this captures the constraints of the system with respect to ensuring specific tasks undertaken align with supporting achievement of the overall system functions and purpose-related functions.

The control activities can be further analysed through the use of a Decision Ladder (DL). A DL is most commonly used within CWA to describe decision-making activity and represents the decision-making process of the combined work system (Rasmussen, 1994). It is specifically focused on the entire decision-making activity, rather than the moment of selection between two potential options. DL models are typically used to represent the information requirements for making a decision triggered by information inputs and outputs to achieve the functional purposes.

The DL itself contains two different types of nodes: rectangular boxes that represent data-processing activities and circles that represent resultant states of knowledge. The left side of the ladder represents the observation for the current system state, while the right side represents the planning and execution of tasks and application of procedures to achieve a target system state or function (Vicente, 1999). A generic example of a DL is provided in Figure 3.

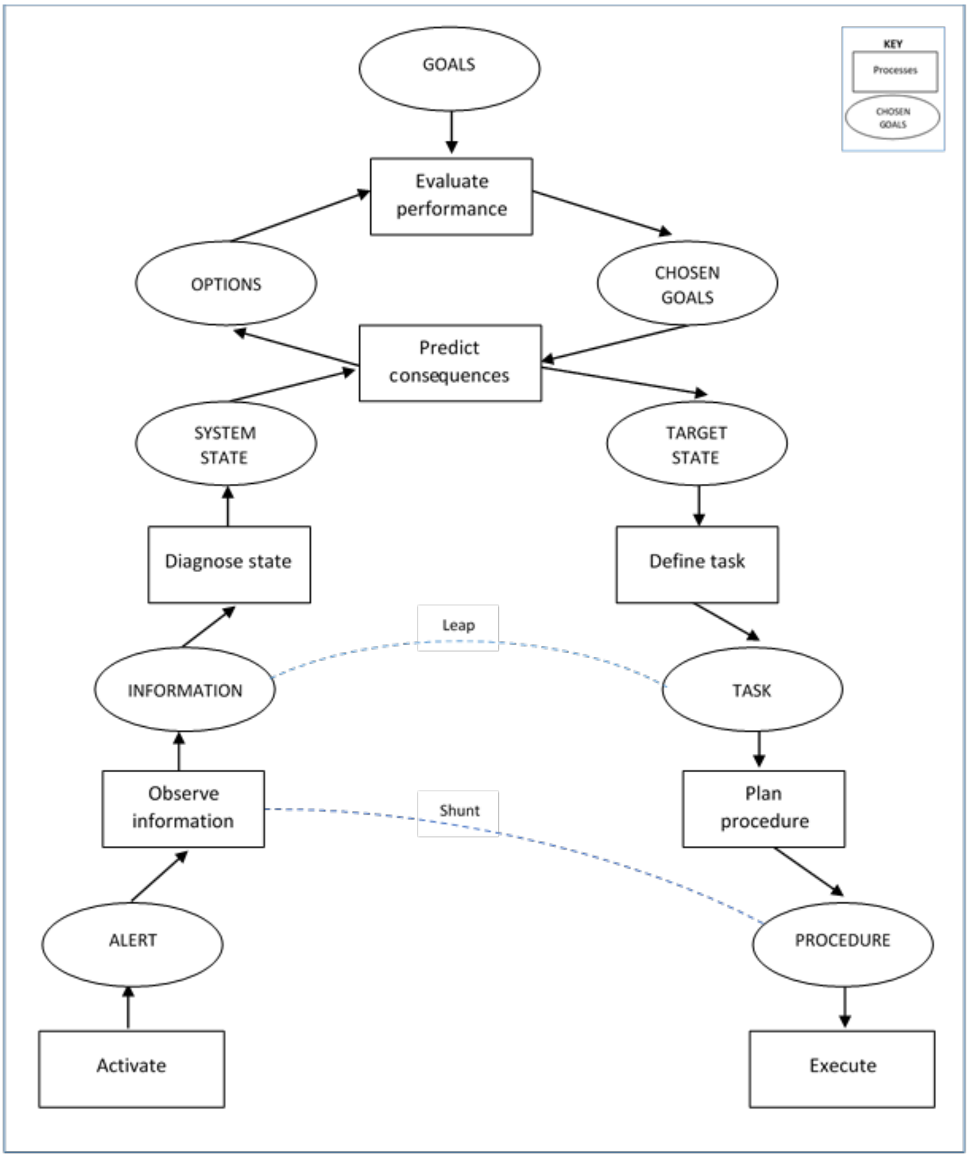

Figure 3. Generic DL showing process and knowledge state as well as 'leaps' or 'shunts'

Novice users typically follow the DL in a linear fashion, progressing up the left-hand side and down the right, whereas expert users typically take 'leaps' or 'shunts' through and across the ladder based on prior experience (Vicente, 1999). A 'leap' is where two states of knowledge are connected (circle to circle), while a 'shunt' is where information-processing activities are connected to a resultant state of knowledge (box to a circle).

3.3.4.3 Phase 5 – Worker Competencies Analysis (WCA)

The purpose of a WCA is to identify the competencies required by actors within a work system to effectively accomplish the controls tasks and linked functions identified. A WCA inherits all of the constraints identified through the previous analytic phases of the CWA to result in a map of competencies required across the work system to support achievement of the system functions identified.

There is no specific methodology referenced for completing the Worker Competencies Analysis, however, Rasmussen's SRK (Rasmussen, 1983) taxonomy forms the basis of this final analytical phase to allow classification of the cognitive activities undertaken by actors during performance of domain specific control tasks (Vicente, 1999). The taxonomy outlines basic distinctions between three main psychological processes: Skill-Based Behaviour (SBB), Rule-Based Behaviour (RBB) and Knowledge-Based Behaviour (KBB) and holds that control tasks must allow for SBB and RBB wherever possible, whilst support KBB wherever necessary (Vicente, 1999). Table 3 provides an overview of the different categorisations of behaviour within the SRK taxonomy and the function and task situations that typically guide the associated level of control.

Table 3. Rasmussen's Skills, Rules and Knowledge taxonomy (Vicente, 1999)

LEVEL OF CONTROL	***DESCRIPTION***	***GOAL OR FUNCTION***	***SITUATION OR TASK***
Skill-Based	Automated action performed without conscious attention. Action is prospective meaning, actions are anticipatory in nature, rather than waiting for changes in the environment that then need to be responded to. Actors typically can't verbalise what is happening at the time of the behaviour.	Explicit	Familiar
Rule-Based	Procedural activities, developed through experience, instruction or previous problem-solving activities. Action is goal-oriented, but goals are implied in the structure of the rules. Workers may know the goals that the rules can achieve, but they are not thinking about those goals when they are following the rules, they are merely using familiar perceptual cues in the environment to trigger actions.	Explicit or implicit, the situation suggests a particular convention	Familiar
Knowledge-Based	Represents serial search based on explicit representation of the goal and understanding of the functional properties of the environment. Knowledge based goals are considered explicitly. Knowledge-Based Behaviour is slow, serial and effortful because it requires focal attention. It is frequently applied in unfamiliar situations where previous experience isn't able to be drawn upon.	Explicit, derived from analysis of a situation and guiding personal aims	Unfamiliar

An SRK analysis and output comprises a table describing specific behaviours that individuals may engage in to complete the information-processing activities and actions described in the DL. The analysis is thus used to generate profiles of competencies that actors must possess to adequately perform the identified control tasks and system functions across the three types of behaviours. In the current application, the WCA is applied specifically with reference to identifying competencies related to effective safety leadership to support the control tasks examined (i.e., regular and non-routine task execution).

For completeness, a number of frameworks, models and methods were not selected for application in the current research. An outline and justification for their exclusion is provided in Appendix 1.

3.4 Conclusion

The aim of this chapter was to identify, review and analyse the strengths and weaknesses of various systems-thinking frameworks, models and methods with a view to recommending a suitable methodology for examining safety leadership across a mining work system. It also provides an overview of the methods applied throughout this thesis.

A structured approach was used to determine a methodology for studying safety leadership from a systems perspective. Four systems-thinking frameworks, models and methods were selected for application. First, Rasmussen's RMF was selected as the underpinning framework for use throughout this research. Along with the framework, the AcciMap Method was also selected for application. The CDM was also selected as the method for capturing data relating to decision-making and through subsequent proposed adaptation, corresponding safety leadership behaviours associated with regular and non-routine operational contexts. Finally, three phases of CWA were selected for application to develop a model of safety leadership whereby competencies can be identified to support control task execution and achievement of system functions.

The following chapter introduces Study 1 in which Rasmussen's RMF, AcciMap Method and the CDM are applied to examine safety leadership during a critical incident scenario. Following analysis of the incident, the methods are evaluated to determine their suitability for examining safety leadership from a systems perspective and the extent to which they provide deeper insights into safety leadership decisions, behaviours and actions across a work system to support safe performance.

4 Evaluating the suitability of Rasmussen's Risk Management Framework, AcciMap Method and the Critical Decision Method for examining safety leadership

Donovan, S.-L., Salmon, P. M., Lenné, M. G., & Horberry, T. (2017) Safety leadership and systems-thinking: application and evaluation of a Risk Management Framework in the mining industry. *Ergonomics*, Vol 60(10): 1336-1350.

4.1 Introduction

With a candidate systems-thinking methodology selected, the aim of Chapter 4 is to examine safety leadership from a systems perspective. This is achieved through a case study analysis of the Bingham Canyon Highwall Failure incident, a large-scale mining incident with a notable positive safety outcome in which no injuries or fatalities occurred.

Study 1 applied Rasmussen's RMF, AcciMap Method and the CDM interview technique to examine the factors across the work system that influenced safety leadership during the critical incident scenario to contribute to the incidents safe outcome. In doing so, Study 1 addresses the following research questions:

RQ 2: Can the application of a systems perspective expand understanding of safety leadership within a complex socio-technical mining system?

RQ 3: What factors influence safety leadership within a complex socio-technical mining system and how do these factors interact?

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Safety leadership and systems thinking: application and evaluation of a Risk Management Framework in the mining industry

Sarah-Louise Donovan[a], Paul M. Salmon[b], Michael G. Lenné[a] and Tim Horberry[a]

[a]Human Factors Group, Monash University Accident Research Centre (MUARC), Monash University, Clayton, Australia; [b]Centre for Human Factors and Sociotechnical Systems, Faculty of Arts and Business, University of the Sunshine Coast, Maroochydore, Australia

ABSTRACT

Safety leadership is an important factor in supporting safety in high-risk industries. This article contends that applying systems-thinking methods to examine safety leadership can support improved learning from incidents. A case study analysis was undertaken of a large-scale mining landslide incident in which no injuries or fatalities were incurred. A multi-method approach was adopted, in which the Critical Decision Method, Rasmussen's Risk Management Framework and Accimap method were applied to examine the safety leadership decisions and actions which enabled the safe outcome. The approach enabled Rasmussen's predictions regarding safety and performance to be examined in the safety leadership context, with findings demonstrating the distribution of safety leadership across leader and system levels, and the presence of vertical integration as key to supporting the successful safety outcome. In doing so, the findings also demonstrate the usefulness of applying systems-thinking methods to examine and learn from incidents in terms of what 'went right'. The implications, including future research directions, are discussed.

Practitioner Summary: This paper presents a case study analysis, in which systems-thinking methods are applied to the examination of safety leadership decisions and actions during a large-scale mining landslide incident. The findings establish safety leadership as a systems phenomenon, and furthermore, demonstrate the usefulness of applying systems-thinking methods to learn from incidents in terms of what 'went right'. Implications, including future research directions, are discussed.

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1. Introduction

1.1. Safety leadership and systems-thinking

In recent years, safety leadership has emerged as an important factor in supporting and maintaining safety within high-risk industries (e.g. Clarke 2013; Griffin and Hu 2013; Hofmann and Morgeson 1999; O'Dea and Flin 2001). Typically defined by a leaders' ability to inspire and motivate followers to achieve common goals (Burns 1978; Chemers 1997), safety leadership is often examined in terms of the influence of different styles of leadership (e.g. Arnold et al. 2000; Burns 1978; Graen and Uhl-Bien 1995; Walumbwa et al. 2008) on performance and outcomes. Positive links have thus been established between various forms of safety leadership, and a range of individual and group performance and outcome variables, such as workforce compliance and participation (Clarke and Ward 2006; Martínez-Córcoles, Gracia et al. 2012), and safety climate (Hystad, Bartone, and Eid 2013; Yagil and Luria 2010; Zohar and Luria 2010). Furthermore, safety leadership has been linked to a reduction in injuries and incidents, particularly in the construction and manufacturing industries (Hoffmeister et al. 2013; Hofmann and Morgeson 1999; Zohar 2002).

While such findings are important, questions still remain around the definition and constructs of safety leadership, the frameworks and methods used to study it, and thus, its ultimate contribution to safety. Indeed, a recent review of the literature (Donovan, Salmon, and Lenné 2016) highlighted several deficiencies with current conceptual and methodological approaches used to examine safety leadership, which limit advancement in understanding of its true contribution. For example, existing research has primarily focused on exploring the relationship between the frontline worker and immediate supervisory level in isolation (e.g. Conchie 2013; Hofmann and Morgeson 1999; Kath, Marks, and Ranney 2010), with questionnaires and surveys the favoured method of data capture. Within this, applying the traditional definition of safety leadership has generated a focus on examining leadership style alone, with little consideration given to important complimentary processes, such as decision-making, and its contribution

CONTACT Sarah-Louise Donovan sarah-louise.donovan@monash.edu

to supporting safe performance. With decision-making widely accepted as an integral part of leadership (Evans and Ward 2007; Rogers and Blenko 2006), improved understanding of its impact in a safety context presents as a valuable line of inquiry.

Perhaps most significantly, however, the review noted a lack of systems-thinking-based approaches having been applied to examine safety leadership (Donovan, Salmon, and Lenné 2016). Thus, the extent to which safety leadership has been examined across organisational systems is negligible, which points to a considerable gap in the current knowledge base. With systems-thinking (e.g. Rasmussen 1997) now considered the leading approach for examining and understanding the factors influencing safety within safety critical systems (Salmon et al. 2016), applying such frameworks and methods to examine and understand safety leadership presents as an important research endeavour. Indeed, Donovan, Salmon, and Lenné (2016) proposed Rasmussen's Risk Management Framework (1997) as a suitable framework through which to examine safety leadership from a systems perspective. However, the appropriateness of this framework has yet to be examined.

Current limitations notwithstanding, safety leadership is an important and positive safety-related concept (Flin and Yule 2004; Zohar 2002; Zohar and Luria 2010). To that end, improved approaches to its examination offer some valuable opportunities to enhance understanding of its contribution. By moving beyond traditional methodological and conceptual approaches (Clarke 2013; Hystad, Bartone, and Eid 2013; Kath, Marks, and Ranney 2010; Lu and Yang 2010), improved insight can be gained into crucial associated processes, including the impact of decision-making on safe performance. Moreover, exploring safety leadership through a systems-thinking lens presents an opportunity to advance knowledge regarding its role in the prevention or minimisation of accidents (Kleiner et al. 2015). In short, to examine and understand performance that 'went right' (Hollnagel 2014; Hollnagel et al. 2013). Learning from incidents, particularly those with positive safety outcomes (i.e. no injury or fatalities sustained), is of critical focus for burgeoning areas of safety science, such as resilience and Safety II (Hollnagel 2014). As such, examining safety leadership in terms of the underlying decisions, behaviours and actions that support successful safety outcomes, offers a valuable opportunity to contribute to this crucial area of interest.

Thus, this article aims to examine safety leadership through a systems-thinking lens by testing the applicability of a popular systems analysis framework in the safety leadership context. Using a case study analysis, data derived from the Critical Decision Method (CDM) interview technique (Klein, Calderwood, and MacGregor 1989) is used to support the development of an Accimap description (Rasmussen 1997) of a large-scale mining landslide incident where no injuries or fatalities were incurred. Such scenarios have been identified as critical for research as part of burgeoning safety concepts such as resilience and safety II (e.g. Hollnagel 2014). The resulting Accimap presents the key safety leadership decisions and actions, and corresponding influencing factors which contributed to the maintenance of safety throughout the incident. Following previous applications in which Accimap is used in new areas (Cassano-Piche, Vicente, and Jamieson 2009; Jenkins et al. 2010; Salmon et al. 2010, 2014), the findings are used to examine a set of predictions made by Rasmussen's Risk Management Framework (Rasmussen 1997) to determine the utility of applying a systems-based approach to the examination of safety leadership. Findings are discussed in terms of the usefulness of applying systems-thinking methods to examine safety leadership, and to learn from incidents by examining positive elements of system performance. Implications, including future research directions, are discussed.

1.2. Rasmussen's Risk Management Framework and Accimap (Rasmussen 1997)

To advance the field of safety leadership research, a theoretical and conceptual shift in thinking is required. In recent years, the adoption of systems-thinking has provided important contributions leading to new knowledge regarding various safety related concepts, such as improvisation (Trotter, Salmon, and Lenné 2013), situation awareness (Salmon, Walker, and Stanton 2015) and understanding specific risks such as manual handling injuries (Goode et al. 2013). This raises the real possibility that systems-thinking can also be applied to enhance systemic-level understanding of safety leadership.

A range of systems-thinking-based accident analysis methods exist, each capable of examining different aspects of accident causation. Salmon et al. (2012) provide a comprehensive review of the advantages and disadvantages of each, and their suitability in application for various areas of focus. For example, the Human Factors Analysis and Classification System (HFACS; Wiegmann and Shappell 2003) provides a taxonomy of failures that can be applied to accident data to identify failures across system levels. The method also supports statistical analysis of the relationships that exist between failures, across various levels. However, a drawback of this method is that it is highly dependent on the quality of data available, making it often difficult to identify failures at higher system levels (Salmon et al. 2012). The Systems-Theoretic Accident Model and Processes (STAMP) method uses a hierarchical control structure diagram to describe failures at each

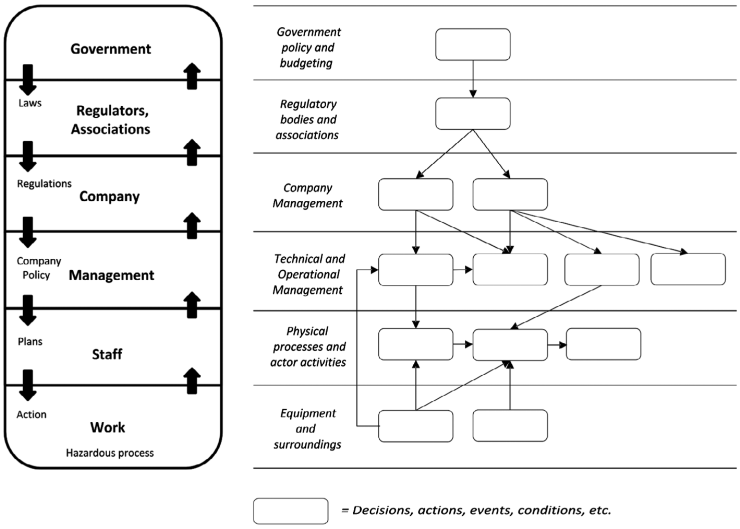

Figure 1. Rasmussen's RMF and Accimap method.

level of control (Leveson 2004). The method allows modelling of non-linear interactions and relationships between components; however, it is complex in application, which has raised questions regarding its reliability (Salmon et al. 2012).

Both the HFACS and STAMP methods focus on identification of failures across work systems. In contrast, a key feature of Rasmussen's Risk Management Framework and Accimap method is that they are generic in nature. Neither the framework, nor method, use taxonomies of failure modes, which supports their flexibility in application (Salmon et al. 2010, 2016). It is for these reasons Donovan, Salmon, and Lenné (2016) proposed the framework, method and the CDM as suitable methods through which to examine safety leadership from a systems perspective.

The framework describes work systems as comprised of various levels (Figure 1), and is underpinned by the premise that safety is an emergent property which is impacted by the decisions, behaviours and actions of actors across all levels of a work system, not just by those of frontline operators alone (Rasmussen 1997). In conjunction with the framework, Rasmussen developed the Accimap method (Rasmussen 1997), a generic approach for exploring and understanding accidents. The method enables development of a graphical representation of elements, actors and related decisions and actions involved in an accident, illustrating contributory factors and interrelationships that existed across the system to allow an accident to occur. Figure 1 shows Rasmussen's RMF and corresponding Accimap for describing work systems.

Both the framework and method have been used to examine catastrophic accidents across a range of domains (e.g. Branford 2011; Cassano-Piche, Vicente, and Jamieson 2009; Hopkins 2000; Newnam and Goode 2015; Salmon et al. 2010, 2014; Stevens and Salmon 2016; Trotter, Salmon, and Lenné 2013; Underwood and Waterson 2014; Vicente and Christoffersen 2006; Woo and Vicente 2003). To date however, and despite widespread demand (e.g. Dekker 2011; Hollnagel 2012, 2014), little focus has been placed on their application to examine non-failure scenarios and positive aspects of system performance (e.g. Trotter, Salmon, and Lenné 2014). Salmon et al. (2016) recently discussed the importance of applying systems-thinking methods to examine such events, as opposed to only using them to examine events that had an adverse safety outcome.

1.3. Rasmussen's predictions and safety leadership

Rasmussen's RMF makes a series of predictions regarding safety and performance in complex socio-technical systems (Rasmussen 1997). These predictions typically form the basis for evaluating the applicability of the framework to new contexts (e.g. Cassano-Piche, Vicente, and Jamieson 2009; Jenkins et al. 2010; Salmon et al. 2010, 2014). In their original form, the predictions relate to understanding factors within systems that have the potential to have an adverse impact on safety (i.e. sub-optimal performance, lack of vertical integration, the migration of work practices across work systems, etc.). With this in mind, in the present analysis, the predictions were required to be adapted to fit the safety leadership context (Table 1). That is, rather than

Table 1. Rasmussen's (1997) predictions regarding accidents in complex socio-technical systems adapted to the safety leadership context.

Rasmussen's original prediction	Amended prediction in the safety leadership context	Example of performance in the safety leadership context
1. Performance is an emergent property of a complex socio-technical system. It is impacted by the decisions of all of the actors – politicians, managers, safety officers and work planners – not just the front-line workers alone	1. Safety Leadership is an emergent property of a complex socio-technical system. It is impacted by the decisions of all of the actors – politicians, managers, safety officers and work planners – not just front-line workers alone	A safety leadership decision to stop production does not occur in isolation, rather it emerges as a result of the sharing and integration of information, communications and interactions between multiple actors within the system. This includes interactions between frontline workers, supervisors, managers, safety team members and directors
2. Sub-optimal performance is usually caused by multiple contributing factors, not just a single catastrophic decision or action	2. Safety leadership involves multiple contributing factors, not just a single decision or action	Multiple contributing factors inform safety leadership decision-making, including communications between multiple actors within the system, as well as consideration of supporting system documentation (i.e. Standard Operating Procedures, emergency response plans) and data (i.e. safety and systems data)
3. Sub-optimal performance can result from a lack of vertical integration (i.e. mismatches) across levels of a complex socio-technical system, not just from deficiencies at any one level	3. Safety leadership is dependent on the presence of vertical integration across different levels of a complex socio-technical system	Communication must occur across multiple levels within an organisational system. This vertical integration can occur both formally and informally, and can be verbal, written or system data exchanges across and between levels, actors and groups
4. The lack of vertical integration is caused, in part, by a lack of feedback across levels of a complex socio-technical system. Actors at each level cannot see how their decisions interact with those made by actors at other levels, so the threats to safety are far from obvious before an accident	4. Vertical integration is supported, in part, by the presence of feedback across levels of a complex socio-technical system, which in turn supports optimal safety leadership	A safety concern relating to operational risk may be raised by front-line workers to a supervisor. The supervisor provides the support and resources to address the concern, and feedback to the workforce to advise of actions taken. This demonstrates a two-way dialogue between leaders and the workforce across system levels
5. Work practices in a complex socio-technical system are not static. They will migrate over time under the influence of a cost gradient driven by financial pressures in an aggressive competitive environment and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance	5. Work practices are not static and migrate over time under the influence of many factors. One integral factor is the form and level of safety leadership present within an organisation. Appropriate safety leadership decisions and actions can assist in the migration away from safety boundaries. On the other hand, inadequate or inappropriate safety leadership decisions and actions can cause migration toward safety boundaries	Integrating available information and considering all interactions, a decision to stop production is enacted to ensure a safe operational and working environment is maintained. This decision ensures migration away from safety boundaries. In contrast, given the same communications and access to information, a decision to continue with production may cause migration towards safety boundaries
6. The migration of work practices can occur at multiple levels of a complex socio-technical system, not just one level alone	6. Safety leadership assisting migration away from safety boundaries can occur at multiple levels of a complex socio-technical system, not just one level alone	In consultation with Subject Matter Expertise, system data and their manager, a supervisor may execute a decision to stop production in the interests of safety. Likewise, a manager may execute the same decision in consultation with their leader, and subordinate team to assist with migration away from safety boundaries
7. Migration of work practices causes the system's defences to degrade and erode gradually over time, not all at once. Sub-optimal performance is released by a combination of this migration in work practices and a triggering event, not just by an unusual action or an entirely new, one-time threat to safety	7. Migration of work practices causes the system's defences to degrade and erode gradually over time, not all at once. Sub-optimal performance is released by a combination of this migration in work practices and a triggering event. Appropriate safety leadership practices and decision-making can strengthen the system's defences, with optimal performance maintained by detecting and responding to potentially harmful triggering events and threats to safety	Safety concerns raised and operational deviations communicated through the organisational system assist with the detection of threats to safety (i.e. unstable operations, hazard identification), which allow and support appropriate safety leadership responses to reduce or mitigate the risks to safety

focusing on identifying factors that negatively impact on performance, the predictions were adapted to focus on factors that support safe performance (i.e. optimal safety leadership performance, the presence of vertical integration across work systems and safety leadership practices and decision-making which assists in the migration away from safety boundaries). The adapted predictions were subsequently examined in light of the case study findings to determine if applying a systems-based analysis approach is appropriate for examining safety leadership, and whether their application in the current context supports improved learning from incidents.

1.4. Case study – Bingham Canyon high-wall failure

The present case study relates to a significant landslide event which occurred at an operational mine site in the USA. The incident was selected for examination due to its significance in both magnitude, and resulting positive safety outcome; no injury or loss of life was incurred. In addition, the system was quickly able to return to normal functioning, which is a key characteristic of resilient safety systems. A key finding in the incident investigation cited '… early detection of the failure allowed the operation to effectively plan, manage and respond to the event, and ensure

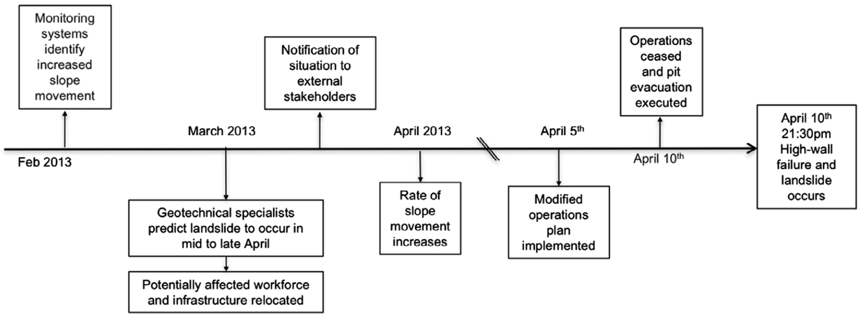

Figure 2. Incident timeline adapted from CDM interviews.

the safety of all workers was maintained …' (Rio Tinto 2013). As such, the incident provided an important and unique opportunity to identify and explore the safety leadership decisions and actions that supported the safe outcome.

The incident occurred in 2013 when a significant high-wall failure and landslide occurred, dislodging more than 150 million tons of earth. In the months preceding the incident, the organisation had identified increasing ground movement on the high-wall, and had implemented measures to manage the safety risks associated with a potential landslide. Ahead of the incident, multiple layers of protection were in place which provided considerable advanced warning, to ensure operations were ceased well in advance of the landslide. Figure 2 below provides an overview of the incident timeline developed from the CDM interviews.

2. Methodology

2.1. Participants

Eight individuals from the mining company participated in the study, and represented five leadership levels within the organisation. The sample size is consistent with other literature having applied the CDM for incident analysis in mining (Horberry and Cooke 2010). Due to the sample size, detail regarding the specific leadership positions interviewed has been withheld to protect anonymity. The average age of participants was 46.1 years (SD = 8.57), with the average time in role at the time of the incident 2.57 years (SD = 2.82).

2.2. Procedure

2.2.1. Data collection

CDM interviews were held with each participant. CDM is a semi-structured interview approach that uses cognitive probes to elicit information regarding cognition and decision-making during critical incidents (Klein, Calderwood, and MacGregor 1989). The use of the CDM has previously been demonstrated as a reliable and robust approach for identifying factors influencing safety across organisational systems (e.g. Goode et al. 2013; Plant and Stanton 2013). Goode et al. (2013) demonstrated the use of the CDM technique to identify system-wide factors that contributed to worker manual handling injuries, and then mapped the factors into Rasmussen's RMF. Further, the CDM has been shown to be remarkably reliable and robust for data capture relating to incident recall (Plant and Stanton 2013). In a test–retest study, Plant and Stanton (2013) demonstrated minimal degradation in memory after a prolonged period (approximately 3 years). This was attributed to the use of the structured probes, which ensured the same questions were asked, and therefore similar responses were elicited. The CDM interviews in the current study were conducted seventeen months after the incident, which fell within the timeframe used for the Plant and Stanton (2013) study. As such, the potential for memory degradation in the current study was judged to be minimal.

The interviews were conducted by a Human Factors researcher with experience applying CDM. Each participant providing written consent to be interviewed and voice recorded. The standard set of CDM probes listed in Stanton et al. (2013) were used to explore key decision points for each participant, in conjunction with the following additional probe designed to elicit information on potential contributory factors across various system levels (e.g. *did you feel like you were constrained/ supported by; standards/rules/ procedures, higher organisational influences, regulation?*).

During each interview, participants constructed an incident timeline outlining their involvement in the incident. Individual critical decisions were identified along the timeline, and agreed for inclusion by both the participant and Human Factors researcher, with each interview lasting approximately 2 h.

2.2.2. Data analysis

The audio data from each interview was transcribed verbatim. Using the approach outlined by Stanton et al. (2013), responses were coded against their associated CDM probe question for each participant. Corresponding elements, activities and influencing factors were identified within the responses for each CDM probe. An inter-rater coding reliability test was undertaken by a second analyst, using the CDM data for two randomly selected participants. Disagreements in terms of the context of participant responses, and corresponding elements, activities and influencing factors present, were resolved through discussion between the analysts. A reliability score was calculated based on percentage agreement regarding the context of participant's responses to probes; that is the number of agreements, divided by the number of times coding was possible, multiplied by 100. This approach is in accordance with the literature, which indicates this is the most suitable way to calculate reliability scores with data of this nature (Plant and Stanton 2013). A percentage agreement of 78.3% was achieved, which is a substantial level of agreement when compared to other studies in high-risk domains (Read, Salmon, and Lenné 2015).

Next, using the approach outlined in Hopkins (2009), the interview data were coded into influencing factors consistent with the six levels of Rasmussen's RMF (Rasmussen 1997). For example, radar data being used to monitor ground movement (IBIS radar data) was coded as an influencing factor that alerted Subject Matter Experts (SMEs) to the moving slope gradient, and was placed at the equipment and surroundings level on the framework as it was provided by a piece of technology. Alternatively, the engagement of internal and external SME support was influencing factors in forming a technical analysis team, which was placed at the 'Physical Process and Actor Activity' level. Influencing factors and elements identified were reviewed by the co-authors, in relation to the work system level at which they resided, with disagreements resolved through discussion.

Following this, CDM decisions for each participant were extracted and placed onto the framework per the level at which they were executed in the organisational system. For example, decisions enacted by the mine leadership team were placed at the 'Management' level. Relationships and links between critical decisions and influencing factors and elements were identified based on the text within the transcripts, and mapped onto the framework. Where an explicit link was mentioned by a participant between a critical decision and influencing factor or element, a connection was made to indicate the direction of influence. An Accimap was constructed from the coded data using the approach also outlined in Hopkins (2009). This included the key safety leadership decisions and actions extracted from the CDM data analysis to describe and map the contribution of safety leadership over the course of the incident.

To ensure accuracy and validity of the overall approach, the coding and resulting Accimap was reviewed by the second and third authors who have significant experience in the application of accident analysis methods (Goode et al. 2013; Lenné et al. 2012; Salmon et al. 2010). The Accimap was further reviewed by three SMEs familiar with the incident, with discrepancies resolved through discussion between the researchers and the SMEs until consensus was reached.

3. Results

3.1. Safety leadership decisions and actions

Fifteen safety leadership decisions and actions related to the safe outcome were identified and examined in the CDM interviews. All fifteen decisions were identified by the participants, and agreed by the analyst and individual participants for inclusion.

Figure 3 provides an overview of the safety leadership decisions and actions identified and explored which supported the safe outcome, as mapped onto Rasmussen's RMF. The decisions were mapped onto the framework based on which actors were responsible for them, and at what Level (L) they resided within the work system.

The 15 decisions and actions explored represent the positive contribution of safety leadership in supporting the safe outcome of the incident. Over half of the decisions explored (n = 8) related to Communications and Engagement-based activities (CE), for example, L3.1 represented a decision to notify upward of the increasing slope movement, while L3.8 related to engagement of the workforce by senior operational leadership regarding the developing situation.

Four decisions were linked to Organisational Processes (OP), for example, L3.3 related to execution of the organisation's internal 'Management of Change' process to evacuate buildings in the identified failure zone, while L3.9 the decision to 'Move to Orange' represented execution of the critical decision to shut down operations and evacuate the mine, in line with the Trigger Action Response Plan (TARP). These decisions were identified as important for inclusion as they demonstrated execution in line with existing organisational processes, the importance of ensuring adherence and not 'opting out' which was noted as supporting the ultimately safe outcome.

The remaining decisions and actions relate to specific Planning (P) activities that were informed by subsequent developments in the evolution of the incident. For example, L3.4 represented the need to bring together a key group of personnel to form an operational planning team to modify mine operations in light of the developing situation, while L3.6 related to a 'mindset shift' in which

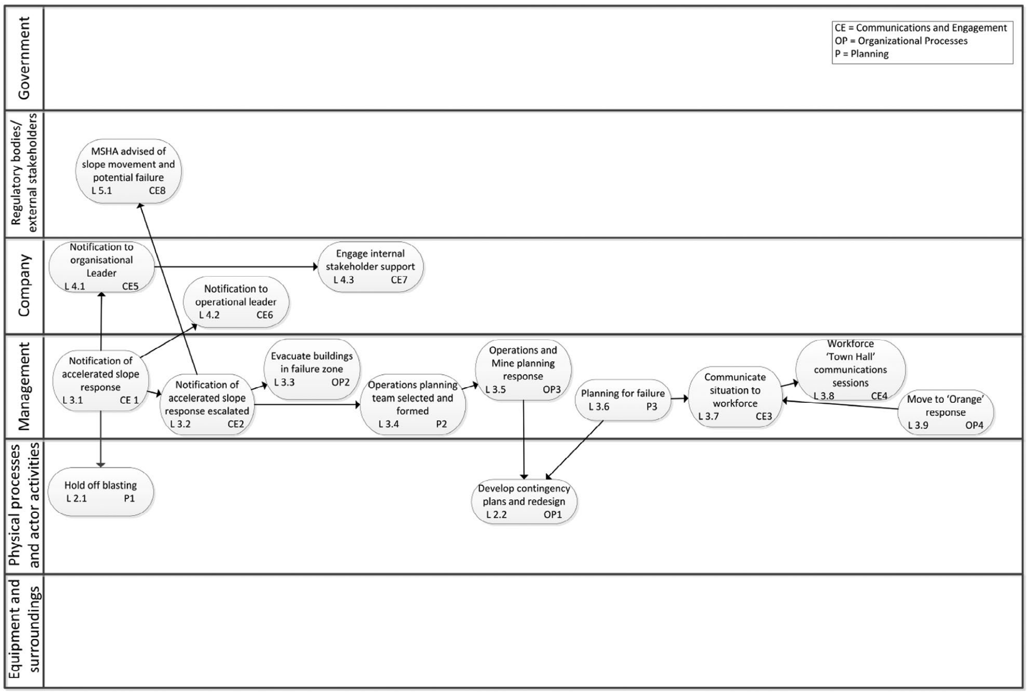

Figure 3. Safety leadership decisions and actions identified within CDM interviews.

activities became solely about 'Planning for Failure' and ceasing exploration of options aimed at prevention.

3.2. Accimap

The Accimap for the incident is presented in Figure 4. Derived from the CDM data, the Accimap analysis presents the safety leadership decisions and actions, and corresponding influencing factors and elements which contributed to the maintenance of safety throughout the incident. The grey oval elements represent the 15 safety leadership decisions and actions explored.

The CDM data and resulting Accimap analysis provide the evidence to support examination of Rasmussen's predictions in the safety leadership context. Examination of the predictions is presented in Section 3.3.

3.3. Examining Rasmussen's predictions in the safety leadership context

3.3.1. Safety leadership is an emergent property, which is impacted by the decisions of actors across multiple levels of the system

The findings of the analysis provide partial support for Prediction 1, that safety leadership is an emergent property of complex socio-technical systems. The CDM data revealed 15 safety leadership decisions and actions identified (Figure 3) were undertaken by multiple actors, across multiple system levels. Specifically, they covered five leadership levels residing over four system levels; Physical Processes and Actor Activities, Management, Company, and Regulatory Bodies and External Stakeholders. Prediction 1 was only considered partially supported, as the analysis did not identify any specific safety leadership elements as residing at the highest system level (Government) within Rasmussen's RMF.

The analysis supports the component of prediction 1 that safety leadership is impacted by decisions of multiple actors across the system. For each decision examined, participants were reliant on information being provided by both lower and higher system levels to aid decision-making, from both human and non-human actors (such as physical systems and documentation). Important cues emerged regarding the reliability and credibility of system information and verbal communications being provided, the integration of information and ability to execute decisions in line with ensuring the safety of all personnel was maintained. For example, had the initial notification (L3.1) not occurred, or had it occurred later than it did, the execution of subsequent decisions and actions

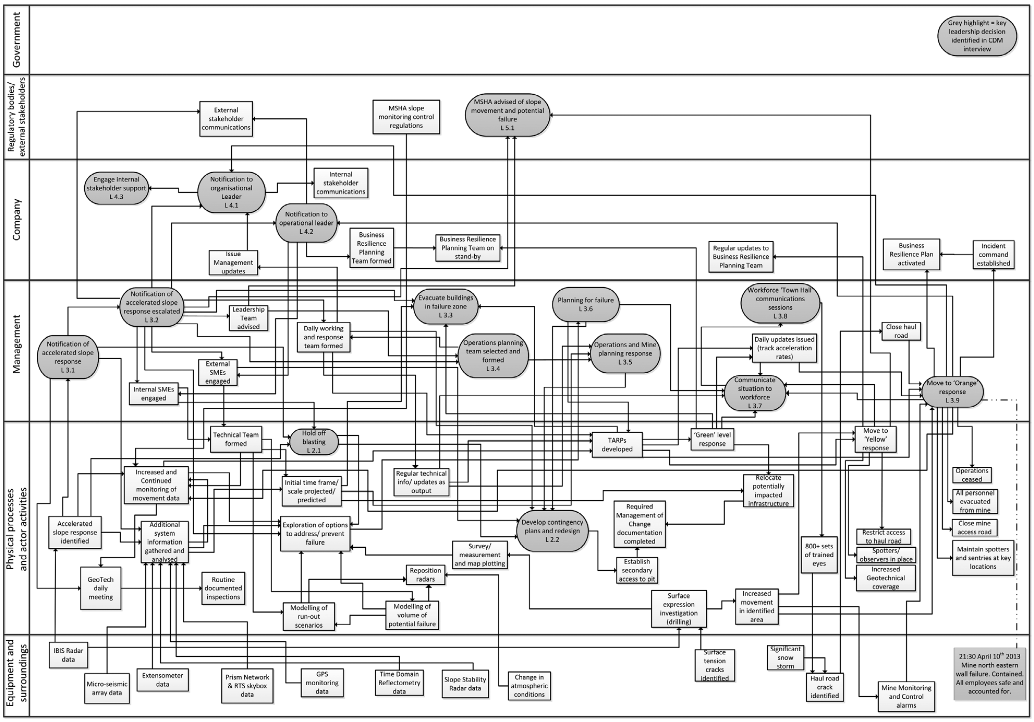

Figure 4. Accimap description of the high-wall failure landslide incident.

(L3.2, L3.3, L4.1 and L4.2) would have likely been delayed, thus having the potential to negatively impact on the outcome of the incident.

Figure 5 outlines the CDM cues that underpinned execution of the initial sequence of safety leadership decisions and actions, across multiple system levels.

3.3.2. Safety leadership involves multiple contributing factors, not just a single decision or action

Prediction 2 was supported, with all 15 of safety leadership decisions demonstrating links with at least one other decision across the incident timeline. Furthermore, multiple contributing factors (associated with both human and non-human actors) were identified as enabling or supporting decision-making. For example, the decision to escalate notification (L3.2) was linked to the subsequent decision to advise the senior leadership team of the situation, and to forming a dedicated technical team to explore options aimed at preventing the failure from occurring, in concurrence with modelling run out scenarios and the volume of potential failure should a landslide occur. The escalated notification (L3.2) was also linked to the decisions to form an operational planning team (L3.4), and to develop and execute an operational response (L3.5) and mine redesign plan (L2.2). These early decisions were key to ensuring the ongoing safety of the overall system, and demonstrate maintaining safe performance was linked to multiple contributing factors.

3.3.3. Safety leadership is dependent on the presence of vertical integration across different system levels

The analysis indicates the flow, accuracy and importance of information propagating up from lower system levels to inform decisions and actions at higher levels, thus supporting the third of Rasmussen's predictions. For example, the provision of technical system data from the 'Equipment and Surroundings' system level, triggered the initial notification and escalation to senior Mine leadership, which precipitated further escalation to leaders at the 'Company' level. In advising Company leaders, a number of communications-based decisions and actions were enacted to inform and seek support both upwards and outwards within the wider organisation (L4.3) and to inform external stakeholders who

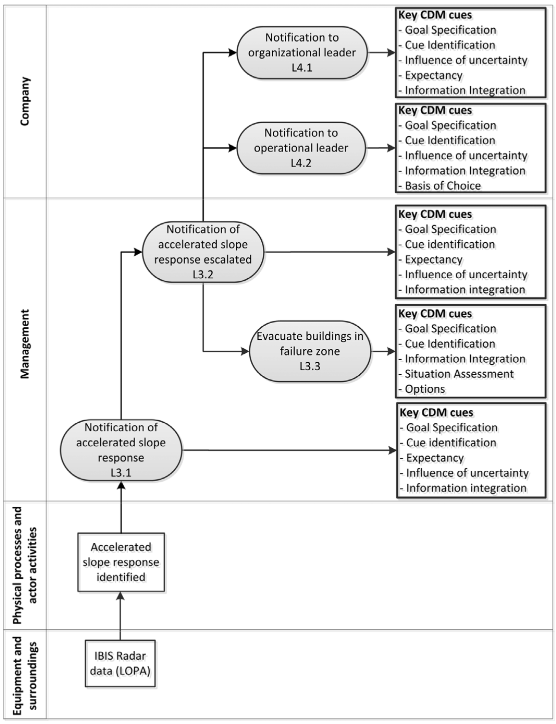

Figure 5. Initial sequence of safety leadership decisions.

would be impacted when the event occurred. Regular two-way communications were subsequently established to enable ongoing internal and external informing. Information was coordinated and communicated both upward and downward from various system levels, which was viewed as important for ensuring the consistency of information being shared by the leadership team as a whole.

3.3.4. Vertical integration is supported by feedback across multiple levels

Communication and feedback played a key role in supporting safety leadership decisions and actions, with both formal and informal communication and feedback loops identified and recognised by participants as contributing to the safe outcome. Feedback is evident with the identification and escalation of concerns to the leadership team regarding the formation of a crack in the haul road on the day prior to the incident occurring (Figure 6). This escalation was promptly responded to with the closure of the haul road, and precipitated the decision to 'Move to Orange' (executing the next TARP level) which saw operations ceased and the mine evacuated, ensuring the safety of all personnel. This sequence is described in Figure 6.

3.3.5. Safety leadership assisted in the migration away from safety boundaries

Safety leadership decisions and actions were shown to assist in the migration away from safety boundaries. Five of the study participants reported a re-distribution of authority regarding decision-making throughout the incident to lower levels within the organisational system. This was viewed as important in providing a level of empowerment and authority to leaders that resided at lower system levels, permitting execution of decisions and actions at those levels to support performance and 'migration away from safety boundaries'. This empowerment provided for a level of efficiency in that decisions were timely and weren't 'waited upon', which would apply pressure to any delayed decision.

An example relates to the decision to 'Hold off blasting' (L2.1). In being notified of the initial identification of accelerated slope response, a decision was made to modify planned operations and hold off blasting a potentially affected area of the Mine (L2.1) while further analysis was conducted to understand the significance of the situation. This decision resided at the technical specialist level (see Figure 4) and afforded additional time for the analysis of technical information to inform subsequent safety, operational planning and response activities, thus supporting

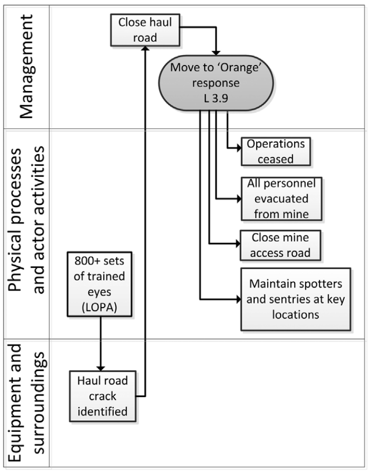

Figure 6. 'Move to Orange' influencing elements and factors.

migration away from safety boundaries and enabling safety performance to be maintained.

3.3.6. Safety leadership assisting migration away from safety boundaries occurs across multiple system levels

Safety leadership decisions and actions were evident across multiple levels of the organisational system, which assisted in migration away from safety boundaries. An important example is evident when it became clear that response activities were not going to prevent the landslide from ultimately occurring. Five participants reported that a 'conscious and deliberate' mindset shift was enacted by the leadership team to move from focusing on activities aimed at prevention, to actively 'Planning for Failure' (L3.6). This shift in safety leadership practices was acknowledged as both 'critical and essential', and underpinned the subsequent decisions to communicate the developing situation to the workforce (L3.7), and schedule the series of 'Town Hall communications sessions' (L3.8), which were executed across multiple levels within the system.

3.3.7. Safety leadership strengthens systems defences, through detecting and appropriately responding to potentially harmful events and threats to safety

The analysis supports the tenet that safety leadership strengthened the systems defences, thus supporting prediction 7. The emergence of decisions and actions was evident over the course of the incident, with each of the fifteen decisions and actions demonstrating a level of flexibility and adaptiveness in responding to the changing situation.

An example relates to the engagement of the workforce in the management of the incident. The importance of their involvement was recognised in terms of 'giving the workforce something they could control', which manifested as the '800+ sets of trained eyes' layer of protection. The workforce was encouraged to 'speak up' and raise any safety concerns to their leaders regarding unusual occurrences they may see in the course of their daily work. This ultimately led to the crack in the haul road being identified by a frontline member of the workforce. The discovery was communicated and escalated through the line leadership, which precipitated the closure of the haul road and importantly, the critical final decision to 'Move to Orange' (L3.9). In ceasing operations and evacuating the Mine, this decision underpinned the positive safety outcome by removing the possibility of harm, injury or fatality occurring to any personnel.

3.4. Summary of findings

Table 2 provides an overview of the predictions examined, and examples of the supporting evidence present in the case study analysis.

4. Discussion

The aim of this article was to apply a systems-thinking approach to the examination of safety leadership, and in doing so, support improved learning from incidents. The CDM was used to gather information to support the development of an Accimap description of a large mining landslide incident where importantly, no injuries or fatalities were incurred. Rasmussen's predictions were examined in the safety leadership context, with the analysis demonstrating the utility of applying systems-thinking methods, to examine characteristics of positive system performance, such as safety leadership. Safety leadership is established as a systems phenomenon, with the distribution of decisions and actions evident across leader, and system levels. The presence of vertical integration was also identified as key to supporting the successful safety outcome. Further, the approach supported improved learning from incidents in terms of what 'went right', which is a key requirement of contemporary safety and resilience models.

4.1. Examining safety leadership – applying systems-thinking vs. existing methods?

A key outcome of the present study relates to the demonstrated advancement in methodological approach to examining safety leadership. The merits of adopting systems-thinking methods are clear, with the methods used offering several advantages over existing, traditional

Table 2. Examples of safety leadership decisions and actions consistent with Rasmussen's predictions.

Prediction	Evidence
1. Safety Leadership is an emergent property of a complex socio-technical system. It is impacted by the decisions of all of the actors – politicians, managers, safety officers and work planners – not just frontline workers alone	Emergent safety leadership decisions and actions were evident across five levels of Rasmussen's RMF (Figure 3), with relationships between decisions and actions demonstrated both within and across different levels of the work system (Figure 4)
2. Safety leadership involves multiple contributing factors, not just a single decision or action	Multiple contributing factors were identified as enabling or supporting safety leadership decision-making across the work system (Figure 4). None of the decisions identified can be considered independently responsible, in isolation, for the overall safe outcome of the incident
3. Safety leadership is dependent on the presence of vertical integration across different levels of a complex socio-technical system	The Accimap (Figure 4) demonstrates the open flow and exchange of information in both an upward and downward direction, across multiple system levels, which aided safety leadership decision-making
4. Vertical integration is supported, in part, by the presence of feedback across levels of a complex socio-technical system, which in turn supports optimal safety leadership	Feedback is evident with the identification and escalation of concerns regarding the formation of a crack in the haul road (Figure 6). This was promptly responded to with the closure of the haul road, and precipitated the decision to 'Move to Orange', which saw operations ceased and the mine evacuated, ensuring the safety of all personnel
5. Work practices are not static and migrate over time under the influence of many factors. One integral factor is the form and level of safety leadership present within an organisation. Appropriate safety leadership decisions and actions can assist in the migration away from safety boundaries. On the other hand, inadequate or inappropriate safety leadership decisions and actions can cause migration toward safety boundaries	Safety leadership decision-making was shown to assist in the migration away from safety boundaries. An example relates to the decision to 'hold off blasting' a potentially affected area of the mine (L2.1) while further analysis was conducted to understand the significance of the situation. This decision demonstrated the commitment to safety, and thus migration away from safety boundaries
6. Safety leadership assisting migration away from safety boundaries can occur at multiple levels of a complex socio-technical system, not just one level alone	The Accimap (Figure 4) demonstrates safety leadership assisting migration away from safety boundaries occurred across multiple levels within the work system. An example relates to the decision to 'Plan for Failure' (L3.6), which occurred at the management system level
7. Migration of work practices causes the system's defences to degrade and erode gradually over time, not all at once. Sub-optimal performance is released by a combination of this migration in work practices and a triggering event. Appropriate safety leadership practices and decision-making can strengthen the system's defences, with optimal performance maintained by detecting and responding to potentially harmful triggering events and threats to safety	A key example relates to the engagement of the workforce in the management of the incident. Through multiple communication channels, the workforce was encouraged to raise any safety concerns to their leaders regarding unusual occurrences they may see in the course of their daily work. This ultimately led to the crack in the haul road being identified by a front-line member of the workforce. The discovery lead to the subsequent closure of the haul road and importantly, the critical final safety leadership decision to 'Move to Orange' (L3.9)

approaches. First, the use of the CDM provides a considerable advance in knowledge as it generates new and unique insights into the ways decision-making manifests in real-world incidents. The findings confirm the importance of examining decision-making as a key component of leadership (Evans and Ward 2007; Rogers and Blenko 2006), as opposed to purely focusing on follower rated perceptions of safety leadership (e.g. Clarke and Ward 2006; de Koster, Stam, and Balk 2011; Neilsen et al. 2013). Interviewing leaders across multiple levels allowed insight to be directly gained into the types of safety leadership decisions made during an incident, and important situational factors and elements that assisted decision-making. This level of insight could not have been gained had traditional approaches been used.

Furthermore, the approach demonstrates the importance of examining and understanding safety leadership across multiple leader and work system levels (e.g. Supervisors, Managers and Managing Directors), rather than focusing on the frontline-supervisory relationship level alone (e.g. Conchie 2013; Hystad, Bartone, and Eid 2013; Martínez-Córcoles, Schöbel et al. 2012; Zohar and Tenne-Gazit 2008). The approach enabled exploration of the network of links between each decision and action, and influencing factors and elements across the system, which helped shape performance.

4.2. *Safety leadership as a systems phenomenon*

An additional key outcome of the methodological approach applied, relates to the establishment of safety leadership as a systems phenomenon. Support was provided through examining Rasmussen's predictions in the safety leadership context, with the analysis demonstrating support for all seven predictions.

Confirming Rasmussen's predictions in the safety leadership context provides two key contributions. First, the results demonstrate safety leadership decisions and actions are characteristic of complex socio-technical system performance, and that the safe performance of such systems is impacted by various actors, decisions and actions, across various system levels (Rasmussen 1997). This result indicates the 'control' of safety in terms of decision-making and action was distributed across the system rather than being centralised, or contained to one leader or system level. Distributed control is recognised as a key feature in supporting safety within complex socio-technical systems (Flach et al. 2015; Reiman et al. 2014), with the present study confirming this is also true within the safety leadership context. The distribution across the organisational system supported the emergence of adaptive and responsive decisions and actions (Flach et al. 2015; Hoffmeister et al. 2013), confirming safety leadership decision-making as an important 'source of safety' during the incident examined (Karwowski, Jacobs, and Soares 2012).

Second, the analysis demonstrates the importance of establishing and promoting vertical integration as a key system characteristic to support safety leadership. The flow and exchange of information across multiple system levels was key to informing the execution of the safety leadership decisions and actions identified. The sharing of critical safety-related information was strong across various system and leadership levels, with feedback further strengthening the interactions and connections identified. The importance of information sharing across and between actors (both human and non-human) in complex systems has been well emphasised as vital for supporting safety (Anderson and McDaniel 2000; Flach et al. 2015; Goldstein 1994; Knowles 2001; McMillan 2008; Nonaka 1988). The present study provides further support to this in terms of promoting vertical integration across work systems. Interactions, and the open sharing of information between actors, is crucial for work systems to be able to function in a structured way, and also to demonstrate necessary flexibility and responsiveness when needed, particularly during times of operational deviation (Goldstein, Hazy, and Lichtenstein 2010; McDaniel and Driebe 2001). As such, the distribution of safety leadership, and presence of vertical integration were crucial to supporting the ultimately successful safety outcome of the incident.

4.3. Learning from incidents – what 'went right'?

A unique contribution lies in the application of systems-based analysis methods to examine and learn from incidents in terms of what went right. The need to understand factors that support positive performance, as opposed to only examining scenarios with adverse safety outcomes (Hollnagel et al. 2013) is a key requirement within emerging areas of safety science, such as resilience engineering and Safety II (Hollnagel 2014). Examining normal behaviours within an accident scenario (Dekker 2011; Leveson 2004; Rasmussen 1997), such as safety leadership decision-making, provides a powerful opportunity to contribute in this regard.

The present study builds on existing research whereby systems-thinking methods have been applied to examine and understand positive system performance characteristics (Trotter, Salmon, and Lenné 2014). In doing so, the analysis demonstrates the approach used, specifically the CDM, RMF and Accimap, were appropriate for the present analysis. The methods demonstrated sufficiently flexibility in application to examine a non-catastrophic accident scenario to explore the contribution of safety leadership decisions and actions to maintaining safety. Thus, the approach provides support for applying these methods to explore and understand incidents in terms of elements that support safe performance (Dekker 2011; Hollnagel 2012; Salmon et al. 2016).

By way of comparison, a notable limitation of other popular accident analysis methods such as Systems-Theoretic Accident Model and Processes (STAMP; Leveson 2004) and Human Factors Analysis and Classification System (HFACS; Wiegmann and Shappell 2003) is that they rely on the application of error taxonomies and failure modes, which force identification of failures (Salmon et al. 2016). An undesirable outcome of this is that normal, and indeed, positive behaviours may not be identified during accident analysis efforts. An even more concerning outcome is that organisation's applying such methods may not develop a sufficient understanding of accidents to prevent future recurrence (Salmon et al. 2016). Therefore, extending and applying generic accident analysis methods such as Rasmussen's Risk Management Framework and Accimap method to examine normal behaviours facilitates learning from incidents in a positive sense.

While it is acknowledged safety leadership decisions and actions are only one small piece of the positive system performance puzzle, the current study demonstrates the merit of investing effort in further extending and applying systems-thinking methods to support improved learning from incidents.

4.4. A positive lead – the way forward?

The findings confirm safety leadership should be considered central to the work of leaders across all levels; not just those who engage with, and supervise workers at the frontline alone (Rasmussen 1997). Opportunities therefore exist to invest time and effort in examining and developing safety leadership capabilities across multiple leader levels within work systems. Understanding job roles, and the associated decisions and actions that are likely to emerge at different leader and system levels (i.e. communication based decisions, execution of organisational processes, etc.) is key to developing and promoting supportive capabilities in this area.

Second, the importance of establishing and promoting vertical integration should not be overlooked as a key element to support safety leadership. The open flow and exchange of information across system levels is vital to support the effectiveness of decision-making. This is of particular importance during times of crisis (Knowles 2002), with an established 'culture' of vertical integration required prior to the emergence of negative events (Reiman et al. 2014). Understanding how safety critical information is sought and exchanged across systems will assist organisations with setting up effective formal, and informal, communication channels. Furthermore, with constructs such as trust and encouraging upward safety communications (Conchie, Taylor, and Donald 2012; Hofmann and Morgeson 1999) recognised as important within a safety leadership context, understanding effective leadership attributes and behaviours which promote the open flow and exchange of information is essential to this process (Donovan, Salmon, and Lenné 2016).

Lastly, future efforts to examine safety leadership should be underpinned by systems-theory based analysis approaches. This would enable new insights to be generated into how safety leadership evolves across different work systems and contexts. In addition, key systems-thinking concepts, such as vertical integration and distribution of control, should feature as essential areas of focus. Moreover, examination of these concepts should occur in a normal operational setting, which may yield important insight into how resilient systems develop, respond and adapt to times of pressure or operational deviation. It may also assist to expand the insights gathered from this single case study to determine their relevance across other events and contexts.

It should be noted that the application of the CDM yielded a rich source of data about the incident. While the use of retrospective interview techniques can be questioned (Klein, Calderwood, and MacGregor 1989; Stanton et al. 2013), the findings of this case study demonstrate the CDM was useful to gain insight into safety leadership decision-making and action. Participants were capable of reflecting on individual decisions made throughout the course of the incident, and through this were able to communicate valuable insight into key factors that supported effective safety leadership. Moreover, the focus of the CDM interviews was understanding the systemic and contextual factors that supported safety leadership decision-making, not the actual step by step process of decision-making. Potential limitations of retrospective interviews and single case study samples could be addressed in future research through examination of safety leadership decisions and actions within a normal operational context. These may be supported by observations, as well as for example, verbal protocol analysis (Stanton et al. 2013) during specific task execution.

5. Conclusion

This paper applied a systems-thinking approach to examine safety leadership decisions and actions during a significant mining landslide incident where importantly, no injuries or fatalities were sustained. The approach tested the applicability of Rasmussen's RMF and Accimap method, using the Accimap output to examine Rasmussen's (1997) predictions in the safety leadership context. The analysis established safety leadership as a systems phenomenon, and demonstrated the utility in applying systems-thinking methods to examine safety leadership as a characteristic of positive system performance. This is a key requirement of contemporary safety and resilience models.

In conclusion, future safety leadership research endeavours should be underpinned by systems-thinking-based methodological and conceptual approaches. Such approaches should focus on key systems-thinking concepts including the promotion of vertical integration and distribution of safety leadership as key to supporting safe performance. Moreover, examination of these concepts should occur in a normal operational setting, rather than a failure context, to yield insight into how resilient systems develop, respond and adapt under times of pressure or operational deviation. This would further expand the insights gathered from this case study to determine their relevance across events and contexts.

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4.2 Discussion

The aim of this study was to examine safety leadership from a systems perspective, applying Rasmussen's RMF, AcciMap Method and the CDM to identify the factors that influenced safety leadership to contribute to the safe outcome of the critical incident examined. A full representation of the AcciMap presented in this chapter is contained in Appendix 2.

Chapter 2 defined a systems-based definition of safety leadership to better reflect the role safety leadership plays in supporting safe system functioning. This set the requirement for the methodology applied in Study 1 to adopt an integrated approach to explore safety leadership in terms of decision-making, behaviours and actions across the work system. In application, the methodology achieved the study aims, and in doing so facilitated improved understanding of safety leadership within complex socio-technical systems both in terms of the concept of safety leadership itself, and its existence as an emergent systems phenomenon. The key findings are now discussed.

The applied methodology highlighted important insight into the factors that supported and influenced safety leadership during the incident examined. The use of the CDM facilitated identification of factors that influenced safety leadership across the work system by allowing examination of decisions in terms of their cognitive basis, and with reference to the factors across the work system that informed them to support the incidents safe outcome. Moreover, the use of the CDM generated new insight by demonstrating the importance of decision-making as a key component of the safety leadership concept. This confirmed safety leadership is much broader and more complex than its representations in the existing literature (Clarke, 2013; Conchie, 2013; de Souza Costa Neves Cavazotte et al., 2013; Hofmann, Morgeson, & Gerras, 2003; Martínez-Córcoles, Gracia, Tomás, & Peiró, 2011) and confirmed the utility of the systems-based definition of safety leadership outlined in Chapter 2.

Further improved understanding was achieved through the application of Rasmussen's RMF and corresponding AcciMap Method, which permitted mapping of the interactions and interconnections between factors across the work system. In doing so, Rasmussen's adapted predictions regarding safety were able to be tested in the safety leadership context. The findings demonstrated that multiple contributing factors enabled or supported safety leadership decision-making across the work system. This supports recent research demonstrating the role of multiple contributory factors in preventing an incident from progressing to an adverse safety outcome (Thoroman et al., 2019; Thoroman, Salmon, & Goode, 2020). Safety leadership was distributed and occurred across four leader and work system levels, with the migration of work practices evident across three system levels. In conjunction with this, Vertical Integration (VI) was evident across five system levels and was identified as having the greatest influence on supporting and enabling effective safety leadership during the course of the incident. Communications and information sharing between actors (both human and non-human) was strong across five system levels, with feedback further strengthening the interactions and interconnections between the factors identified and leadership decisions, behaviours and actions. The approach showed all seven of Rasmussen's adapted predictions were supported, which established safety leadership as a systems phenomenon. This is a key finding, as it demonstrates the importance of examining and understanding safety leadership from a systems perspective in order to optimise its effectiveness.

4.3 Conclusion

The present findings demonstrate the utility of applying Rasmussen's RMF, AcciMap Method and the CDM interview technique for examining safety leadership from a systems perspective. Safety leadership was established as a systems phenomenon, through evidence-based assessment of the study findings against Rasmussen's adapted predictions regarding safety in complex socio-technical systems. Safety leadership was found to be influenced by a range of factors across the work system, with Vertical Integration (communications and feedback) having the greatest impact in terms of supporting and enabling effective safety leadership.

The findings have implications for the future direction of safety leadership research. In addressing shortcomings identified within the existing literature, Study 1 goes beyond existing favoured approaches used to examine safety leadership to demonstrate the need to consider safety leadership from a systems perspective.

With the utility of the methodological approach now established, a necessary next stage of investigation is to further examine safety leadership across the mining work system. Chapter 5 will provide a further in-depth analysis of the Bingham Canyon Highwall Failure incident in terms of examining the types of decisions that occurred across the work system, the inputs that informed them and the corresponding safety leadership behaviours and practices that underpinned their successful execution.

5 Examining safety leadership decisions, behaviours and actions during a critical incident scenario

Donovan, S.-L., Salmon, P. M., Horberry, T., & Lenné, M. G. (2018) Ending on a positive: Examining the role of safety leadership decisions, behaviours and actions in a critical incident scenario. *Applied Ergonomics*, *66*, 139-150.

5.1 Introduction

Building on the approach and findings presented in the previous chapter, Chapter 5 provides a further in-depth examination of the Bingham Canyon Highwall Failure incident. The present analysis goes considerably beyond that described in the previous chapter by exploring in depth the types of decisions that occurred across the work system, the specific decision elements linked to supporting Vertical Integration and the corresponding effective safety leadership behaviours that occurred to support safety, as linked to decision execution across the system.

To achieve this, Rasmussen's RMF, AcciMap Method and CDM are again applied, this time in conjunction with a self-reporting approach to identify the effective safety leadership behaviours that occurred across the system over the course of the incident. Through incorporation of the self-report method, an integrated perspective of safety leadership was obtained in line with the definition stated in Chapter 2.

The study described in this chapter provides deeper insight and evidence to address the following research questions:

> RQ 2: Can the application of a systems perspective expand understanding of safety leadership within a complex socio-technical mining system?
>
> RQ 3: What factors influence safety leadership within a complex socio-technical mining system and how do these factors interact?

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Ending on a positive: Examining the role of safety leadership decisions, behaviours and actions in a safety critical situation

Sarah-Louise Donovan [a,*], Paul M. Salmon [b], Timothy Horberry [a], Michael G. Lenné [a]

[a] Human Factors Group, Monash University Accident Research Centre (MUARC), Monash Injury Research Institute (MIRI), Building 70, Monash University, Victoria 3800, Australia
[b] Centre for Human Factors and Sociotechnical Systems, Faculty of Arts and Business, University of the Sunshine Coast, Queensland 4558, Australia

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ABSTRACT

Safety leadership is an important factor in supporting safe performance in the workplace. The present case study examined the role of safety leadership during the Bingham Canyon Mine high-wall failure, a significant mining incident in which no fatalities or injuries were incurred. The Critical Decision Method (CDM) was used in conjunction with a self-reporting approach to examine safety leadership in terms of decisions, behaviours and actions that contributed to the incidents' safe outcome. Mapping the analysis onto Rasmussen's Risk Management Framework (Rasmussen, 1997), the findings demonstrate clear links between safety leadership decisions, and emergent behaviours and actions across the work system. Communication and engagement based decisions featured most prominently, and were linked to different leadership practices across the work system. Further, a core sub-set of CDM decision elements were linked to the open flow and exchange of information across the work system, which was critical to supporting the safe outcome. The findings provide practical implications for the development of safety leadership capability to support safety within the mining industry.

1. Introduction

Over the past two decades, a body of research has emerged examining the role of safety leadership in supporting improved performance and outcomes, with important links established between a range of practices, and performance and outcome measures (Clarke, 2013; Yagil and Luria, 2010; Zohar and Luria, 2010).

Traditionally defined, safety leadership refers to the ability of leaders to inspire and motivate followers to achieve common goals (Burns, 1978; Chemers, 1997), with research to date suggesting an overall positive influence on performance and outcomes. However, findings are considered by no means definitive in explaining the relationship. Indeed, a recent review of the literature discussed several deficiencies associated with existing research, particularly in relation to the ability of current conceptual and methodological approaches to effectively describe and examine the influence of safety leadership on performance and outcomes (Donovan et al., 2016). For example, research to date has tended to focus on the overall effectiveness of individual leadership styles in influencing performance (Clarke and Ward, 2006; Hofmann and Morgeson, 1999; Martínez-Córcoles, Schöbel, Gracia, Tomás and Peiró, 2012; Nielsen et al., 2013). In contrast, few studies have examined the underlying attributes of different leadership styles at the individual level, and their respective links to supporting improved performance (Hoffmeister et al., 2013). As a result, little consensus exists regarding what leadership styles, and indeed underlying behaviours, are the most effective in supporting and promoting safe performance (Donovan et al., 2016).

Furthermore, examining and defining safety leadership purely in terms of a leaders' ability to inspire and motivate followers, has precipitated a dominant focus on exploring leadership style in isolation. This is compounded by the use of questionnaires and surveys as the principal method of data capture (Michael et al., 2006; Nielsen et al., 2013; Zohar and Tenne-Gazit, 2008), which seek to elicit insight into follower perceptions of safety leadership, rather than to explore safety leadership itself from a 'first person' perspective. As such, understanding of processes considered integral to leadership, such as decision making (Collins, 2001; Lipshitz and Mann, 2005; Rogers and Blenko, 2006; Vroom, 1973), remains limited, which points to a considerable gap in the current knowledge base. Therefore, improved understanding of the relationship

* Corresponding author.
E-mail address: sarah-louise.donovan@monash.edu (S.-L. Donovan).

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between decision making, and behaviour and action in the safety leadership context, presents as an important research endeavour (Donovan et al., 2017).

Perhaps the most notable shortcoming of existing research however, relates to the lack of exploration, and understanding of safety leadership across work systems (Donovan et al., 2016). The majority of existing research examines the relationship between the frontline worker and immediate supervisory level alone (Conchie, 2013; Hofmann and Morgeson, 1999; Kath et al., 2010a,b). While some research is evident which examines the relationship between leadership and performance at higher organisational levels (Fruhen et al., 2014; Noruzy et al., 2013; Zohar, 2002b), the prevailing focus remains constrained to examining relationship dyads within one work system level (e.g., supervisor-manager relationship (Hofmann and Morgeson, 1999; Zohar, 2002a)). This neglects consideration of factors that exist and interact outside of such dyads, and across multiple work system levels to positively influence safety. Thus, the extent to which safety leadership has been examined across work systems remains largely unexplored (Donovan et al., 2016).

Despite apparent conceptual and methodological limitations, safety leadership is unquestionably an important safety-related concept (Flin and Yule, 2004). To that end, improved approaches to its examination offer the ability to enhance understanding of its role in supporting safe performance within complex socio-technical systems (Walker et al., 2008). The application of systems-thinking methods and concepts present as a valuable opportunity to contribute in this regard (Donovan et al., 2016). Systems-thinking (Leveson, 2004; Rasmussen, 1997) is widely acknowledged as the dominant paradigm for examining and understanding safety and performance across work systems (Goode et al., 2014; Leveson, 2011; Salmon et al., 2017). Indeed, an underpinning premise of systems-thinking relates to understanding the decisions, behaviours and actions of actors across all levels within work systems, which interact to influence performance (Rasmussen, 1997). As such, examining safety leadership through a systems-thinking lens presents as a worthy line of inquiry. In moving beyond conventional conceptual and methodological approaches (Martínez-Córcoles, Gracia, Tomás, Peiró and Schöbel, 2012; Nielsen et al., 2013; Zohar and Tenne-Gazit, 2008), improved insight can be gained into how safety leadership decisions, behaviours and actions manifest across work systems to ultimately support safe performance.

1.1. Safety leadership and systems thinking - Rasmussen's Risk Management Framework

Rasmussen's Risk Management Framework (Rasmussen, 1997) has been previously established as an appropriate systems-based theoretical framework through which to examine safety leadership (Donovan et al., 2017). The framework describes work systems as comprised of six levels; government; regulatory bodies and associations; company management; technical and operational management; staff; and work, and is underpinned by the premise that safety is impacted by the decisions, behaviours and actions of actors across all levels the work system, not just by those of frontline operators alone (Rasmussen, 1997). Decisions at higher work system levels (i.e. Company, Regulatory, Government) should shape actions at lower levels, while information about the current state of the system (i.e. from workers, technical systems and data, etc.) should propagate upwards to inform and aid decision making at higher levels. This process is known as vertical integration (Rasmussen, 1997), and is recognised as critical to supporting safety within high-risk environments.

The flexibility of the framework in application (Salmon et al., 2014) provides a means by which to examine safety leadership as a positive aspect of system performance, in terms of emergent decisions, behaviours and actions across a work system that assist in the maintenance of safety. Further, the ability to represent the open flow and exchange of information in a safety leadership context is critical to understanding the relationships that exist between safety leadership decisions, behaviours and action, and their ultimate contribution to safety (Donovan et al., 2017).

The aim of the current study was to examine the role of safety leadership decisions, behaviours and actions during a significant mining landslide incident, the Bingham Canyon Mine high-wall failure (Tinto, 2013), using Rasmussen's framework. The incident occurred on April 10th, 2013, when the Mine experienced a significant slide along a geotechnical fault line of its north-eastern wall. In the weeks leading up to the incident, increasing ground movement had been detected, and pre-emptive measures had been put in place where workers, facilities and infrastructure were relocated prior to the slide. At the time of the incident, all operations had been ceased, with all employees safe and accounted for. The incident was selected for examination due to its significance in both magnitude, and the positive safety outcome in which no injuries or fatalities were incurred. The incident provided an important and unique opportunity to examine the safety leadership decisions, behaviours and actions that played a significant role in achieving the positive safety outcome.

Recognising the limitations of previous research (Donovan et al., 2016), a multi-method approach was adopted which included the Critical Decision Method (Klein et al., 1989), and a self-reporting approach to examine the safety leadership decisions, behaviours and actions that contributed to the incidents' safe outcome. Rasmussen's Risk Management Framework (Rasmussen, 1997) was applied to the analysis to demonstrate where the identified safety leadership decisions and actions resided within the work system, the behaviours that supported and aided their execution, and the role of vertical integration in supporting the safe outcome.

2. Methodology

2.1. Participants

Eight individuals from within the mining organisation involved in the incident participated in the study. The participant cohort represented five leadership levels within the organisation. To protect anonymity, the specific leadership levels and roles are not disclosed. The average age of participants was 46.1 years ($SD = 8.57$), with the average time in role at the time of the incident 2.57 years ($SD = 2.82$). Formal ethics approval for the study was granted by the Monash University Human Ethics Research Committee.

2.2. Procedure

2.2.1. Data collection

The Critical Decision Method (CDM) (Klein et al., 1989) was used to examine the safety leadership decisions and actions executed across the work system that contributed to the safe outcome. The CDM is a semi-structured interview technique that uses cognitive probes to extract information regarding cognition and decision making during critical incidents (Klein et al., 1989). The CDM has been used extensively to examine decision making and behaviour in different safety critical contexts (Mulvihill et al., 2016; Read et al., 2016; Righi and Saurin, 2015; Wachs et al., 2016). Notably, recent applications have involved examining system wide influences on behaviour by mapping CDM data onto Rasmussen's Risk Management Framework (Goode et al., 2014).

CDM interviews were held with all eight participants, and were conducted by a Human Factors researcher with experience in conducting safety-related interviews, and the use of the CDM interview technique. The interviews were held in a private room at the participants' workplaces, with each participant providing written consent to be interviewed and audio voice recorded.

Interviews were held in two parts, with part one consisting of a standard CDM interview incorporating development of an incident timeline, followed by a standard set of CDM questions (Stanton, 2013) to explore key decisions points along the timeline for each participant. Additional items were included to gather information on potential contributory factors at higher system levels (e.g., *did you feel like you were constrained*/supported *by; standards/rules/procedures, higher organisational influences, regulation?*).

During each interview, participants were asked to reconstruct a timeline outlining their involvement in the incident. Critical decisions were identified for each participant along the timeline, and agreed for inclusion in the analysis by both the participant and the researcher. The CDM decision elements which aided and supported decision making were explored for each decision, with each interview lasting approximately two hours.

The set of CDM decision elements and associated probe questions used is presented in Table 1.

The second part of the interview focused specifically on the safety leadership styles, attributes and behaviours associated with each of the critical decisions on the incident timeline. Following identification and discussion of individual critical decisions in part one, participants were provided with a randomised list of leadership attributes and behavioural examples associated with five leadership styles. The leadership attributes and behaviours were extracted from five prominent leadership questionnaires used extensively within the safety leadership literature (Donovan et al., 2016), and related to the following leadership styles; Transformational, Transactional, Leader-Member Exchange, Empowering, and Authentic leadership (Arnold et al., 2000; Burns, 1978; Graen and Uhl-Bien, 1995; Walumbwa et al., 2008).

Table 2 outlines the safety leadership styles, attributes and behaviours presented for the five individual leadership styles. Of importance, participants were not provided with the specific name of the leadership styles presented, rather, just a randomised list of the leadership attributes and behavioural examples. This was done to prevent potential for bias in selection of recognisable, or known leadership styles.

Each individual critical decision was revisited during part two of the interview, and data were collected in relation to the associated leadership attributes and behaviours displayed. Participants were asked to self-identify from the list provided which safety leadership attributes they engaged in for each critical decision by describing the example behaviour they engaged in at the time.

2.2.2. Data analysis

2.2.2.1. Critical Decision Method data analysis. The audio data from each interview were transcribed verbatim. Using the approach outlined by Stanton (2013), participant responses were coded against their associated CDM probe question for each participant. An inter-rater coding reliability test was undertaken by a second analyst with experience in the use of the CDM (Read et al., 2016). Data were coded for two randomly selected participants, with a

Table 1
CDM decision elements and probe questions.

CDM Decision Element	Element ID	Probe Question
Goal Specification	GS1	What were your specific goals and objectives at the time?
Cue Identification	CI1	What features were you looking for when you formulated your decision?
	CI2	How did you know that you needed to make the decision?
	CI3	How did you know when to make the decision?
	CI4	Were there others involved in making the decision?
Expectancy	EXT1	Were you expecting to make this sort of decision during the course of the event?
Conceptual	C1	Are there any situations in which your decision would have turned out differently?
	C2	What would have changed the outcome of your decision?
Influence of uncertainty	IU1	At any stage, were you uncertain about the reliability or the relevance of the information you had available?
Information integration	II1	What was the most important piece of information you used to formulate the decision?
Situation Awareness	SAW1	What information did you have available to you at the time of the decision?
	SAW2	What information did you use in making this decision and how was it obtained?
	SAW3	Where was information was being sourced? How timely and by what means it was being shared?
Situation Assessment	SAS1	Did you use all of the information available to you when formulating the decision?
	SAS2	Was there any additional information that you might have used to assist in the formulation of the decision?
	SAS3	Did you consult with others whilst you were assessing the situation?
Options	O1	Were there any other alternatives available to you other than the decision you made?
	O2	What other courses of action were considered or were available?
Decision making	DM1	How much time pressure was involved in making this decision? How long did it take to actually make this decision?
Decision blocking/ stress	DB1	Was there any stage during the decision making process in which you found it difficult to process and integrate the information available?
Basis of choice	BOC1	How was this option selected/other options rejected? What rule was being followed?
	BOC2	Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision successfully?
Analogy/ Generalisation	AG1	At the time, were you reminded of previous experience in which a similar decision was made? How about a different decision?
Standard scenario	SS1	Doe this case fit a standard or typical scenario? Does it fit a scenario you were trained to deal with?
Mental modelling	MM1	Did you imagine the possible consequences of this decision? Did you imagine the events that would unfold?
Experience	EXR1	What specific training or experience was necessary or helpful in making this decision? What training/knowledge or information might have helped?
External influences	EI1	Did you at any time feel like the decisions and actions you were making were constrained by standards/rules/procedures?
	EI2	Did you at any time feel like the decisions and actions you were making were constrained by higher organisational influences?
	EI3	Did you at any time feel like the decisions and actions you were making were constrained by Regulation (OSHA/MSHA)?
	EI4	Did you at any time feel like the decisions and actions you were making were constrained by Government considerations?

Table 2
Safety leadership styles, attributes and behaviours presented.

Style	Leadership Attribute	Example Behaviour
Transformational	Idealised Influence	Displays commitment to safety, determined to maintain a safe working environment
	Inspirational Motivation	Talks about own values and beliefs of importance of safety
	Intellectual Stimulation	Encourages others to express opinions about safety at work
	Individualised Consideration	Listens to concerns about safety
Transactional	Contingent reward	Rewards people for achieving safety targets
	Management by exception	Intervene when others do not follow rules/procedures
Empowering	Leading by Example	Sets high standards and good example by behaviour
	Participative Decision Making	Encourages workgroup suggestions and ideas and uses to aid decision making
	Coaching	Provides help to workgroup members
	Informing	Explains company decisions and goals, explains own decisions and actions
	Shows concerns and interacts with team	Shows concerns for workgroup members, makes time to discuss concerns
Authentic	Self-Awareness	Seeks feedback to improve interactions with others
	Relational Transparency	Says exactly what he/she means, is willing to admit mistakes
	Internalised Moral Perspective	Makes decisions based on core beliefs, demonstrates actions consistent with beliefs
	Balanced Processing	Listens carefully to different views before making conclusions, solicits views that challenge own
Leader-Member Exchange	Respect	Team members know where they stand with me
	Obligation	Understands teams job problems and needs
	Trust	Team would 'back me up/my decisions' in my absence

percentage agreement of 78.33% achieved. Disagreements in coding regarding the context of participant responses, were resolved through discussion between the analysts.

Data were mapped in terms of each critical decision, and the associated CDM elements engaged in to support each decision (i.e., Cue Identification, Situation Awareness, Experience, etc.). Each critical decision, and supporting CDM elements were then classified and mapped onto Rasmussen's Risk Management Framework (Rasmussen, 1997) in relation to the work system level at which they occurred (i.e., worker level, managerial level, etc.). Decision classification was reviewed and agreed upon by the co-authors. The resulting matrix allowed analysis of how and where safety leadership decisions and actions emerged across the work system, the underlying CDM decision cues and elements that supported them, and the relationships that existed between them.

2.2.2.2. Safety leadership data analysis. To support the analysis of safety leadership styles, attributes and behaviours, the interview data were analysed using KH Coder (Higuchi, 2014), a content analysis software that enables both quantitative and qualitative analysis. KH Coder (Higuchi, 2014) was used to analyse the safety leadership styles, attributes and behaviours engaged in across multiple system levels, as associated with each of the critical decisions explored. KH Coder supports in depth analysis of textual content, making it suitable for examining and analysing large amounts of transcribed interview content. The software enables identification of themes and concepts (Ryan and Bernard, 2003) within textual content through word frequency analysis, co-location and co-occurrence analysis for strings of words. KH Coder has been used to support quantitative and qualitative content analysis in over thirteen-hundred published research papers (http://khc.sourceforge.net/en/).

First, the interview transcripts for each participant were run through the software to identify data to be cleansed. A word frequency list was generated, and a list of six-hundred and twelve 'stop words' was identified for exclusion from the analysis (e.g., 'a', 'as', 'was'). Next, a leadership coding scheme was applied based on the safety leadership styles, attributes and associated behaviours explored. The coding scheme was developed from the items of the five prominent safety leadership measurement scales used during the interviews (Arnold et al., 2000; Burns, 1978; Graen and Uhl-Bien, 1995; Walumbwa et al., 2008). The software was then run to identify example behaviours by single words, or prominent strings of words. For example, the coding for Transformational leadership included searching for text strings including 'safe working environment' and 'commitment to safety', while the coding for Leader-Member Exchange (LMX) attributes included 'trust', 'trusting relationship', and 'respect'. The coding scheme applied is provided in Table 3.

Data were then analysed in relation to the presence of safety leadership attributes and example behaviours, as linked to individual critical decisions, across leader and work system level.

3. Results

The results are presented in terms of the critical decisions and actions identified, and the underlying safety leadership styles, attributes and behaviours associated with them.

3.1. Critical decisions and actions

Fifteen critical decisions and actions were identified by participants during part one of the CDM interviews. Fig. 1 presents the identified decisions mapped onto Rasmussen's Risk Management Framework.

Fig. 1 shows the critical decisions which supported the incidents' safe outcome were executed at multiple levels within the work system. Sixty percent (n = 9) of the decisions explored occurred at the 'Management' work system level, indicating considerable direct involvement from this work system level in the overall management and response to the incident. These decisions related to communication and engagement based activities (L3.1, L3.2, L3.7, L3.8), ensuring important systems and processes continued to be followed to support decision making (L3.3, L3.5, L3.9), and planning tasks and activities (L3.4, L3.6) related to ensuring safe management of the incident as it developed.

Of the remaining decisions and actions, those that occurred at higher work system levels were related to communications and engagement based activities (L4.1, L4.2, L4.3, L5.1), while those at lower levels within the work system related to the execution (L2.2), and also, deliberate non-execution (i.e., Hold off Blasting (L2.1)) of specific tasks.

3.2. CDM decision elements by work system level

Fig. 2 illustrates the CDM decision elements engaged in for each critical decision examined. Higher numbers of reported engagement between CDM decision elements (right hand side of diagram)

Table 3
Safety leadership themes.

Transformational	Transactional	LMX	Empowering	Authentic
Idealised Influence	Management by Exception	Respect/Respecting/Respectful	Leading by Example	Self-awareness
Inspirational Motivation	Rewards safety targets	Trust/Trusts/Trusted/Trusting relationship	Participative Decision Making	Relational Transparency
Intellectual Stimulation	Intervenes to correct behaviours	Obligation	Coaching/Coaches/Coach	Internalised Moral Perspective
Individualised Consideration	Ensures rules and procedures are followed	Team members know where they stand	Informs and explains	Balanced Processing
Commitment to safety		Understands job problems	Shows concern	Says exactly what he/she means
Safe working environment		Team members would back me up	Interacts with team	Admits mistakes
Values and beliefs			Discusses concerns	Seeks feedback to improve interactions
Importance of safety			Sets high standards	Makes decisions and demonstrates actions based on core beliefs
Encourages expressions of opinion			Treats team members as equals	Solicits views that challenge own
Listens to concerns			Makes suggestions on how to work safely	

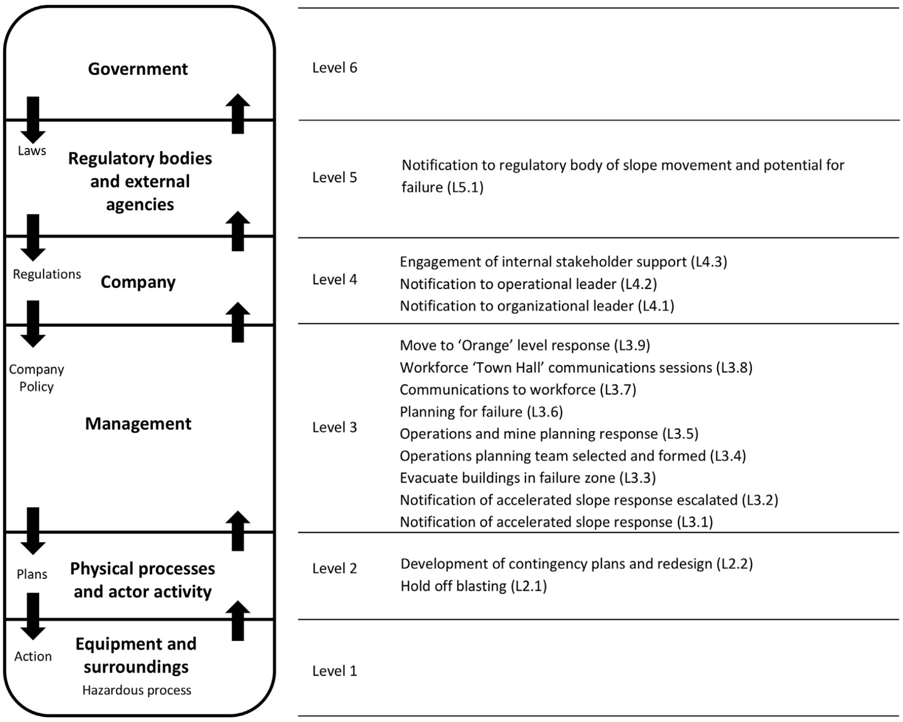

Fig. 1. Safety leadership critical decisions identified.

and individual decisions (left hand side of diagram) indicates increased dependence on these cues to support and aid decision making.

Eighty percent of all decisions explored (n = 12) were underpinned by a block of nine elements alone, those being *Goal Specification* (GS1), *Cue Identification* (CI1-CI4), *Situation Awareness* (SAW1-3), *Information Integration* (II1), *Decision Making (time criticality/pressure)* (DM1), *Situation Assessment* (SAS3), *External Influences* (EXT1), *Basis of Choice* (BOC1) and *Influence of Uncertainty* (IU1). These results indicate a stronger reliance on a smaller sub-set of decision elements to aid and support safety leadership decision making. Participants across all leader levels articulated clear and unambiguous goals that underpinned each decision, as well as evidence of looking for specific features to assist and support decision making. For example, for the 'Notification of accelerated slope response (L3.2)', '*Goal Specification*' was articulated as needing 'to understand the information that was being provided, and the potential impact this would have on safety'. *Cue*

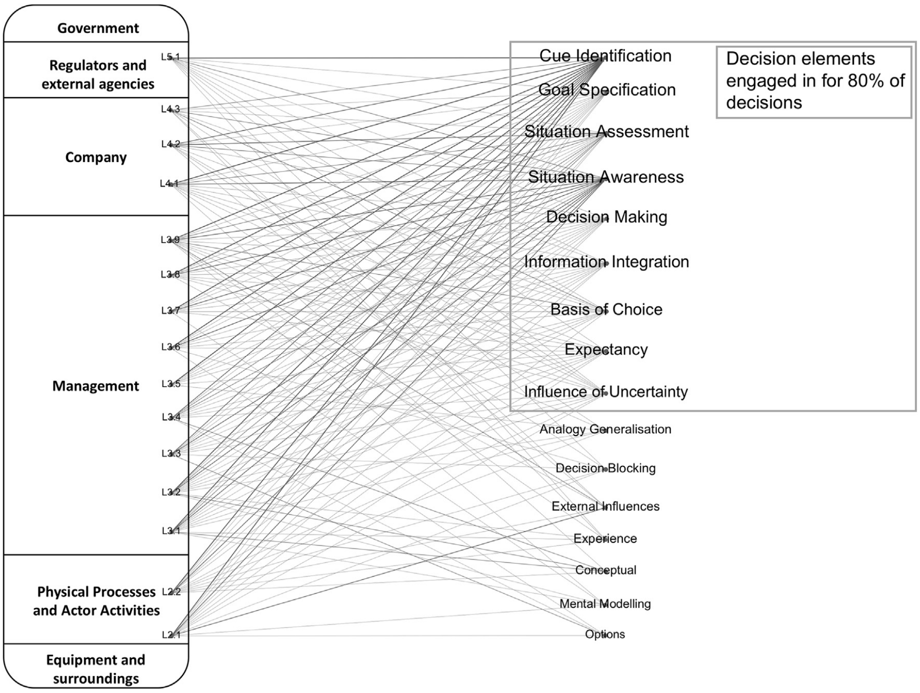

Fig. 2. CDM decision element engagement by individual decisions.

Identification to support this decision was reliant on 'technical information [system data] to support what was being communicated [by Subject Matter Experts] to determine the need to raise the situation to senior leadership'. Further, decision element engagement was shown to be distributed across leader and work system levels, with neither appearing to influence selection or engagement.

The analysis also indicated a range of elements informed decisions in less than 20% of cases, specifically; *Situation Assessment* (SAS2), *Basis of Choice* (BOC2), *Options* (O2), *Standard Situation* (SS1) and *External Influences* (EI3 & EI4). These results are not unexpected, as they suggest access to information was considered sufficient, the situation was fluid and required adaptive and flexible responses, clear courses of action were able to be determined due to the information being shared, and that external influences did not hinder decisions and actions. As such, these elements were relied on less to aid decision making.

3.3. CDM decision elements to support vertical integration

Given the importance of communication in safety systems, Fig. 3 provides an overview of the CDM decision elements linked to supporting communication and information exchange, outlining the source (i.e., verbal or written communications, technical system data), and the target audience and recipients (i.e., upward and downward communications) across the work system.

Fig. 3 shows vertical integration was present across the work system, and played an important role in supporting safety leadership decision making. Information was reported as being exchanged openly from a range of sources, and in multiple directions (upwards, downwards, and outwards) across multiple system levels. The associated decision elements indicated information required to aid decision making was readily available, and reliably sourced. Consultation with others to inform decisions featured as a key activity in the majority of decisions, and the subsequent ability to execute decisions was independent of potential constraints presented by external influences (i.e., higher organisational or regulatory constraints).

Fig. 3 demonstrates the downward dissemination, and two-way exchange of information was greatest at the 'Management' level. Evidence of this is present in decisions L3.7 'Communication to workforce', and L3.8 'Workforce "Town Hall" Communications sessions', which further confirms the considerable direct involvement from this level in the overall management and response to the incident. At the 'Company' and 'Regulatory' level, information flow was focused in an upward and outward direction to advise stakeholders of the situation, and keep them appraised as it developed. At the 'Physical Process and Actor Activity' level, information flow was primarily focused in a downward direction, which represented the dissemination of information being provided from the 'Management' system level to inform and update the workforce of the incident situation as it evolved.

3.4. Safety leadership styles, attributes and behaviours by critical decision

A range of leadership styles were reported as engaged in, with Fig. 4 demonstrating the relationship between critical decisions, and the associated leadership attributes and behaviours that underpinned them.

System level		Cue identification		Influence of Uncertainty	Information Integration	Situation Awareness	Situation Assessment	External Influences	
		CI1	CI4	IU1	II1	SAW3	SAS3	EI2	EI3
Government									
Regulators and external agencies	L5.1	↑ Upward verbal communications, technical system data	↑ Upward and external verbal and written communications	Technical and system data	Technical and system data		↑ Upward verbal communications		
Company	L4.3	↑ Upward verbal communications			↑ Upward verbal communications	↕ Two-way verbal and written communications			
	L4.2	Internal SME input and technical system data	↑ Upward verbal communications	Internal and External SME input and technical system data			↕ Two-way verbal and written communications		
	L4.1	Internal SME input and technical system data		Technical and system data	↓ Downward verbal communications	↑ Upward verbal and written communications	↓ Downward verbal communications		
Management	L3.9	Technical and system data	↕ Two-way verbal and written communications	Technical and system data, SME input	Technical and system data	↓ Downward verbal communications, technical system data	↕ Two-way verbal communications	↑ Upward verbal and written communications	
	L3.8	↓ Downward verbal and written communications	↓ Downward verbal communications	↕ Two-way verbal and written communications	↓ Downward verbal and written communications	Technical and system data	↕ Two-way verbal and written communications	↑ Upward verbal and written communications	
	L3.7	↕ Two-way verbal and written communications	↕ Two-way verbal and written communications		↕ Two-way verbal and written communications	↓ Downward verbal and written communications	↑ Upward verbal communications		
	L3.6	Technical and system data, downward verbal and written communications			Technical system data	↓ Downward verbal and written communications	↑ Upward verbal communications		
	L3.5	Technical and system data	↓ Downward verbal communications		↓ Downward verbal communications	↓ Downward verbal communications	↓ Downward verbal communications		
	L3.4	↓ Downward verbal communications	↓ Downward verbal communications	↓ Downward verbal communications	↓ Downward verbal communications		↓ Downward verbal communications		
	L3.3	Technical and system data			Technical and system data	↓ Downward verbal communications			
	L3.2	Internal SME input and technical system data	↓ Downward verbal communications, SME input	↓ Downward verbal communications	↓ Downward verbal communications, SME input	↓ Downward verbal and written communications	↓ Downward verbal communications		
	L3.1	Internal SME input and technical system data	↓ Downward verbal communications, SME input	↓ Downward verbal communications	↓ Downward verbal communications, SME input	↓ Downward verbal and written communications	↓ Downward verbal communications		
Physical Processes and Actor Activities	L2.2	Internal SME input and technical system data	↓ Downward verbal communications	Internal SME input and technical system data	Technical and system data	↕ Two-way verbal and written communications	↕ Two-way verbal and written communications, technical system data		
	L2.1	Internal SME input and technical system data	↓ Downward verbal communications	Internal SME input and technical system data	Internal SME input and technical system data	↓ Downward verbal communications	↕ Two-way verbal and written communications	↓ Downward verbal communications	↑ Upward verbal communications
Equipment and surroundings									

Fig. 3. Decision elements to vertical integration.

The analysis shows leadership style varied across critical decisions. For example, the decision to 'hold off blasting' (L2.1), which related to non-execution of a routine task, involved a range of leadership styles including Transformational leadership behaviours, whereas the decision to focus on 'planning for failure' (L3.6) included Transactional leadership behaviours. This decision was one of the few that reported 'Management by Exception' was necessary to ensure timely execution of required tasks to ensure continued safe management of the situation.

For communication and engagement based decisions and actions, such as 'Notification of accelerated slope response (L3.1)' and 'Communicate situation to the workforce (L3.7)', Transformational and LMX leadership practices were reported more frequently. Associated behaviours were linked to listening to concerns regarding safety (*Individualised Consideration*), communicating personal values regarding the importance of safety (*Inspirational Motivation),* and demonstrating *Trust* (LMX) in individuals and teams regarding the sharing of information related to the safety of the situation as it developed.

Of note, the analysis showed individual decisions were linked to numerous leadership styles and underlying behaviours. This indicated selection of leadership style and behaviour was dynamic and flexible, and was dependent on the decision being executed at the time.

3.5. Safety leadership styles, attributes and behaviours by work system level

Safety leadership styles, attributes and behaviours also varied by work system level over the course of the incident. Fig. 5 shows the overall average number of times each leadership style was reported as being engaged in, by work system level.

At the 'Company' work system level, Authentic, Transformational and Empowering leadership practices were reported as the most frequently engaged in. *Relational Transparency* and *Coaching* were closely related, with leaders at this system level providing assistance to subordinate teams through the sharing of experience. *Inspirational Motivation* was demonstrated by continuing to communicate the value and importance of safety, both within the organisation, and to external stakeholders. Table 4 provides a number of behavioural examples associated with the highly reported leadership attributes for the 'Company' system level.

As shown in Fig. 5, leaders residing at the 'Management' work system level reported engaging in overall higher numbers of associated behaviours across all five leadership styles. Leaders at the 'Management' work system level reported engaging most frequently in Transformational, LMX and Authentic leadership practices, with *Individualised Consideration, Inspirational Motivation* and *Idealised Influence* the most frequently reported Transformational leadership attributes.

The highest LMX practices were related to '*Trust*' relationships between individuals and teams across the work system, as well as trust in relation to system data and technical information that was being provided. The presence of trust between teams and individuals was viewed as important to support information flow and exchange. Participants indicated high levels of trust were present among the leadership team, and also, with leaders higher up within the organisation and importantly, with teams of subordinates.

The Authentic leadership practice of '*Relational Transparency*' also featured at the 'Management' system level, and related to being clear and unwavering in the decisions that were being made at the time, and were based on the credibility and trust in information being provided. Table 5 provides a number of behavioural examples associated with the highly reported leadership attributes for the 'Management' system level.

System level	Level	Transformational Leadership	Transactional Leadership	Leader Member Exchange	Empowering Leadership	Authentic Leadership
Government						
Regulators and external agencies	L5.1	Idealized Influence Inspirational Motivation		Trust		Relational Transparency Internalized Moral Perspective
Company	L4.3	Inspirational Motivation Individualized Concern	Management By Exception	Trust	Coaching	Relational Transparency Balanced Processing
Company	L4.2	Inspirational Motivation		Trust	Informing Shows Concern	Self awareness Relational Transparency Internalized Moral Perspective
Company	L4.1	Idealized Influence Inspirational Motivation Individualized Concern		Respect	Leading By Example	Internalised Moral Perspective
Management	L3.9	Inspirational Motivation Individualized Concern		Respect Trust	Informing Shows Concern	Balanced Processing
Management	L3.8	Individualsed Concern		Respect Trust	Leading By Example Informing Shows Concern	
Management	L3.7	Idealized Influencd Inspirational Motivation Individualized Concern		Trust	Participative Decision Making	Relational Transparency Balanced Processing
Management	L3.6	Idealized Influence Intellectual Stimulation	Contingent Reward Management By Exception		Participative Decision Making	Relational Transparency Internalized Moral Perspective
Management	L3.5	Inspirational Motivation Individualized Concern				Balanced Processing
Management	L3.4			Respect Trust		Self awareness Relational Transparency
Management	L3.3	Individualised Concern		Respect Trust	Participative Decision Making Coaching Informing	Relational Transparency
Management	L3.2	Individualised Concern		Trust	Informing Shows Concern	Self awareness Relational Transparency
Management	L3.1	Inspirational Motivation Intellectual Stimulation Individualized Concern		Respect Trust	Shows concern	Internalised Moral Perspective
Physical Processes and Actor Activities	L2.2	Inspirational Motivation Individualized Concern		Respect Obligation	Shows concern	Balanced Processing
Physical Processes and Actor Activities	L2.1	Idealized Influence Inspirational Motivation Individualized Concern		Trust	Informing Shows Concern	Balanced Processing
Equipment and surroundings						

Fig. 4. Leadership styles associated with critical decisions.

Leaders at the 'Physical Process and Actor Activity' work system level reported engaging most frequently in Transformational leadership practices. *Inspirational Motivation* and *Individualised Consideration* behavioural practices were the most frequently reported attributes, with participants emphasising the importance of listening to concerns raised about safety. Table 6 provides a number of behavioural examples associated with the highly reported leadership attributes for the ''Physical Process and Actor Activities' system level.

Transactional leadership, and behaviours focused on promoting participative involvement in decision making (attribute of Empowering leadership) were reported the least. This is not unexpected, as time was of critical importance in this incident, therefore seeking participative involvement had the potential to delay important decision making and action. Further, Transactional interactions were minimally required to ensure adequate management of the developing situation.

4. Discussion

The aim of this research was to examine safety leadership decisions, behaviours and actions within the context of a critical incident scenario: the Bingham Canyon Mine high-wall failure (Tinto, 2013). The Critical Decision Method (Klein et al., 1989) was used in conjunction with a self-reporting approach to identifying leadership behaviours, to shed new light on the components of safety leadership across the work system that contributed to the incidents' safe outcome. Using Rasmussen's Risk Management

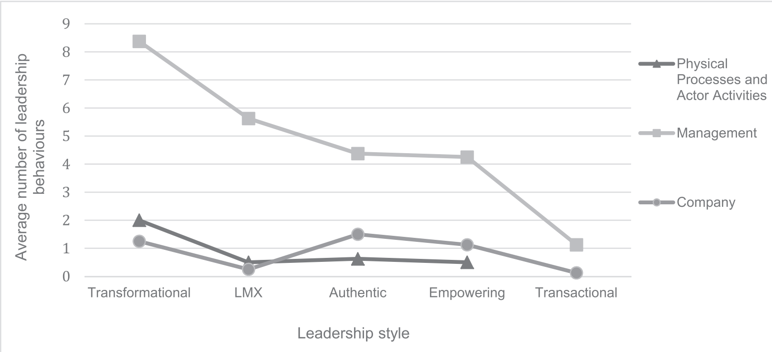

Fig. 5. Leadership style by work system level.

Table 4
Leadership behavioural examples at company system level.

Decision	Leadership Style	Leadership attribute	Behavioural example
Notification to Operational Leader (L4.2)	Authentic	Relational Transparency	*' … I was very open and shared with my subordinate that I'm going to have conversations with indirect subordinates and teams. I'm going to make sure that with all my years of experience …, that they get the benefit of that insight [to help manage the situation] … '*
Notification to Organisational leader (L4.1)	Empowering	Coaching	*' … I recognised that I needed to take on a coaching role [to subordinates] … '*
Engagement of internal stakeholder support (L4.3)	Transformational	Inspirational Motivation	*' … I made sure we communicated [to stakeholder support teams] the importance of making sure what we were doing [contingency planning and operations] was safe … '*

Table 5
Leadership behavioural examples at management system level.

Decision	Leadership Style	Leadership attribute	Behavioural example
Notification of Accelerated Slope Response (L3.1)	Transformational	Individualised Consideration	*"receiving information on the situation [related to potential safety concerns] and immediately needing to make [my leader] aware of it'.*
Move to Orange level response (L3.9)	Transformational	Inspirational Motivation	*' … it was important to remind people that production is never more important than safety …"*
Move to Orange level response (L3.9)	Transformational	Idealised influence	*"… that decision was really easy because the team were all in alignment, and this decision showed we were all committed to safety …"*
Communications to Workforce (L3.7)	Leader-Member Exchange	Trust	*' … we saw very quickly that it was important to communicate the situation to the workforce, to gain their trust in how we were managing the situation …"*
Planning for Failure (L3.6)	Authentic	Relational Transparency	*' … with this decision, I wanted to be very clear; we needed to start planning for failure. If I was wrong [if no failure occurred], fine, I accept that, and I'll wear that, but this is where we are at, and this is the decision I've made [Plan for Failure] … '*

Table 6
Leadership behavioural examples at physical process and actor activities system level.

Decision	Leadership Style	Leadership attribute	Behavioural example
Hold off blasting (L2.1)	Transformational	Inspirational motivation	*' … when [the SME] came to me with concerns [about safety], I made sure to listen to them and address them. I got the experts in the room, and we sat down and talked about the potential outcomes, and how could we keep people safe … '*
Hold off blasting (L2.1)	Transformational	Individualised consideration	*' … My personal value and belief system is safety first. I am committed to keeping you safe … '*

Framework (Rasmussen, 1997), the analysis demonstrates clear links between safety leadership decision making, and subsequent behaviours and actions across the work system. A core sub-set of nine CDM decision elements underpinned eighty percent of decisions explored, demonstrating consistent reliance on these elements as key to informing decisions in the safety leadership context. A further sub-set of CDM decision elements were identified as linked to vertical integration, underpinning the open flow and exchange of information across the work system, which was critical to supporting the safe outcome.

The results also demonstrate a range of safety leadership styles, attributes and behaviours were engaged in, which varied across individual decisions, and work system levels. Communication and engagement based decisions featured most prominently, and were linked to Transformational (*Individualised Consideration* and *Inspirational Motivation*), LMX (*Trust*) and Authentic (*Relational Transparency*) leadership practices. In line with this, decisions at the 'Company' level were linked most frequently to Authentic (*Relational Transparency*), Transformational (*Inspirational Motivation*) and Empowering (*Coaching*) leadership practices. At the 'Management' system level, decisions were linked to Transformational (*Inspirational Motivation, Idealised Influence,* and *Individualised Consideration*), Leader-Member Exchange (*Trust*) and Authentic (*Relational Transparency*) leadership practices most frequently. At the 'Physical Process and Actor Activity' system level, Transformational leadership practices associated with *Inspirational Motivation* and *Individualised Consideration* emerged as the most frequent behaviours.

The findings of the present study provide a number of important and unique contributions to the safety leadership literature. First, they demonstrate the emergence, and subsequent importance of engaging in specific Transformational, LMX and Authentic leadership behaviours across different levels within an organisational system to support safe outcomes. In doing so, the current study provides some alignment with Fruhen et al (Fruhen et al., 2014). regarding the need for senior and executive leaders to demonstrate Transformational and Authentic leadership behaviours to positively influence safety. While the current study specifically examined safety leadership during a critical incident scenario, the concurrence in findings with Fruhen et al. (2014) suggest the effectiveness of these leadership behaviours is independent of operational context (i.e., normal vs. abnormal operations). This is important, as it provides the first step towards determining the most effective leadership practices, and underlying attributes and behaviours to support and promote safe performance (Donovan et al., 2016).

Further, in moving beyond examination of leadership style alone (Clarke and Ward, 2006; Hoffmeister et al., 2013; Martínez-Córcoles et al., 2012a,b), the methodology applied facilitated improved insight into the specific components of safety leadership that contributed to the incidents' safe outcome. By examining the relationships that existed between safety leadership decisions, behaviours and actions across the work system, the present study demonstrates leadership style is not independent of decision making. Further, the decisions, behaviours and actions examined resided across multiple levels within the work system. In line with Donovan et al. (2016), this suggests an integrated approach, underpinned by systems-thinking, is key to gaining improved insight into the emergent nature of safety leadership across work systems (Donovan et al., 2016).

A range of safety leadership styles and behaviours were engaged in across different leader, and work system levels over the course of the incident. This is significant as it provides important insight into the patterns of leadership behaviour that emerged across different levels within a work system. At higher the 'Management' system level, the emergence of behaviours and practices focused more on the quality of interpersonal relationships, and interactions with teams and individuals. In line with this, actively listening to concerns about safety (*Individualised Consideration*), and communicating personal values regarding the importance of safety, helped establish *Trust*, which was central to support communications based activities. This indicates the quality of relationships was key to support vertical integration and facilitate the open sharing, flow and exchange of information. These findings are in agreement with previous research relating to the promotion of open safety communications (Hofmann and Morgeson, 1999; Kath et al., 2010a,b; Martínez-Córcoles et al., 2012a,b; Michael et al., 2006) and the importance of two-way trust in leader-subordinate relationships (Conchie and Donald, 2009; Conchie et al., 2012; Hofmann and Morgeson, 1999). The present study provides new meaning to these findings by demonstrating vertical integration is fundamental to supporting the different leadership styles and behaviours required to safely manage an incident of this magnitude.

The variability in leadership style evident shows the safety leadership behaviours engaged in were adaptive and responsive to situational change, with the elements that underpinned critical decisions acting to provide input into selection of both style and behaviour. This supports the 'system realism perspective' put forward by Conklin (2012), and the systemic accident model described by Dekker (2006). In systems, actors adapt their performance to match conditions and demands, and are capable of detecting and correcting actions and approaches to prevent things from 'going wrong' (Reiman et al., 2014). Thus, understanding actors as flexible and adaptive with regard to enacting safety leadership decisions, behaviours and actions is critical to ensuring ongoing system safety, particularly during critical incident scenarios (Lintern, 2011).

Further, Authentic leadership practices also underpinned the critical evaluation of information, indicating openness and transparency in interactions across levels, which assisted individuals and teams in managing the incident. These results also provide support to existing research regarding the importance of interactions and information sharing between individuals and teams in complex socio-technical systems (Goldstein, 1994; McDaniel and Driebe, 2001; McMillan, 2008; Nonaka, 1988). Communication and interaction between actors is needed for a system to perform in an organised way, and also to enable flexibility to respond and adapt when needed (Reiman et al., 2014). Within this, trust is considered a key element that supports such interactions, and communications between individuals and teams (Conchie et al., 2012; Hofmann and Morgeson, 1999). When actors trust and respect each other's skills and knowledge, an environment of open communications, and willingness to share information is achieved (McDaniel and Driebe, 2001). As such, the results show the key role of communications, and the flow and exchange of information across system levels in supporting safe performance (Kath et al., 2010a,b; Martínez-Córcoles et al., 2012a,b; Michael et al., 2006). They also highlight the significance of interpersonal interactions, and the quality of these relationships with respect to trust, openness and transparency.

In line with the above, the theoretical implications of the present research clearly demonstrate the importance of establishing vertical integration (Rasmussen, 1997) as key to supporting safety leadership decisions, behaviours and actions. The methodological approach enabled a deeper understanding of the types of decisions made across the work system to support the safe outcome (e.g., communications and engagement based decisions), and the CDM decision elements that underpinned them. The analysis demonstrates the CDM decision elements of *Cue Identification*, *Influence of Uncertainty*, *Information Integration*, *Situation Awareness*, *Situation Assessment* and *External Influences* enabled vertical integration by facilitating the flow and exchange of information across the work system. This finding provides important insight into the mechanisms by which critical information was received and shared over the course of the incident, and the corresponding decisions, behaviours and actions that emerged as a result.

The findings from the present study offer a number of practical implications to consider for organisations in high-risk industries wishing to develop safety leadership capability. The findings provide insight into the specific safety leadership characteristics required to develop effective safety leaders. As such, the findings presented can have relevance in the development of scenario-based training programs which focus on the types of decisions made at different work system levels, and the corresponding supportive leadership behaviours that will be most effective in application to support safety. Such programs could be tailored for different leader levels, and focus on capability development in terms of responding to emergency or abnormal operational circumstances. Development of such an approach should be explored in further work, across different safety-critical domains to ensure applicability.

A number of limitations should be acknowledged. While the findings provide agreement with those of Fruhen et al. (2014), the sample size in the current study was restricted to one organisation only, within the context of responding to a critical incident scenario. As such, caution is urged when generalising findings to other domains. Future research endeavours should seek to understand safety leadership decisions, behaviours and actions within the context of a normal operational setting, and across multiple domains. In addition, future studies should also seek to capture a wider sample size across multiple domains to support generalisation of results. Second, the present study focused on the decisions, behaviours and actions present within the organisational system examined. While this approach yielded important understanding at an organisational level, it was unable to do so for decisions, behaviours and actions present at higher system levels (i.e., government) which may subsequently influence safety performance and outcomes. Further, decisions at the lowest system level, 'Equipment and Surroundings' (i.e., triggers and responses by technical systems and environmental cues), were not assessed as they were not executed by human actors within the system, therefore, the components of safety leadership could not be identified.

As such, future endeavours should seek to incorporate data capture and analysis from all levels within the work system, including participants at the government level, to help better understand additional influencing factors and interactions across system levels which may be present. Last, an acknowledged limitation of the CDM technique relates to the inability to enable direct capture and analysis of safety leadership styles and behaviours. The technique has been used in the present study to demonstrate the link between decision making and safety leadership behaviours and actions. However, further development and extension of the technique itself could enable capture of such data directly.

5. Conclusion

In conclusion, the findings of the present study provide important new insight into the safety leadership decisions, behaviours and actions required to maintain safety during a critical incident scenario, specifically the Bingham Canyon Mine high-wall failure (Tinto, 2013). The methodology used successfully demonstrates the importance of applying a systems-thinking approach to examine safety leadership. Mapping the CDM data and self-reporting safety leadership behavioural data onto Rasmussen's Risk Management Framework (Rasmussen, 1997), the findings provide important insight into the links that exist between safety leadership decisions, and emergent behaviours and actions across the work system. Moreover, the approach enabled specific insight into the types of decisions made across the work system, and the leadership practices that underpinned their successful execution. Vertical integration, and the open flow and exchange of information across the system was fundamental to supporting decision making and the associated leadership behaviours.

The findings have practical implications for the development of safety leadership capability, and improvement of safety across work systems in complex, high-risk work domains. The present research approach should be replicated in a normal operational context to determine generalisability, and the fundamental safety leadership decisions and behavioural attributes required of leaders to support safety across safety-critical work systems.

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5.2 Discussion

This study examined the role of, and relationship between, safety leadership decision-making, behaviours and actions during a critical incident scenario; the Bingham Canyon Mine Highwall Failure incident. The key findings are now discussed with reference to the research questions outlined in section 5.1.

First, and in line with the key findings presented in Chapter 4, VI was again recognised as fundamental to supporting safety leadership and effective incident response. The analysis highlights new mechanisms by which critical information was received and shared across the work system to support the safe outcome. The flow and exchange of information across the system took many forms over the course of the incident and included upward, downward and two-way verbal and written communications. Technical system data and input from Subject Matter Experts (SMEs) was also recognised as influencing safety leadership decision-making and subsequent behaviours. In addition, the analysis demonstrated that some decisions were indeed directly influenced by other, prior decisions.

Figure 4 provides an overview of how VI supported and influenced safety leadership and how 'other decisions' also influenced safety leadership, with specific regard to communication and engagement-based decisions. Further, Figure 4 also draws out an important feature in which the Leader-Member Exchange (LMX) attribute of '*Trust*' was identified as a key factor that supported individual and team interactions across the work system. The presence of '*Trust*' is well acknowledged as a factor that creates an environment where open communications and sharing of information is accomplished (Conchie, Taylor, & Donald, 2012; Hofmann & Morgeson, 1999; McDaniel & Driebe, 2001). The analysis highlights the significance of '*Trust*' in interpersonal interactions and the quality of these relationships with respect to promoting VI to support, influence and enhance safety leadership.

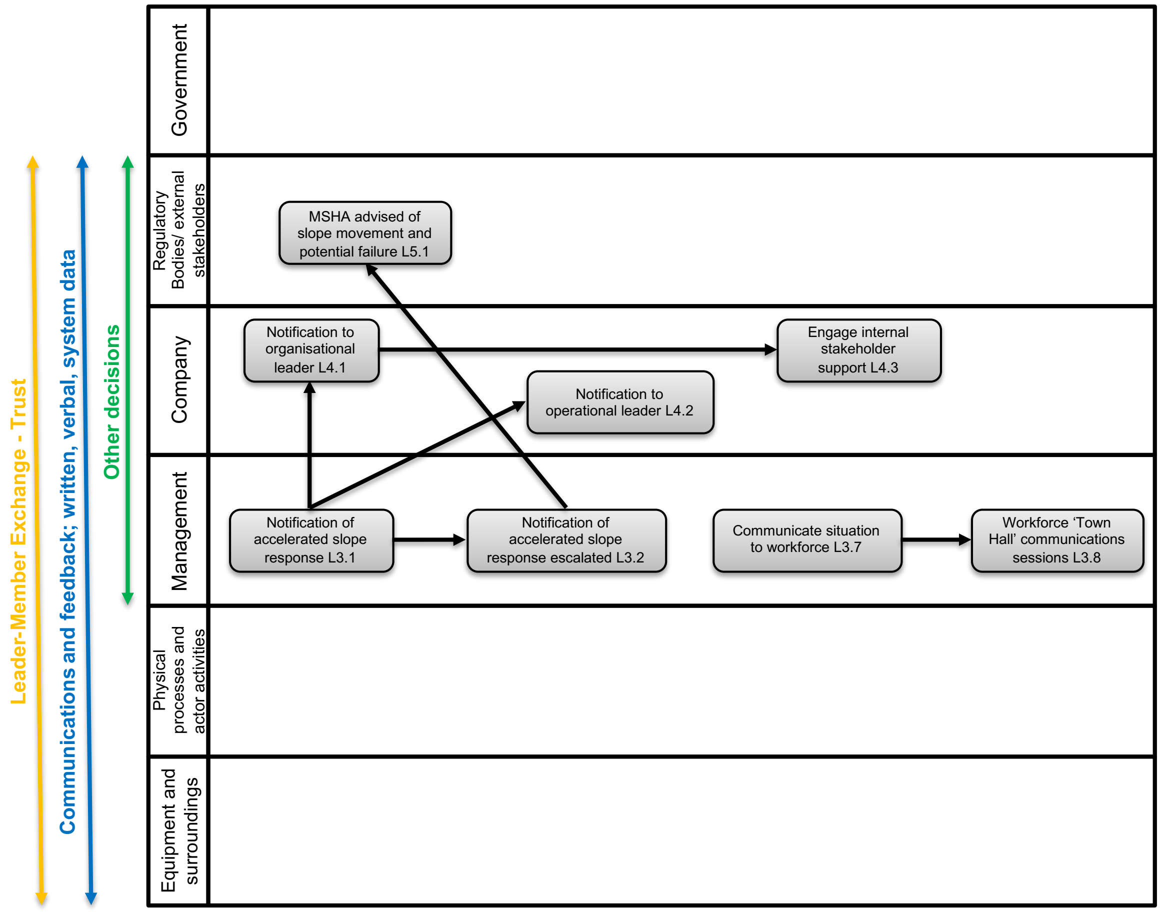

Figure 4. Factors that influence safety leadership associated with communication and engagement-based decisions

Second, communications and engagement-based decisions featured most frequently over the course of the incident, occurring across three levels of the work system. In terms of decision-making, '*Goal Specification*', '*Cue Identification*', '*Situation Awareness*' and '*Basis of Choice'* were salient factors in decision-making for all communications and engagement-based decisions. This suggests that the selection and execution of such decisions is reliant on adequate availability of contextual information (*Cue Identification* and *Situation Awareness*) to inform selection of an appropriate decision (*Basis of Choice*) and to ensure alignment with individual and espoused goals (*Goal Specification*).

In terms of behaviour, Transformational Leadership (TRFL) and Authentic Leadership (AL) practices featured prominently in association with the communications and engagement-based decisions explored. *Trust* was further recognised as central to supporting individual and team interactions, indicating the quality of relationships is a crucial factor underpinning such decisions, particularly within the context of a critical incident scenario. Table 4 below outlines the salient decision-making elements and leadership behaviours associated with the communication and engagement-based decisions explored.

Table 4. Decision element, leadership style and attribute alignment with communication and engagement-based decisions

SYSTEM LEVEL	CRITICAL DECISION	DECISION-MAKING ELEMENT	TRANSFORMATIONAL LEADERSHIP	AUTHENTIC LEADERSHIP	LEADER MEMBER EXCHANGE
REGULATORY	Notification to regulatory body of slope movement and potential for failure	Goal Specification Cue Identification Situation Awareness Basis of Choice	Idealised Influence Inspirational Motivation	Internalised Moral Perspective Relational Transparency	Trust
COMPANY	Engagement of internal stakeholder support	Goal Specification Cue Identification Situation Awareness Basis of Choice	Inspirational Motivation Individualised Concern	Balanced Processing Relational Transparency	Trust
	Notification to operational leader	Goal Specification Cue Identification Situation Awareness Basis of Choice	Inspirational Motivation	Internalised Moral Perspective Self-awareness Relational Transparency	Trust
	Notification to organisational leader	Goal Specification Cue Identification Situation Awareness Basis of Choice	Idealised Influence Inspirational Motivation Individualised Concern	Internalised Moral Perspective	Respect
MANAGEMENT	Workforce 'Town Hall' communications sessions	Goal Specification Cue Identification Situation Awareness Basis of Choice	Individualised Concern		Respect Trust
	Communications to workforce	Goal Specification Cue Identification Situation Awareness Basis of Choice	Idealised Influence Inspirational Motivation Individualised Concern	Balanced Processing Relational Transparency	Trust
	Notification of accelerated slope response escalated	Goal Specification Cue Identification Situation Awareness Basis of Choice	Individualised Concern	Self-awareness Relational Transparency	Trust
	Notification of accelerated slope response	Goal Specification Cue Identification Situation Awareness Basis of Choice	Inspirational Motivation Intellectual Stimulation Individualised Concern	Internalised Moral Perspective	Respect Trust

A third key finding relates to improved understanding of the relationship between decision-making and leadership behaviour in the safety context, particularly with regard to communications and engagement-based decisions. The agreement evident between the CDM prompts that inform decision-making and the behavioural attributes associated with the leadership practices reported further demonstrate that leader decision-making and behaviour are integrally linked in the safety context. For example, in the decision relating to '*Communicating to the workforce*', '*Goal Specification*' related to having specific safety goals and objectives at the time of the decision, while the corresponding TRFL behaviour of '*Idealised Influence*' related to determination to maintain a safe workplace, which represents the behavioural component of *Goal Specification*. A further example of alignment relates to the decision to '*Notify the organisational leader*', whereby '*Cue Identification*' aligned with the AL practice of '*Internalised Moral Perspective*'. This was such that the decision was made based on core beliefs regarding the importance of safety and recognising individual responsibilities for executing the decision in line with that. These findings provide further strong alignment with the definition of safety leadership proposed in Chapter 2 of this thesis, particularly with regard to the important connection between establishing clear and common goals regarding safety.

5.3 Conclusion

The findings from this study provided new insight into the relationship between safety leadership decision-making and behaviour across a mining work system, particularly with regard to communications and engagement-based decisions enacted during the critical incident scenario examined. Vertical Integration was again recognised as a key influencing factor, with 'other decisions' also recognised as having input to, or being the resulting output of, some decisions explored. A notable finding relates to the important relationship between VI, the LMX attribute of '*Trust*' and their reciprocal value in terms of supporting and enabling effective safety leadership. The findings further validated the utility of applying a systems-based methodology and offer confidence towards efforts to optimise the capacity of safety leadership to support safe performance.

A limitation is acknowledged regarding the methodological approach used to extract insight into the behavioural component of safety leadership. To remedy this, an extension to the CDM interview technique was proposed to support an integrated approach to capture leadership behaviours as linked to decision-making. Development of this extension is outlined in Chapter 6.

6 Developing a methodological extension of the Critical Decision Method to support improved identification of effective safety leadership behaviours

6.1 Introduction

The previous chapter highlighted a need to extend the CDM to improve its capacity to gather data on the factors influencing safety leadership. The present chapter describes the development of a methodological extension to support the use of the CDM for examining safety leadership in line with the systems-based definition applied throughout this research. The methodological extension was developed for integration into the standard CDM interview technique (Klein, Calderwood, & Macgregor, 1989). It was designed to improve elicitation of the behavioural component of safety leadership associated with decisions that occur across a work system, to further understanding of the relationship between decision-making, behaviour and performance in the safety leadership context.

6.2 Background

In Chapters 4 and 5, the CDM was applied in its original form to examine decision-making associated with safety leadership during a critical incident scenario. This facilitated exploration of the decision-making component of safety leadership; however, the CDM itself was not able to adequately capture the corresponding leadership behaviours associated with decision-making to support safe system functioning. As such, in order to capture data in line with the systems-based definition of safety leadership applied in this thesis, Study 1 utilised a self-report approach for participants to identify leadership behaviours that corresponded to decision-making during the incident. This approach was applied in conjunction with the standard CDM interview technique, with the content of the self-reported behaviours derived from the five prominent leadership styles and behavioural attributes outlined in Chapter 2. The self-reported leadership behaviours specifically related to; Empowering Leadership (EL), Transactional Leadership (TRSL), Authentic Leadership (AL), Leader-Member Exchange (LMX), and Transformational (TRFL) practices (Arnold, Arad, Rhoades, & Drasgow, 2000; Bass, Avolio, & Atwater, 1996; Burns, 1978; Graen & Uhl-Bien, 1995). The CDM interviews described in Chapters 4 and 5 were split into two parts, with Part 1 following the standard approach using the set of CDM probes outlined in Stanton (2013). Part 2 of the interview related to identifying leadership behaviours as associated with the critical decisions explored and required participants to self-select the behavioural attributes they engaged in, as linked to individual decisions during the incident. Table 5 outlines the safety leadership styles, attributes and behaviours explored in Part 2 of the CDM interviews as described in Chapters 4 and 5 (Study 1).

Table 5. Safety leadership styles, attributes and behaviours as derived from the literature

LEADERSHIP STYLE	LEADERSHIP ATTRIBUTE	EXAMPLE BEHAVIOUR
AUTHENTIC	Self-Awareness	Seeks feedback to improve interaction with others
	Relational Transparency	Says exactly what he/ she means, is willing to admit mistakes
	Internalised Moral Perspective	Makes decisions based on core beliefs, demonstrates actions consistent with beliefs
	Balanced Processing	Listens carefully to different views before making conclusions, solicits views that challenge own
EMPOWERING	Leading by Example	Sets high standards and good example by behaviour (lead by example)
	Participative Decision-making	Encourages workgroup suggestions and ideas and uses to aid decision-making
	Coaching	Provides help to workgroup members
	Informing	Explains company decisions and goals, explains own decisions and actions
	Shows concern and interacts with team	Shows concern for workgroup members, makes time to discuss concerns
LEADER-MEMBER EXCHANGE	Obligation	Understands teams job problems and needs
	Respect	Team members know where they stand with me
	Trust	Team would ‘back me up/ my decisions’ in my absence
TRANSFORMATIONAL	Idealised Influence	Displays commitment to safety, determine to maintain safe work environment
	Inspirational Motivation	Talks about own values and beliefs of importance of safety
	Intellectual Stimulation	Encourages others to express opinions about safety at work
	Individualised Consideration	Listens to concerns about safety
TRANSACTIONAL	Contingent Reward	Rewards people for achieving safety targets
	Management by Exception	Intervene when others do not follow rules/ procedures

While the methodological approach taken in Study 1 was successful in identifying behaviours that corresponded with decision-making across the work system, the approach had some acknowledged limitations. Specifically, the method of data capture required participants to self-select by way of choosing the appropriate perception-based items as extracted from the prominent safety leadership questionnaires. Consequently, this meant the insight gathered was perception-based regarding behavioural engagement, rather than supporting elicitation of deeper cognitive understanding regarding the factors, context, or circumstances across the system that influenced behaviour. Second, the approach somewhat segregated the data capture relating to the behavioural component of safety leadership from decision-making in that the two parts of the interview were conducted sequentially, rather than simultaneously. This meant considerable effort was required on the part of the interviewer to ensure participants were reporting behavioural engagement as associated with the specific individual decisions explored, and not 'holistically' across the course of the incident.

These two observations highlighted a need to better align the approach of capturing safety leadership behavioural data with a systems-thinking methodological and conceptual underpinning. Specifically, any method used must support improved elicitation of safety leadership behaviours and the factors that influence it across the work system. Second, any method used must also ensure an integrated approach to examining emergent decisions, behaviours and actions to align with the definition of safety leadership applied in this thesis. Thus, an improved approach to exploring leadership behaviours was required to progress with the next phase of investigation, which sought to address the two noted concerns.

6.3 Safety leadership behavioural cognitive probe development

To remedy the limitations described, a modified version of the CDM technique was developed to incorporate cognitive probes that specifically aimed to elicit information on leadership behaviours engaged in as associated with decision-making. To develop the leadership behavioural probes, the self-report items outlined in Table 5 (applied in Chapters 4 and 5) were translated from perception-based expressions of behaviour into queries designed to elicit information regarding the associated behavioural attribute. This approach aligned with current thinking regarding the application of cognitive interviewing (Beatty & Willis, 2007; Dickinson, Compo, Carol, Schwartz, & McCauley, 2019) and thus each safety leadership behavioural probe was phrased as an open-ended question that participants could respond to and elaborate on.

Phrasing of the safety leadership behavioural probes were carefully worded so as not to reference the specific behavioural attribute directly. For example, for the EL attribute of '*Participative Decision Making*' was phrased '*How did you involve others in making this decision?*' which permitted respondents to elaborate on the specific actions they took to encourage participative decision-making. Similarly, the probe for the LMX attribute of '*Trust*' was phrased '*What were the most important interpersonal relationship factors to you at the time? To your team/ individuals?*' which aimed to elicit information regarding '*Trust*' without directly referencing the term. This was done to ensure minimal opportunity for participants to identify the behavioural attribute and corresponding parent leadership style, which may have influenced responses. The developed probes were reviewed by two analysts associated with the research project with experience in conducting CDM interviews and also experience in the design and development of analysis methods (Cornelissen et al., 2015; Horberry & Cooke, 2010; Read et al., 2015). A number of modifications were made to the wording of some of the probes. Where a modification was suggested, the suggested amendments were discussed between all three analysts, with disagreements resolved through discussion. For example, the AL probe relating to '*Balanced Processing'* was initially phrased as '*Did you seek out different views to inform your decision? How did you assess different views received/ obtained?'*. This probe was amended to '*How did you seek out and assess different views to inform your decision?*' to position the probe as more clearly open ended. The final set of safety leadership behavioural probes developed and corresponding example behaviours, is presented in Table 6.

Table 6. Extension of the Critical Decision Method – Safety Leadership Behavioural Probes

LEADERSHIP STYLE	BEHAVIOURAL ATTRIBUTE	EXAMPLE BEHAVIOURS	SAFETY LEADERSHIP BEHAVIOURAL PROBE
AUTHENTIC	Self-Awareness	Seeks feedback to improve interactions	Did you seek feedback from anyone (teams/ individuals, peers etc.) on your decision/ interactions?
	Relational Transparency	Leader says exactly what he/ she means	How did you raise the issue/ your concerns? (openly and honestly, face to face, in plain language)?
	Internalised Moral Perspective	Makes decisions based on / consistent with core values and beliefs	What were the values/ beliefs that underpinned your decision?
	Balanced Processing	Seeks views to challenge own, balanced processing and listening skills	How did you seek out and assess different views to inform your decision?
EMPOWERING	Leading by Example	Influences followers through displaying commitment to safety and sets high standards by own behaviour	What visible behaviours /actions did you display at the time?
	Participative Decision-making	Encourages participative decision-making	Who did you involve in making this decision, and how did you involve them?
	Coaching	Encourages team and individual problem solving, information sharing	How did you offer assistance to help solve the situation?
	Informing	Communicates and informs (goals, company decisions)	What information did you communicate to individuals/ teams, and how did you select who to communicate it to?
	Shows Concern	Demonstrates care for team (discusses concerns, treats individuals as equals)	How did you respond to concerns raised by others?
LEADER-MEMBER EXCHANGE	Obligation	Demonstrates understanding of others' job problems	How experienced were you in the task at hand/ situation?
	Respect	Demonstrates respect	How did interpersonal relationship factors inform your decision?
	Trust	Fosters trust (team members would 'back up' leader's decisions in their absence and vice versa)	What were the most important interpersonal relationship factors to you at the time? To your team/ individuals?
TRANSFORMATIONAL	Idealised Influence	Influences followers through displaying commitment to safety	Did you adjust your visible behaviour based on/ in response to the situation?
	Inspirational Motivation	Communicates own values and beliefs to motivate followers	How did you display your values/ beliefs? And who to? (teams/ individuals)
	Intellectual Stimulation	Encourages individuals to express ideas and improvements	What information/ suggestions did you receive back from individuals/ teams?
	Individualised Consideration	Listens to ideas and concerns	How did you demonstrate listening to ideas and concerns raised by others?

LEADERSHIP STYLE	BEHAVIOURAL ATTRIBUTE	EXAMPLE BEHAVIOURS	SAFETY LEADERSHIP BEHAVIOURAL PROBE
TRANSACTIONAL	Contingent Reward	Rewards individuals and teams for compliant behaviour	Did you reward or recognise individuals/ teams for their behaviours?
	Manage by Exception	Intervenes when necessary to correct individual/ team behaviours	Did you feel at any time you needed to intervene to correct individual/ team behaviours to ensure safety?

The development of the safety leadership behavioural probes outlined in Table 6 provided a potential new and improved method for examining safety leadership across a work system. However, to test the utility of the approach for examining safety leadership behaviours in association with decision-making, a necessary first step was to conduct a pilot test as outlined in section 6.4 below.

6.4 Pilot testing the Critical Decision Method – Safety Leadership (CDM-SL) Behavioural Probes

6.4.1 Participants

Four individuals from within the mining industry (n=2) and associated safety regulatory bodies (n=2) participated in pilot testing of the CDM – Safety Leadership (CDM-SL) behavioural probes. The participant cohort represented three levels from across Rasmussen's RMF; the Regulatory, Company and Management levels. To protect anonymity of the participants, the specific role titles and leader levels are not disclosed.

Two women and two men participated in the pilot testing, with the average age of participants being 48.75 years (SD = 6.70), with the average years of industry experience at 27.5 years (SD = 5.06). Formal ethics approval to test the developed probes was granted by the Monash University Human Ethics Research Committee.

6.4.2 Data Collection

Using the same approach outlined in Chapters 4 and 5, the CDM interview technique was applied with the addition of the embedded safety leadership behavioural probes. The CDM is a semi-structured interview technique that uses cognitive probes to extract information regarding cognition and decision-making (Klein et al., 1989). The safety leadership behavioural probes outlined in Table 6 were asked in conjunction with the standard CDM probe set to test the approach fully and allow an integrated examination of safety leadership decision-making and behaviours.

CDM-SL behavioural interviews were held with all four participants and were conducted by the primary analyst, who has significant experience in conducting safety-related interviews and the use of the CDM interview technique (Donovan, Salmon, Horberry, & Lenné, 2018; Donovan, Salmon, & Lenné, 2015; Donovan, Salmon, Lenné, & Horberry, 2017). The interviews were held in a private room at the participants' workplaces, with each participant providing written consent to be interviewed and audio voice recorded. Each interview lasted approximately two hours, during which the standard set of CDM probes (Stanton, 2013) were applied in conjunction with the safety leadership behavioural probes outlined in Table 6.

Participants were asked to recall and describe a specific safety-related task that they regularly engaged in, or an event in which they were involved in some way. In a departure from the traditional approach of the CDM, and to align with the intent to examine positive performance across the work system, no timeline of events or incidents was developed. This step was omitted, as all four participants elected to recall and discuss events or situations that were not directly related to any incident. The four tasks described by participants related to: engagement with an organisation to conduct an inspection or regulatory compliance activity (n=2), hazard identification and risk management regarding a specific safety concern that affected multiple organisations (n=1), and, observation of a routine maintenance task being completed by an operational team (n=1).

The full set of CDM and safety leadership behavioural probes asked is presented in Table 7 below. Participants were asked each question from the standard CDM probe question set and also the safety leadership behavioural question set.

Table 7. CDM-SL behavioural probe interview questions

Cue set	**Element/ Attribute**	**Cognitive Probes**
CDM	Goal Specification	What were your specific goals and objectives at the time?
CDM	Cue Identification	What features were you looking for when you formulated your decision? How did you know that you needed to make the decision? How did you know when to make the decision? Were there others involved in making the decision?
CDM	Expectancy	Were you expecting to make this sort of decision during the course of the event?
CDM	Conceptual	Are there any situations in which your decision would have turned out differently? What would have changed the outcome of your decision?
CDM	Influence of uncertainty	At any stage, were you uncertain about the reliability or the relevance of the information you had available?
CDM	Information integration	What was the most important piece of information you used to formulate the decision?
CDM	Situation Awareness	What information did you have available to you at the time of the decision? What information did you use in making this decision and how was it obtained? Where was information was being sourced? How timely and by what means it was being shared?
CDM	Situation Assessment	Did you use all of the information available to you when formulating the decision? Was there any additional information that you might have used to assist in the formulation of the decision? Did you consult with others whilst you were assessing the situation?
CDM	Options	Were there any other alternatives available to you other than the decision you made? What other courses of action were considered or were available?
CDM	Decision-making	How much time pressure was involved in making this decision? How long did it take to actually make this decision?
CDM	Decision blocking – stress	Was there any stage during the decision-making process in which you found it difficult to process and integrate the information available?
CDM	Basis of choice	How was this option selected/ other options rejected? What rule was being followed? Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision successfully?
CDM	Analogy/ Generalisation	At the time, were you reminded of previous experience in which a similar decision was made? How about a different decision?
CDM	Standard scenario	Does this case fit a standard or typical scenario? Does it fit a scenario you were trained to deal with?
CDM	Mental modelling	Did you imagine the possible consequences of this decision? Did you imagine the events that would unfold?
CDM	Experience	What specific training or experience was necessary or helpful in making this decision? What training/ knowledge or information might have helped?
CDM	External influences	Did you at any time feel like the decisions and actions you were making were constrained by: · standards/ rules/ procedures · higher organisational influences · Regulation (Occupational Health & Safety or Mine Health & Safety) · Government considerations

Cue set	Element/ Attribute	Cognitive Probes
SL	Internalised Moral Perspective	What were the values/ beliefs that underpinned your decision?
SL	Balanced Processing	How did you seek out and assess different views to inform your decision?
SL	Relational Transparency	How did you raise the issue/ your concerns? (openly and honestly, face to face, in plain language)?
SL	Self-Awareness	Did you seek feedback from anyone (teams/ individuals, peers etc.) on your decision/ interactions?
SL	Leading by Example	What visible behaviours did you display at the time?
SL	Informing	What information did you communicate to individuals/ teams?
SL	Coaching	How did you offer assistance to help solve the situation?
SL	Shows Concern	How did you respond to concerns raised by others?
SL	Participative Decision-making	How did you involve others in making this decision?
SL	Obligation	How experienced were you in the task at hand/ situation?
SL	Trust	What were the most important interpersonal relationship factors to you at the time? To your team/ individuals?
SL	Respect	How did interpersonal relationship factors inform your decision?
SL	Idealised Influence	Did you adjust your visible behaviour based on/ in response to the situation?
SL	Inspirational Motivation	How did you display your values/ beliefs? And who to? (teams/ individuals)
SL	Intellectual Stimulation	What information/ suggestions did you receive back from individuals/ teams?
SL	Individualised Consideration	How did you demonstrate listening to ideas and concerns raised by others?
SL	Manage by Exception	Did you feel at any time you needed to intervene to correct individual/ team behaviours to ensure safety?
SL	Contingent Reward	Did you reward or recognise individuals/ teams for their behaviours?

In addition to the CDM-SL behavioural probes, and in line with the same approach detailed in Chapter 5, a ‘Part 2’ of the interview was also conducted whereby participants were required to self-report the safety leadership behavioural attributes they engaged in as related to the tasks and scenarios explored. This was done to enable a statistical comparison between the previously applied method in Chapter 5, and the new method for accurately and reliably capturing and describing data for the behavioural component of safety leadership.

6.4.3 Data Analysis

The audio data from each interview were transcribed verbatim. Using the approach outlined by Stanton (2013), participant responses were coded against their associated CDM or CDM-SL behavioural probe for each participant relating to the scenario being explored. On occasion, it was possible for participants to respond to a probe with a ‘nil’, ‘no’ or ‘none’ response to one of the cognitive prompts. In such cases, ‘no data’ was recorded against the associated prompt, with the related prompt subsequently excluded from the analysis for that participant. This was done to ensure the accuracy of the data sets in terms of being able to compare the safety leadership behavioural probe and self-report data sets and the emergent prominent leadership behaviours reported being engaged in.

To ensure the robustness of the coded data, an inter-rater reliability test was undertaken by a second analyst prior to commencing the analysis. Data were coded for two randomly selected participants, with a percentage agreement of 81.65% achieved. Disagreements in coding regarding the context or intent of participant responses were resolved through discussion between the two analysts.

It is important to note, that while a full CDM interview was conducted for each participant during pilot testing, only the data relating to the safety leadership behavioural probes and self-reported data were coded for analysis. This was done for the purpose of assessing the utility of the developed safety leadership behavioural probes for eliciting deeper insight into safety leadership behaviours. The CDM data collected was not analysed as part of the pilot test data set, as the validity and reliability of the method for extracting information on decision-making is already a well-established. Therefore, a matrix of data was the output for each participant, which included the verbatim responses to the safety leadership behavioural probes, and also, the self-report data only.

6.4.4 Results

Table 8 provides the raw data obtained for all four participants across both safety leadership behavioural data sets. The table shows the number of participants (out of a total of 4) who provided a response to a CDM-SL behavioural probe, and also, the number of participants (out of a total of 4) that self-reported the related behavioural attribute for the task being examined (in Part 2 of the CDM interview).

Table 8. Raw data for pilot testing of CDM-SL behavioural probe and self-reported safety leadership data

LEADERSHIP STYLE	ATTRIBUTE	CDM-SL PROBE DATA FOR N PARTICIPANTS	SELF-REPORTED SAFETY LEADERSHIP BEHAVIOURAL DATA FOR N PARTICIPANTS
EMPOWERING	Participative Decision Making	3	2
	Coaching	3	3
	Leading by example	2	3
	Shows Concern	3	3
	Informing	4	4
TRANSACTIONAL	Management by Exception	2	2
	Contingent Reward	1	0
LEADER-MEMBER EXCHANGE	Obligation	3	1
	Trust	3	3
	Respect	2	1
AUTHENTIC	Balanced Processing	1	3
	Relational Transparency	3	3
	Internalised Moral Perspective	3	2
	Self-Awareness	2	2
TRANSFORMATIONAL	Intellectual Stimulation	3	2
	Inspirational Motivation	3	4
	Idealised Influence	4	4
	Individualised Consideration	3	3

As seen in Table 8, concurrence between the two datasets is evident for a number of attributes, specifically for the EL attributes of '*Coaching*', '*Shows Concern*' and '*Informing*', the TRSL attribute of '*Management by Exception*', the LMX attribute of '*Trust*', the AL attributes of '*Relational Transparency*' and '*Self-Awareness*' and the TRFL attributes of '*Idealised Influence*' and '*Individualised Consideration*'. This indicated that 100% of participants who provided responses to the CDM-SL probes also self-reported the related behavioural attribute as having been engaged in.

As with the data captured and reported in Chapter 5, it is not unusual for a range of behaviours to be reported as engaged in, further confirming the dynamic and flexible nature of safety leadership behaviours required to support decision-making and task execution. In general, participants provided equivalent or higher numbers of responses to the CDM-SL behavioural probes than when asked to self-report the behaviours they engaged in, with the exception of the following attributes; EL - *Leading by Example*, AL - *Balanced Processing* and TRFL - *Inspirational Motivation.* This indicates the CDM-SL probes provide greater opportunity for participants to reflect on the cognitive component of the behavioural attributes in association with decision-making and task execution.

Table 9 below provides a number of examples of the verbatim responses to the CDM-SL behavioural probe and the self-reported data for two attributes that showed equivalence; EL – *Coaching* and TRFL - *Idealised Influence.*

Table 9. Example responses to safety leadership behavioural set and corresponding self-reported behavioural

PARTICIPANT	LEADERSHIP STYLE AND ATTRIBUTE	RESPONSE TO CDM-SL PROBE	SELF-REPORTED BEHAVIOUR (PART 2 OF CDM INTERVIEW)
REGULATORY OFFICER 1	Empowering Leadership - Coaching	*… "As an inspector, I was really concerned with the level of risk I was seeing, and I needed them [the organisation] to see it too. So, we sat down as a group and I posed a number of 'what if' scenarios to them as an educational opportunity. And you could almost see the moment the 'lightbulb' switched on for them and they said 'oh, we understand now!'… We then talked through how they might go about reducing the risk across their operations [fall from height potential]"...*	I provided support to workgroup members, by helping them solve the problem on their own
OPERATIONAL SUPERVISOR 1	Empowering Leadership - Coaching	*… "Recently, we'd had to make an interim change to the process itself to keep it running, which had introduced a risk for those operating the bagging equipment to potentially get their fingers pinched. We'd identified the risk during the change, so my job was to ensure we were vigilant in managing it… During the morning toolbox, we revisited the risk and I challenged the team to present to the group how they were going to solve or reduce the pinch risk until the original process was back in play. About 2 days into the change, the morning shift came up with an interim fix which involved a change in gloves and also decreasing the pressure resistance so that the auto-shut off would kick in earlier before a pinch could occur. This was great, because they'd come up with it themselves and implemented it and it worked. I was pretty proud of them!"…*	I provided support to workgroup members, by helping them solve the problem on their own
REGULATORY OFFICER 2	Transformational Leadership – Idealised Influence	*… "It's tough sometimes, because you don't want to come across as just enforcing rules, which is why for me one of the most important things is to demonstrate your commitment to safety. And you can do that in a number of ways. During this particular inspection, I regularly bought the situation back to a personal level and talked about why following rules and procedures are an important focus for me personally, so that I get to spend time with my family and doing the things I enjoy. I expressed I want to help them make sure they get to spend time doing the same, to help them make that connection between compliance and commitment…"*	I displayed commitment to safety and determination to maintain a safe work environment
OPERATIONAL SUPERVISOR 2	Transformational Leadership – Idealised Influence	*… "Unfortunately, I've worked in an organisation where a serious [permanently disabling] injury occurred, and it is just a horrific experience. It really changes you, and in some ways it's worse than a fatality because of the life-long impact it has on the injured person… [Points to picture on wall] I worked with [the injured worker] and I keep this picture of us and our team on my wall for everyone to see. I regularly talk about what happened to him and*	I displayed commitment to safety and determination to maintain a safe work environment

		how the systems and processes the organisation had at the time let him down which contributed to his incident. It may sound strange, but in some way doing this helps keeps him here 'on the tools', and people get my determination to make sure we don't have the same thing happen here, ever…"

The results of the CDM-SL pilot test provide promising evidence of the face validity of the developed probes in measuring safety leadership behaviour. The concurrence in responses for the two data sets indicate the developed behavioural probes provide equivalent or improved ability to capture and describe data relating to the behavioural attributes of safety leadership they purport to measure.

In terms of considering construct validity, the CDM-SL behavioural probes were developed directly from existing validated questionnaire items used to identify specific behavioural attributes of safety leadership (Arnold, Arad, Rhoades & Drasgow, 2000; Bass, Avolio, & Atwater, 1996; Burns, 1978; Graen & Uhl-Bien, 1995). In doing so, they are considered to align with, and measure known indicators of the relevant safety leadership styles, attributes and underpinning behaviours, with the qualitative data presented and discussed providing a further level of assurance of the construct validity of the developed probes.

6.5 Conclusion

Chapter 6 outlined the development of a methodological extension to the CDM to facilitate exploration of safety leadership behavioural engagement in conjunction with decision-making. The CDM-SL behavioural probes outlined in Table 6 were developed from the findings of the literature review presented in Chapter 2 and covered the five prominent leadership styles and associated attributes evident within the literature; AL, EL, LMX, TRFL and TRSL leadership behavioural practices (Arnold, Arad, Rhoades, & Drasgow, 2000; Bass, Avolio, & Atwater, 1996; Burns, 1978; Graen & Uhl-Bien, 1995). The probes were developed to support improved elicitation of the cognitive basis of safety leadership behaviours engaged in across work systems, and to further understanding of the relationship between decision-making and behaviour.

The following chapter presents Study 2, which describes the application of the extended CDM-SL method as presented in Table 6. To compliment the approach described in Chapters 4 and 5, the extension of the CDM was now applied to examine safety leadership decision-making and behaviours during regular safety-related task execution. This was done to build on the findings for Chapters 4 and 5 to understand how safety leadership occurs in an every-day context to support safe functioning, and to further identify the factors that both support and influence decisions, behaviours and actions across a work system in a normal operational context.

7 Examining safety leadership decision-making and behaviour during regular safety-related tasks

Donovan, S.-L., Salmon, P. M., Horberry, T., & Lenné, M. G. (2020) All in a day's work: towards improved understanding of safety leadership during regular safety-related tasks in mining. *Human Factors and Ergonomics in Manufacturing and Service Industries.*

7.1 Introduction

To further understanding of the factors that influence safety leadership to support safe functioning across a mining work system, a necessary advance on the research described in Chapters 4 and 5 was to examine safety leadership decision-making and behaviour during regular safety-related tasks. This was important to identify additional factors that both influence and support safety leadership during normal performance scenarios, as key to understanding and seeking to optimise what assists in maintaining safe functioning in an every-day context.

This chapter presents Study 2, which applied the extended CDM developed and pilot tested in the previous chapter. The extended method was applied to examine safety leadership decision-making and behaviour during regular safety-related tasks conducted across a mining work system. In doing so, this chapter provides additional evidence to address the following research questions:

RQ 2: Can the application of a systems perspective expand understanding of safety leadership within a complex socio-technical mining system?

RQ 3: What factors influence safety leadership within a complex socio-technical mining system and how do these factors interact?

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RESEARCH ARTICLE

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All in a day's work: Towards improved understanding of safety leadership during regular safety-related tasks in mining

Sarah-Louise Donovan[1] | Paul M. Salmon[2] | Tim Horberry[1] | Michael G. Lenné[1]

[1]Monash University Accident Research Centre (MUARC), Monash University, Victoria, Australia

[2]Centre for Human Factors and Sociotechnical Systems, Faculty of Arts and Business, University of the Sunshine Coast, Queensland, Australia

Correspondence
Sarah-Louise Donovan, Monash University Accident Research Centre (MUARC), Monash University, Bldg 70, Victoria 3800, Australia.
Email: sarah-louise.donovan@monash.edu

Abstract

This article examines safety leadership during regular safety-related tasks conducted across a mining work system. Applying a systems-thinking methodology, a modified version of the critical decision method (CDM) interview technique was used to examine decision-making and behavior in association with five safety-related tasks executed across the work system; hazard identification, inspections, standard operating procedure development, task observation and return to work coordination activities. Data were mapped onto Rasmussen's risk management framework to explore the characteristics of safety leadership decision-making and behavior which occurred across the work system to support successful task execution. Vertical integration was present and was associated with a core set of decision-making elements and leadership behaviors that facilitated the communication and exchange of information within and across the work system in association with tasks executed. In addition, different profiles of decision-making characteristics and behavioral engagement were evident at different system levels, which indicated variability in safety leadership was required to support successful task execution across the work system. Task type was found to influence safety leadership, with structured tasks demonstrating less intensive decision-making and behavioral engagement requirements than unstructured tasks. The findings add to the knowledge base on safety leadership through improved understanding of the concept, its occurrence across tasks and work system levels, and the factors which influence it to support safe system functioning. Future research endeavors and practical implications are discussed.

KEYWORDS
behaviors, decisions, mining, safety leadership, systems-thinking, tasks

1 | INTRODUCTION

In recent years, safety leadership has emerged as an important concept in the mining industry (Du & Sun, 2012). Described as the decisions, behaviors and actions of leaders that combine and interact to support and maintain safe performance (Donovan et al., 2018), safety leadership has been linked to a range of improvements across the industry. At an individual level, research has demonstrated leaders' visible commitment to safety, active concern for worker welfare, and alignment of safety attitudes can have a positive impact on key safety metrics, such as reductions in worker injuries (Hine et al., 1999; Paul & Maiti, 2008). Further, leaders' active management and monitoring practices have also been shown to enhance safety climate, which is recognized as an important indicator of safe performance (Du & Sun, 2012; Du & Zhao, 2011). At an organizational level, positive links between leadership behaviors and performance improvements are also evident, with systems, policies, and procedures instilled by leaders also linked to lower workforce injury rates (Hine et al., 1999). At a system-wide level, external factors such as regulatory practices have shown positive influence over leadership behavior within an organization (Zhang et al., 2017), which demonstrates the important role outside agencies can play in promoting effective safety leadership within an organization.

While such findings provide compelling evidence for the positive capacity of safety leadership to support safety in a mining context, their utility in practice remains somewhat limited. For example, existing research tends to take a narrow view of the concept of safety leadership by examining the influence of leader behavior on follower performance in isolation from important complementary processes, such as decision-making. With decision-making widely recognized an integral component of leadership (Collins, 2001; Donovan et al., 2018; Lipshitz & Mann, 2005; Rogers & Blenko, 2006; Vroom, 1973), it is, therefore, crucial to understand the factors that provide input to, and positively influence decision-making and subsequent behavior in the safety leadership context (Wickens & Hollands, 2000). This is particularly important when considering the potential negative consequences which may arise from poor leadership practices (e.g., Zweifel & Haegeli, 2014). Indeed, Wang et al. (2019) recently called for a need to better understand the inputs and cues required to support safety-related decision-making as a key factor in maintaining safe performance (Wang et al., 2019). This line of inquiry remains thus far, unexamined. Further, popular methodological approaches to examine safety leadership focus on exploring leader behavior from the viewpoint of followers only (Du & Sun, 2012; Du & Zhao, 2011) rather than seeking to understand safety leadership from a "first person" perspective. This also constrains understanding of the safety leadership concept considerably, since only inference can be made regarding the factors which influence safety leadership decision-making and behavior, and the resulting impact this has on performance.

Perhaps the most significant limitation of existing research, however, relates to the extent to which safety leadership has been examined across work systems. The predominant focus of existing research is on the relationship between the frontline worker and immediate supervisor alone (Conchie et al., 2013; Hofmann & Morgeson, 1999; Kath et al., 2010). This neglects consideration of factors that exist and interact outside of this dyad, and across multiple levels within a work system to positively influence safety. Contemporary approaches to examining safety strongly advocate for the application of systems-thinking concepts and methods to understand what influences safety across work systems (Hollnagel, 2014; Salmon et al., 2017; Trotter et al., 2014; Wachs et al., 2016; Walker et al., 2010). Indeed, applying systems-thinking has yielded important new insight into key safety-related concepts such as improvisation (Trotter et al., 2014) and situation awareness (Salmon et al., 2015). Yet despite this, relatively few systems-thinking based approaches have been applied to study other important concepts, such as safety leadership (Marchildon & Fletcher, 2016; Phillips et al., 2016; Pilbeam et al., 2016). This is especially the case in mining (Donovan et al., 2017, 2018; Lenné et al., 2012), which is surprising given the noted established links between safety leadership and system-wide factors at an individual, organizational and regulatory level which influence performance (Colley & Neal, 2012; Hine et al., 1999; Paul & Maiti, 2008; Zhang et al., 2017).

Thus, the present study therefore argues, to advance understanding of the positive capacity of safety leadership to support safe performance, a key research imperative exists relating to the application of systems-thinking. Applying systems-thinking to examine safety leadership offers the ability to provide enhanced knowledge both in terms of the concept itself, and how it occurs within and across complex sociotechnical systems to support safe functioning (Walker et al., 2008). Indeed, a key underpinning premise of systems-thinking relates to understanding the decisions and behaviors of actors across all levels within a work system which interact to influence performance (Rasmussen, 1997). Examining safety leadership from a systems perspective, therefore, presents as a worthy line of inquiry (Donovan et al., 2018), with the potential to provide improved insight into what constitutes effective safety leadership, and the factors which underpin and influence safety leadership to support safe performance. This is particularly important when considering how safety leadership occurs in association with regular safety-related tasks across work systems, which are considered fundamental to maintaining safe system performance in an every-day context (Donovan et al., 2017; Rasmussen, 1997).

The benefits of examining safety leadership through a systems-thinking lens are twofold; it would seek to identify the central elements of effective safety leadership in terms of defining the factors which influence decision-making and behavior across mining work systems to support core tasks. Second, it would serve as a starting point to integrate such elements into key organizational and systemic approaches to enhance safety leadership, to optimize its effectiveness to better manage safety and risk across the industry.

With this in mind, the aim of the present study was to apply a systems-thinking methodology to examine safety leadership across a mining work system. In a point of departure from previous research (Donovan et al., 2017), this study focuses on examining safety leadership in terms of decision-making inputs and behavior associated with regular safety-related tasks, to identify the key elements of decision-making and subsequent behaviors which support safe system functioning in an every-day context. An adapted version of the critical decision method (CDM) interview technique (Klein et al., 1989) was applied to examine factors and inputs which support decision-making associated with the execution of regular safety-related tasks. A set of safety leadership cognitive prompts was developed and integrated into the CDM interview technique to identify leadership behaviors as they corresponded to elements of decision-making and task execution across the work system. The data were mapped onto Rasmussen's risk management framework (Rasmussen, 1997) to explore the types of tasks undertaken at different system levels and the corresponding elements of decision-making and behaviors that underpinned them to support every-day safe functioning. Implications, including future research directions, are discussed.

1.1 | Safety leadership and systems-thinking

Rasmussen's risk management framework (Rasmussen, 1997) has previously been demonstrated as an appropriate systems-thinking framework through which to gain an improved understanding of safety leadership in a mining context. The framework has been applied to examine and understand the factors which influence safety leadership during a critical incident scenario (Donovan et al., 2017, 2018). Describing work systems as comprised of various levels (Figure 1), the framework is underpinned by the premise that safety is influenced by the decisions, behaviors, and actions of actors across all levels of a work system (Rasmussen, 1997). To shape performance, decisions and behaviors at higher system levels help inform those at lower levels, while information about the system state (i.e., from workers, technical systems, data, etc.) propagates upward to inform and aid decision-making at higher system levels. This process is known as Vertical Integration (Rasmussen, 1997) and is considered critical to supporting safety (Cassano-Piche et al., 2009) within high-risk work environments such as mining (Grote, 2012).

The CDM (Klein et al., 1989) is a semi-structured interview technique that uses cognitive prompts to elicit information and facilitate understanding of the inputs and cues which aid decision-making. The method has been used extensively to examine decision-making in different contexts (Mulvihill et al., 2016; Read et al., 2016; Righi & Saurin, 2015; Wachs et al., 2016), with notable recent applications examining system-wide influence by mapping CDM data onto Rasmussen's risk management framework (Donovan et al., 2017; Goode et al., 2014).

The CDM provides insight into how the flow and exchange of information across a work system supports decision-making, and when coupled with methods designed to elicit information regarding the behavioral component of safety leadership (e.g., Donovan et al., 2018), an integrated, systems perspective of safety leadership is achieved. This enables improved understanding to be gained regarding the relationship between safety leadership decision-making and behavior, how safety leadership occurs across a mining work system, and the factors which influence it to support safe system functioning.

2 | METHODOLOGY

2.1 | Participants

Thirteen participants were involved in the study, comprising representatives from within a global mining organization and an

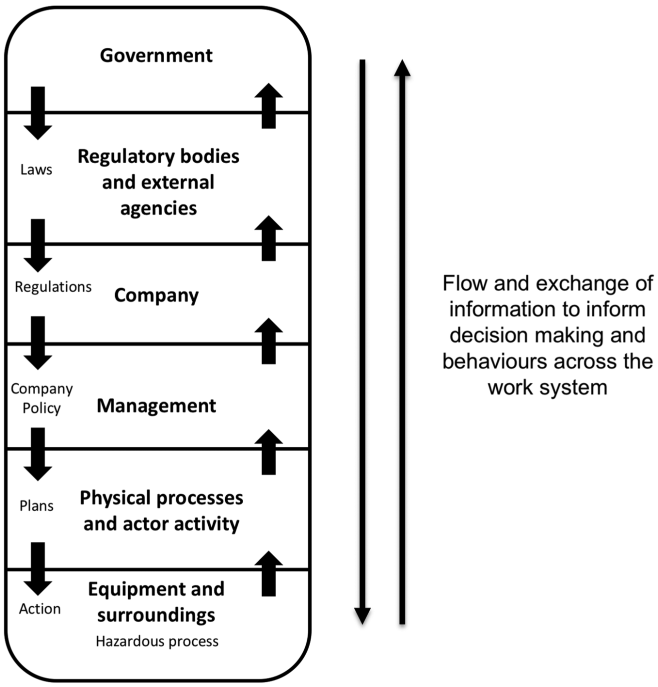

FIGURE 1 Rasmussen's risk management framework (adapted from Rasmussen, 1997)

associated regulatory body. The roles covered by participants included operational, business support services, and safety-based functions. Participants represented a range of levels of leadership within the respective organizations and included operations superintendents, senior inspectors, principal safety advisors, operations managers, general managers, executive team leaders, and chief executive officers.

All participants in the study were male, with an average age of 46.38 years (*SD* = 10.29), an average time in industry of 19.76 years (*SD* = 10.24), and an average time in the role of 2.31 years (*SD* = 2.20). Ethics approval was granted by the Monash University Human Ethics Research Committee.

2.2 | Procedure

2.2.1 | Data collection

Individual interviews were held with all participants and were conducted by the first author who has extensive experience in conducting safety-related interviews and the use of the CDM technique (Donovan et al., 2017). All interviews were held in a private room at the participants' workplaces. Each participant provided written consent to be interviewed and to have the interview voice recorded.

At the start of each interview, participants were asked to identify a safety-related task or activity that they regularly engaged in as part of their role. Task selection was determined by participants rather than stipulated by the interviewer, to allow insight into the range of tasks required to be undertaken by leaders to fulfill safety-related functions across multiple levels within the work system. Tasks identified for exploration included, for example, inspection and audit activities and the development of standard operating procedures (SOPs). Each task or activity was explored with reference to a specific recent instance (occurring within the last 3 months) in which that task was engaged in by the participant.

A CDM interview (Klein et al., 1989) was then conducted to examine the safety leadership decisions and behaviors across the work system as they occurred in relation to regular tasks executed. While the CDM technique is primarily applied to examine decision-making during an incident, the generic nature of the probes ensures flexibility of the method in application to facilitate examining decision-making also under normal operational scenarios. The current study applied the CDM technique to identify safety leadership decision inputs as linked to regular task execution under a normal performance scenario. As such, no incident timeline was constructed, as the tasks explored were not linked to any incidents or injuries. The set of CDM probes contained in Table 1 were used to examine leader decision-making.

Additionally, a set of prompts developed by the authors and relating to safety leadership behaviors were also used. The safety leadership prompts were applied to explore behavior in association with decision-making during the tasks explored. The prompts were based on the extraction of key leadership attributes and behaviors as derived from five prominent leadership style questionnaires (Donovan et al., 2017) evident within the safety leadership literature. The prompts covered the following leadership styles and associated attributes of; Authentic, Empowering, Leader-Member Exchange, Transformational and Transactional leadership (Arnold et al., 2000; Burns, 1978; Graen & Uhl-Bien, 1995; Walumbwa et al., 2008), which have all been implicated in positive improvements in safety (e.g., Clarke, 2013; Michael et al., 2006; Peterson et al., 2012). Table 2 contains the list of safety leadership prompts used as adapted from Donovan et al. (2017).

All prompts from each question set (CDM and safety leaders behavioral prompts) were asked of each participant, with each interview lasting between one hour and a half, to two hours. The CDM and safety leadership behavioral data were collected with reference to the regular tasks explored.

2.2.2 | Data analysis

The data from each interview were transcribed verbatim. Using the approach outlined in (Stanton, 2013), individual responses were coded against their associated CDM or safety leadership prompt. Each response was then classified using the human factors classification scheme outlined in (Goode et al., 2017) to be mapped onto Rasmussen's risk management framework (Rasmussen, 1997). Data were mapped onto the framework based on system-level, task and the associated decision elements and safety leadership behaviors engaged in. For example, responses from Superintendents to the CDM cue relating to "Information Integration" were coded at the "Physical Processes and Actor Activity" system level, while responses from General Managers were coded at the "Company" level. Similarly, responses from Inspectors relating to safety leadership behaviors, such as "Compliance" were placed at the "Regulatory" system level, while responses from Plant Managers were placed at the "Management" system level.

On occasion, it was possible for a participant to respond to the CDM cues or safety leadership prompts with a "nil," "no," or "none" response. In such cases, "no data" was recorded against the associated cue, with the related prompt excluded from the analysis for that participant. This was done to identify the most prominent links between specific decision elements, behaviors, tasks, and system-level for both question sets.

To ensure the robustness of the coded data, an interrater reliability test was performed before commencing the analysis. A second analyst classified the data for two randomly selected participants using the classification scheme outlined in Goode et al. (2017), mapping the identified factors onto Rasmussen's risk management framework. A percentage agreement of 81.2% was achieved, which is considered acceptable within the literature (Goode et al., 2017).

The data for all participants were then imported into the analysis software NVivo 9, where a matrix of the coded data was produced. This allowed analysis of the tasks undertaken, the system level at which they occurred, and the underpinning decision elements and leadership behaviors that were engaged in to support successful task execution across the work system. The data were also analyzed to identify relationships and links between decision-making elements

TABLE 1 Critical decision method decision elements cognitive prompts

Goal specification	What were your specific goals and objectives at the time?
Cue identification	What features were you looking for when you formulated your decision? How did you know that you needed to make the decision? How did you know when to make the decision? Were there others involved in making the decision?
Expectancy	Were you expecting to make this sort of decision during the course of the event?
Conceptual	Are there any situations in which your decision would have turned out differently? What would have changed the outcome of your decision?
Influence of uncertainty	At any stage, were you uncertain about the reliability or the relevance of the information you had available?
Information integration	What was the most important piece of information you used to formulate the decision?
Situation awareness	What information did you have available to you at the time of the decision? What information did you use in making this decision and how was it obtained? Where was information was being sourced? How timely and by what means it was being shared?
Situation assessment	Did you use all of the information available to you when formulating the decision? Was there any additional information that you might have used to assist in the formulation of the decision? Did you consult with others whilst you were assessing the situation?
Options	Were there any other alternatives available to you other than the decision you made? What other courses of action were considered or were available?
Decision-making/time pressure	How much time pressure was involved in making this decision? How long did it take to actually make this decision?
Decision blocking/stress	Was there any stage during the decision-making process in which you found it difficult to process and integrate the information available?
Basis of choice	How was this option selected/other options rejected? What rule was being followed? Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision successfully?
Analogy/generalization	At the time, were you reminded of previous experience in which a similar decision was made? How about a different decision?
Standard scenario	Doe this case fit a standard or typical scenario? Does it fit a scenario you were trained to deal with?
Mental modeling	Did you imagine the possible consequences of this decision? Did you imagine the events that would unfold?
Experience	What specific training or experience was necessary or helpful in making this decision? What training/knowledge or information might have helped?
External influences	Did you at any time feel like the decisions you were making were constrained by standards/rules/procedures? Did you at any time feel like the decisions you were making were constrained by higher organizational influences? Did you at any time feel like the decisions you were making were constrained by Regulation (OSHA/MSHA)? Did you at any time feel like the decisions you were making were constrained by Government considerations?

and safety leadership behaviors according to task and system level. Gephi Network Analysis and Visualization software were used to map the identified links, their strengths, and interactions in network form (Bastian et al., 2009).

3 | RESULTS

3.1 | Regular safety-related tasks

Five tasks were reported by participants as indicative of a safety-related task regularly engaged in. The tasks identified and explored related to; identifying and addressing hazards in the work environment, conducting safety inspections and audits, developing SOPs, postincident return to work (RTW) coordination activities and direct task observation of teams and individuals.

Hazard identification and safety inspections were the most frequent tasks reported as being engaged in by participants at the Management, Company, and Regulatory system levels. Direct task observation was a regular task at the lowest system level (physical processes and actor activities [PPAA]) and related to Supervisory practices of the frontline workforce. The development of SOPs was reported as a regular task undertaken at both

TABLE 2 Safety leadership cognitive prompts (adapted from Donovan et al., 2017)

Leadership style	Associated behavioral attribute	Safety leadership cognitive prompt	Example behaviors
Authentic	Internalized moral perspective	What were the values/beliefs that underpinned your decision?	Makes decisions based on/consistent with core values and beliefs
	Balanced processing	How did you seek out and assess different views to inform your decision?	Seeks views to challenge own, balanced processing and listening skills
	Relational transparency	How did you raise the issue/your concerns? (openly and honestly, face to face, in plain language)?	Leader says exactly what he/she means
	Self-awareness	Did you seek feedback from anyone (teams/individuals, peers, etc.) on your decision/interactions?	Seeks feedback to improve interactions
Empowering	Leading by example	What visible behaviors did you display at the time?	Sets high standards by own behavior, leads by example
	Informing	What information did you communicate to individuals/teams?	Communicates and informs (goals, company decisions)
	Coaching	How did you offer assistance to help solve the situation?	Encourages team and individual problem-solving, information sharing
	Shows concern	How did you respond to concerns raised by others?	Demonstrates care for team (discusses concerns, treats individuals as equals)
	Participative decision-making	How did you involve others in making this decision?	Encourages participative decision-making
Leader-Member EXchange	Obligation	How experienced were you in the task at hand/situation?	Demonstrates understanding of others' job problems
	Trust	What were the most important interpersonal relationship factors to you at the time? To your team/individuals?	Fosters trust (team members would "back up" leader's decisions in their absence and vice versa)
	Respect	How did interpersonal relationship factors inform your decision?	Demonstrates respect
Transactional	Management by exception	Did you feel at any time you needed to intervene to correct individual/team behaviors to ensure safety?	Intervenes when necessary to correct individual or team behaviors
	Contingent Reward	Did you reward or recognize individuals/teams for their behaviors?	Rewards individuals and teams for compliant behavior
Transformational	Idealized Influence	Did you adjust your visible behavior based on/in response to the situation?	Influences followers through displaying a commitment to safety
	Inspirational motivation	How did you display your values/beliefs? And who to? (teams/individuals)	Communicates own values and beliefs to motivate followers
	Intellectual stimulation	What information/suggestions did you receive back from individuals/teams?	Encourages individuals to express ideas and improvements
	Individualized Consideration	How did you demonstrate listening to ideas and concerns raised by others?	Listens to ideas and concerns

the Regulatory and PPAA levels, while RTW coordination for an injured worker was reported at the lowest system level alone.

The five tasks were reported by participants as being both structured and unstructured in nature. Structured tasks were defined by participants as having a documented policy or procedure to instruct execution, while unstructured tasks were defined as having an absence of documented process or procedure to specify execution. Table 3 provides a description of the tasks examined, as well as information in relation to the classification of each task.

At higher system levels (regulatory, company, and management), all tasks engaged in were structured, while at the lowest system level (PPAA), tasks engaged in were both structured and unstructured. Figure 2 provides an overview of the tasks examined by system-level and task type.

3.2 | Elements of decision-making by system-level and task type

The analysis showed each of the five tasks were linked to considerable aspects of decision-making, as derived from the CDM interviews. In terms of frequency, the decision-making elements

TABLE 3 Safety-related task classification and description

Task or activity	Classification	Description
Hazard identification	Structured	Documented policy and procedure exists for engagement in hazard identification activities as part of a risk management procedures (organizational and regulatory level)
Inspections and audits	Structured	Documented policy and procedure exists for the conduct of inspections and audits (organizational and regulatory level)
Standard operating procedure (SOP) development	Structured	Documented policy and procedure exists for development of SOPs (organizational and regulatory level)
Task observation	Unstructured	Task observation required as part of supervisory function for frontline staff. No documented procedure on conduct of task observation
Return to work coordination	Unstructured	Return to Work coordination for injured workers is often required as part of a specific supervisory function. Policy and process for the management of injury exists, however, the nature of RTW coordination activities is inherently variable, due to injury type. As such, actions and support requirements are identified and assessed on a case by case basis.

relating to *External Influences*, *Goal Specification*, and *Information Integration* were prominent for all tasks and participants (*n* = 13) across all system levels. Figure 3 illustrates the prominent decision-making elements identified at each system level.

In addition to the prominent decision-making elements, a number of additional elements were identified as prominent at different system levels. At the Regulatory level, participants indicated *Expectancy*, as well as *Cue Identification* as prominent across all tasks. Both were reported with reference to ensuring compliance with relevant regulation, where participants identified a deviation from safe work practices (*Cue Identification*) and then expected they would have to communicate regulatory compliance requirements to teams and individuals, as they were either not known or not well understood (*Expectancy*).

At the Management and Company level, *Time Pressure* emerged as prominent across all tasks. Of note, *Time Pressure* was referred to in a positive context by all participants, in that participants did not feel any time pressure related to decision-making or associated task execution. At the PPAA level, *Expectancy* and *Situation Assessment* were prominent for all participants. These two elements of decision-making were closely linked to Task Observation and RTW coordination activities. Participants at this system-level frequently reported *Expectancy* in terms of having to intervene when they observed an unsafe act. In doing so, they reported a higher associated need for *Situation Assessment* to not only

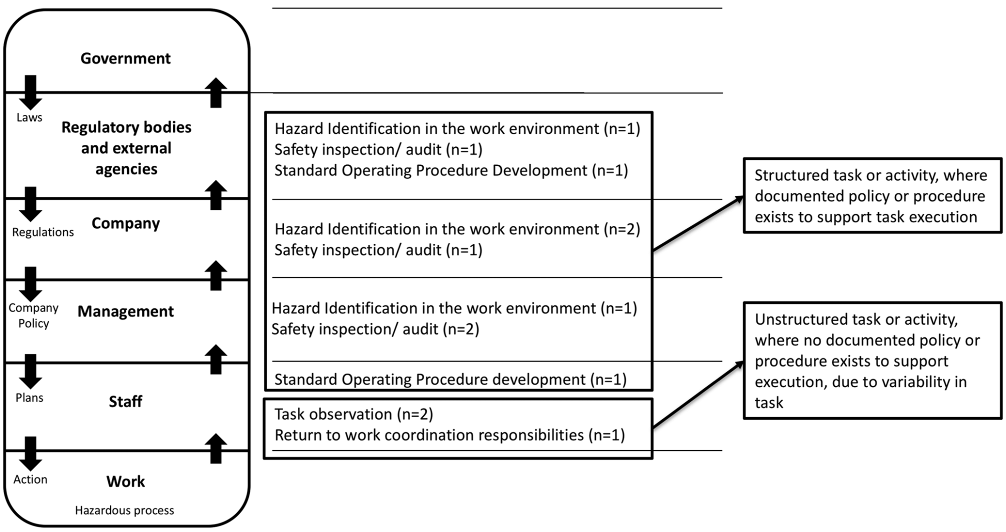

FIGURE 2 Safety-related tasks by system-level (mapped onto Rasmussen's risk management framework)

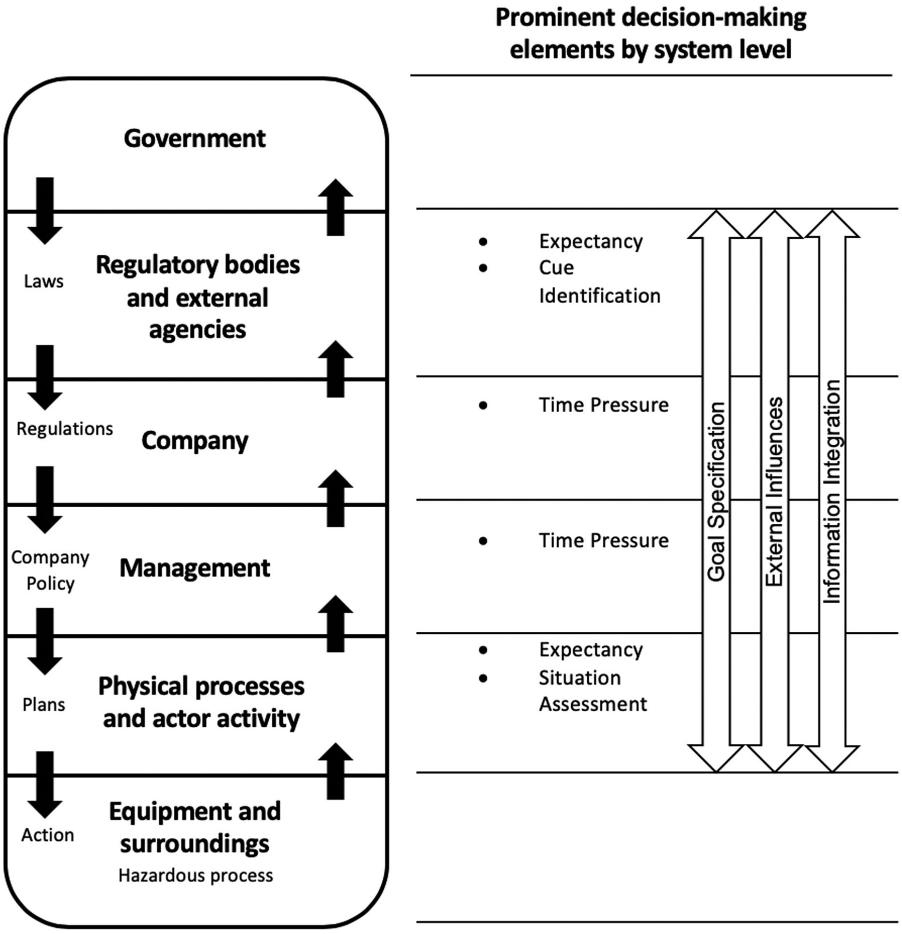

FIGURE 3 Prominent decision-making elements by system level

decide to step in, but also assess the safety of the situation for themselves before intervening.

Table 4 provides a number of participant response examples associated with the prominent elements of decision-making across each system level.

3.3 | Safety leadership behaviors by system-level and task type

In terms of leadership behaviors, overall Empowering leadership behaviors were reported as the most frequently engaged in across all levels of the work system. *Informing* emerged as the most frequent behavior associated with the tasks examined and related to communications and the open flow and exchange of information with individuals and teams to support task execution. The Leader-Member Exchange attribute relating to *Obligation* also emerged as frequently engaged in across system levels and tasks, with the exception of Return to Work coordination. *Obligation* was found to be related to the participants' understanding of job-related challenges faced by individuals and teams associated with the tasks being undertaken. Figure 4 illustrates the prominent emergent leadership behaviors by the system level.

In terms of behaviors relative to each system level, at the Regulatory level, the most frequent behavior engaged in related to the Empowering leadership practice of *Coaching*. This was reported as a reflection of the nature of the relationship between representatives of an external agency engaging with organizational representatives

TABLE 4 Decision-making element examples by system-level and task

System level	Decision-making element	Task	Behavioral example
Regulatory bodies	Expectancy	Hazard identification	"… I was expecting to have to make the decision [to stop operation]. They [operators] weren't identifying the issue [hazard associated with cable damage in underground operations] and so it fell under my duties as the Regulator to raise it… I couldn't walk away from the site feeling like there was no immediate risk and since my mining colleagues weren't identifying it, it was my responsibility to call a stop…"
Company	Information integration	Hazard identification	"…The conveyor had been replaced the year before and it didn't have guarding on it. So, I wasn't very comfortable with that and told the team that I wasn't very comfortable and what I saw it as the risk. It was interesting, the general feeling [from the operators] was 'this is how we've always done it, this is how it is'. They felt 'this is a new conveyor and it still doesn't have guarding, so obviously, we don't need it'. So, that told me I needed to challenge that thinking by continually asking 'how are you going with that issue [installing guarding]'. The team then came up with the solution and now it is a fully guarded installation…"
Management	Time pressure	Inspection	"…There were many different aspects to the same conversation [Critical Control Verification Inspection] and we spent well over an hour with the team, going through the task and associated risks, looking at parts of the equipment and discussing with the operators… We then regrouped as a leadership team and spent another hour talking about what we saw, what was good and what could be improved. And this is standard practice…"
Physical processes and actor activities	Situation assessment	Task observation	"… I was observing a maintainer removing a pipe. I could see it contained an amount liquid, which with my experience in that part of the plant, meant it was hydrochloric acid. He had the correct PPE on, however the pipe was in a position that if he took it down, it could have tilted too far and the liquid would have spilled on him. He was a newer employee and my concern was he wasn't able to see he was putting himself at risk. I stopped him and we had a lengthy conversation about safer ways to remove the pipe. In the end, he got the crane over…"

to provide a positive influence on safe performance and outcomes from a compliance perspective. This was particularly reported as being particularly related to the tasks of "hazard identification" and "inspection." At the Company level, the Empowering leadership practice of *Participative Decision-Making* was reported frequently and related to involving teams and individuals in decisions regarding how best to manage hazards identified. At the Management level, the Leader-Member Exchange attribute of *Trust* emerged as prominent and related to building rapport with teams and individuals during the execution of tasks, to help workers recognize the presence of hazards and seek to implement improved controls.

While the Transactional leadership attribute of *Management by Exception* did feature across all system levels and tasks, it was most frequent at the PPAA level, which suggested a preference or greater need to engage in this behavior specifically at this system level to support safety. Table 5 provides a number of behavioral examples associated with the highly reported leadership attributes by task and system level.

3.4 | Average engagement in decision-making elements and behaviors by system level

Figure 5 shows the average number of decision-making elements and associated safety leadership behaviors engaged in as reported by participants across each work system level.

Overall, higher average engagement in decision-making requirements and behaviors were reported at the PPAA system level when compared with other system levels. This suggests that the nature of tasks undertaken at this level involved intensive decision-making and corresponding behavioral engagement, with particular reference to the unstructured tasks executed. Two tasks at this system-level were unstructured and involved considerable direct interaction with individuals or teams and the ongoing assessment and integration of information to aid decision-making. This indicated a need for participants at this level to adapt and respond to the task or situation as it developed. This adaptation was also coupled with *Management by*

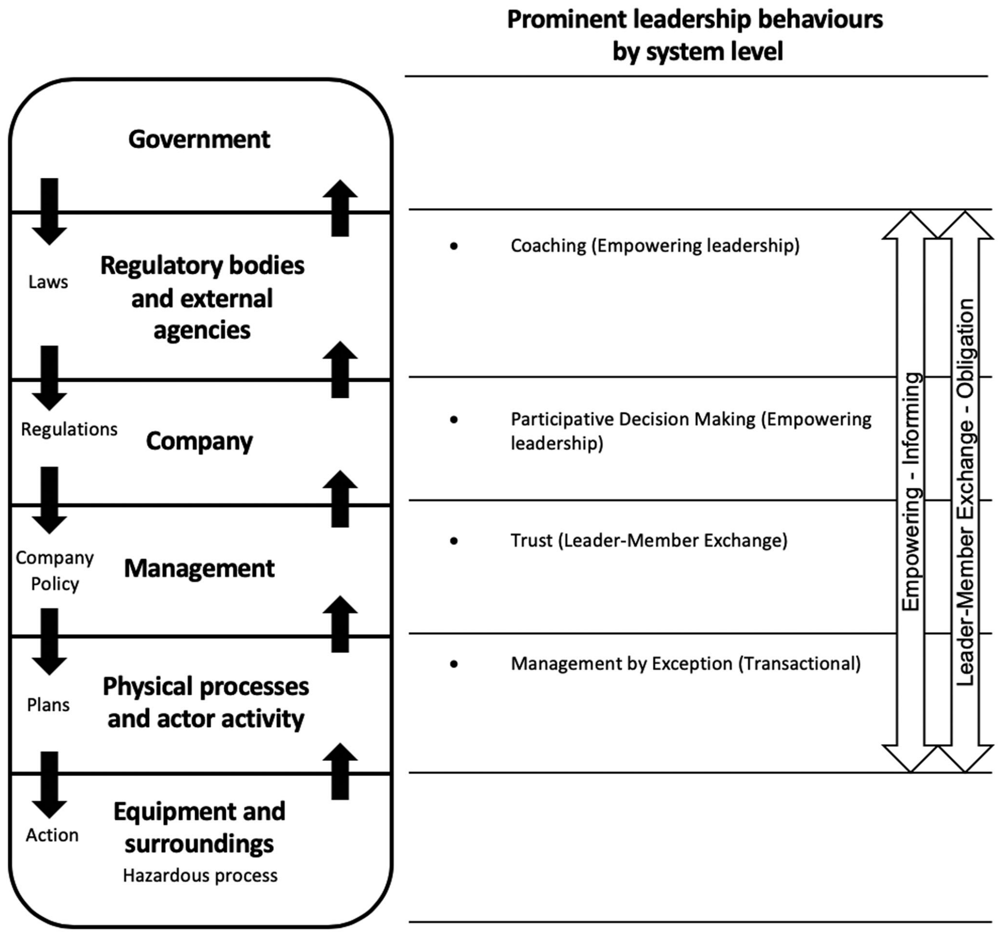

FIGURE 4 Prominent safety leadership behaviors by system level

Exception intervention requirements to ensure ongoing safety of the workforce.

At the Regulatory level, participants also indicated increased decision-making requirements, due to a greater need to seek out procedures (i.e., *External Influences*) and supporting information (i.e., *Information Integration*) associated with task execution. This was reported as a result of being external to the organization, which required an increased need to seek specific information related to the activity being undertaken to aid decision-making. Increased *Coaching* requirements were also evident and further reflected the nature of the relationship of an external agency engaging with organizational representatives to provide a positive influence on safe outcomes from a compliance perspective.

In contrast, the average engagement in elements of decision-making and behavior at the Management and Company levels was considerably lower. Participants indicated the structured nature of the tasks undertaken at these levels were underpinned by systems and processes, such as procedures for safety inspections and risk management activities. This was reported as supporting task execution and corresponded to less intensive decision-making requirements as tasks were clearly specified. Also, the corresponding behavioral engagement was lower for these two system levels, suggesting the regular execution of the tasks at these system levels require a more consolidated set of decision-making and leadership behaviors to support successful execution.

TABLE 5 Prominent safety leadership behavioral examples by system level and task

System level	Leadership Style and Behavioral attribute	Task	Behavioral example
Regulatory	Empowering—coaching	Hazard identification	"…I grabbed the miner driver and the cable hand and got them both involved. I said 'look, we've got a problem here, what do you think it might be?' I didn't want to give them the solution, I wanted them to be able to identify the hazard and tell me how they can fix it…'
Company	Empowering— participative decision-making	Hazard identification	"… I said to them I wasn't comfortable with what I was seeing and challenged the team to work together and see what options they could come up with to help mitigate the fall hazard. They went away and looked at ideas and came back with a solution."
Management	Leader—member exchange—trust		'…To build trust, you've got to start with a personal rapport, so I talked about more than the just issue we were inspecting… We ended up talking about our trucks! This really opened up communications and we then talked openly about the task. Then, it was easy to raise concerns…"
Physical processes and actor activities	Transactional—management by exception	Task observation	"…My biggest concern was he was not able to understand [the risk], so I stopped him and we had a conversation about risk tolerance… to me, it [the task] was not a risk that he should have been taking…"

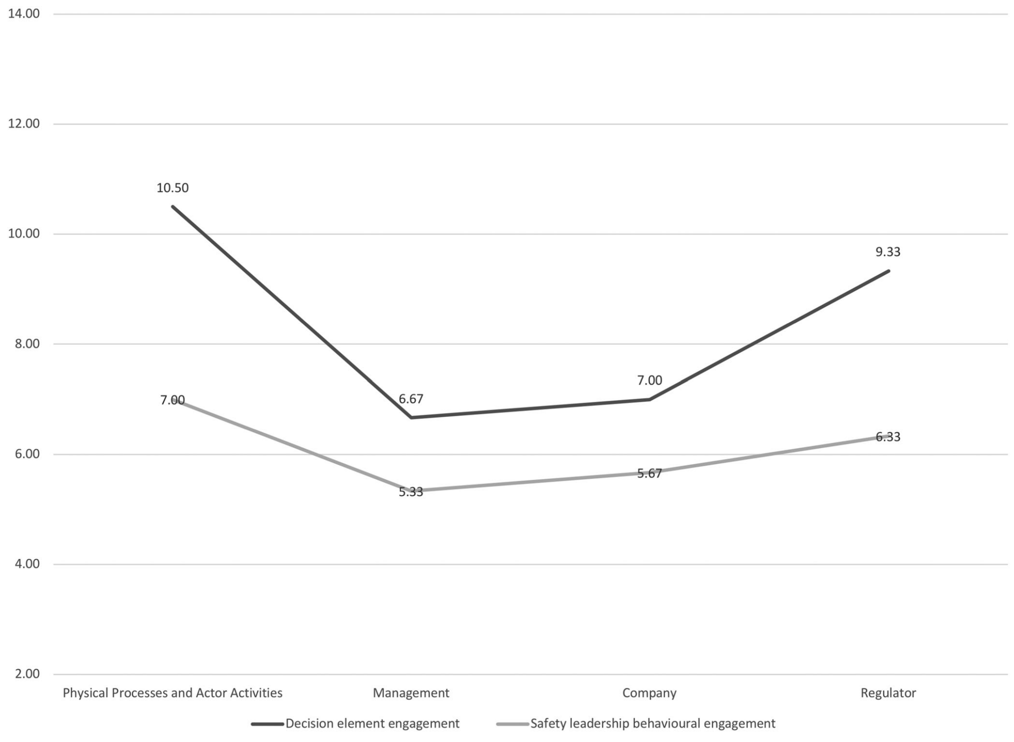

FIGURE 5 Average decision element and safety leadership behavioral engagement across the work system

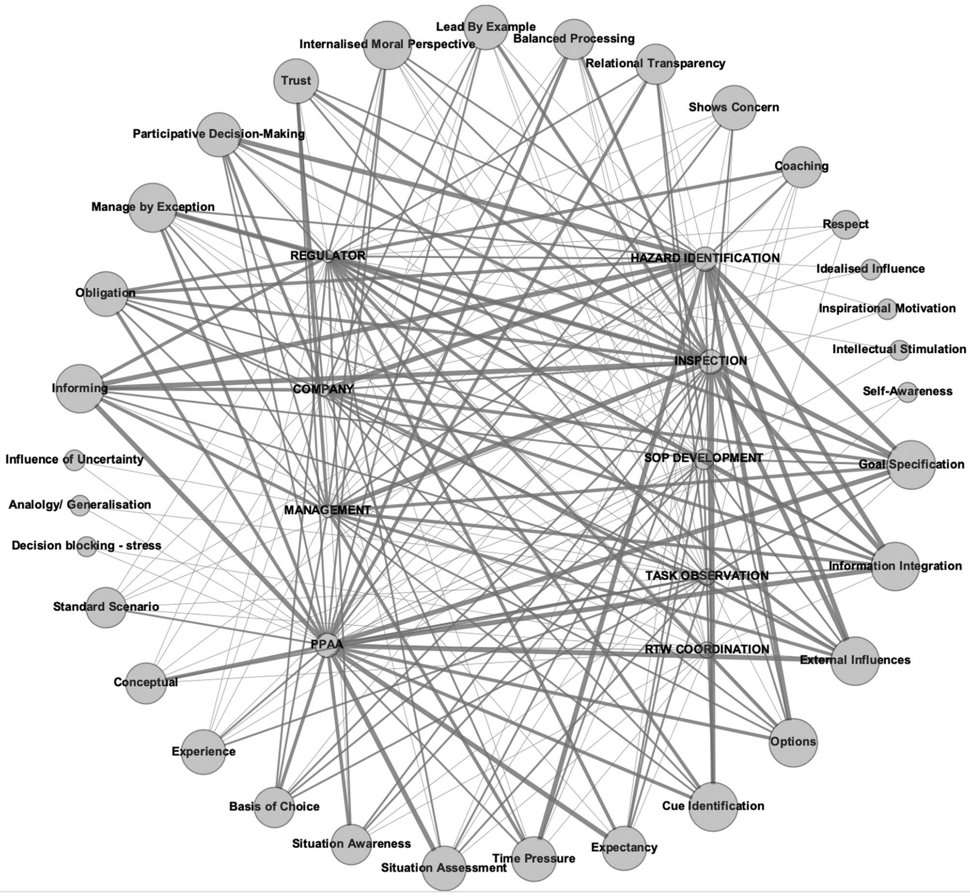

FIGURE 6 Summary of analysis—relationships between decision-making elements, leadership behaviors, tasks, and system levels

3.5 | Summary of analysis

Figure 6 provides a consolidated view of the analysis to illustrate the identified relationships between the elements of decision-making and behaviors reported in association with the five tasks explored across the work system. The outer circle represents all decision-making elements and behavioral attributes reported as being engaged in. The bottom half of the circle shows the decision-making elements, with larger nodes indicating the relative prominence of reported engagement across the work system (i.e., *Goal Specification*, *Information Integration*, and *External Influences* on the right-hand side are the largest nodes). The top half of the circle shows the behaviors engaged in across the work system, with larger nodes also indicating their relative prominence (i.e., Empowering leadership—*Informing* and Leader Member Exchange—*Obligation* on the left-hand side are the largest nodes). The central nodes represent the tasks, and system levels at which they occurred. Thicker lines between nodes indicate a stronger relationship (i.e., the number of participants that reported a specific node with reference to another node) between individual tasks, decision-making elements, behaviors and the system level at which they occurred.

Figure 6 indicates the core decision-making elements and behaviors, and their strength of association with tasks and system levels. For example, *Situation Assessment* was strongly associated with Task Observation at the PPAA system level, while less strongly associated with Hazard Identification at the Regulatory level. Similarly, Participative Decision-Making was strongly associated with Hazard Identification at the Company level, while less strongly associated with SOP development at the PPAA system level. This representation provides visibility of the core characteristics of safety leadership decision-making and behavior associated with the regular safety-related tasks executed, which can be developed and enhanced to support every-day safe functioning across mining work systems.

4 | DISCUSSION

The aim of this study was to apply systems-thinking to examine safety leadership decision-making and behavior during regular, safety-related tasks executed across a mining work system. The study was conducted to identify the key characteristics of safety leadership decision-making and behaviors which support safe performance across the work system, as a function of tasks executed in an every-day context. Five tasks were identified as indicative of regular undertakings associated with safety leadership, specifically; hazard identification, inspections, SOP development, task observation, and RTW coordination. The tasks explored were found to be associated with a set of core decision-making elements and corresponding leadership behaviors across the work system. At an overall level, "*External Influences*," "*Goal Specification*," and "*Information Integration*" were identified as key elements of decision-making across all tasks and work system levels. The corresponding highly associated safety leadership behaviors across the work system related to the Empowering leadership practices of "*Informing*," in conjunction with Leader-Member Exchange behaviors relating to '*Obligation*'. Additional decision-making elements and behavioral engagement requirements were evident for different tasks and levels within and across the work system, which indicated the characteristics of effective safety leadership varied across the work system to support safe system functioning.

The findings of the present study provide a number of important contributions to the safety leadership literature. First, in applying a systems-thinking methodology, the findings demonstrate the presence of Vertical Integration across the work system, which is recognized as a key factor associated with effective safety leadership to support safe system functioning (Donovan et al., 2017, 2018). The analysis demonstrates the decision-making elements relating to "*Information Integration*" and the associated Empowering leadership behavior of "*Informing*" enabled Vertical Integration by facilitating the communication, flow, and exchange of information within and across levels within the work system. Together, these components of safety leadership underpinned the open sharing of information between individuals and teams to support successful task execution. At higher system levels (i.e., Company and Regulatory) this was evident with these components of safety leadership relating to seeking assurance, and communicating requirements and expectations regarding adherence to law, regulation, and procedures across the work system. This was also evidenced in the types of tasks undertaken by participants at higher system levels, which demonstrated greater reliance on the need to seek out and integrate situation and tasks specific information to effectively communicate with individuals and teams. In a complementary fashion, "*Information Integration*" and "*Informing*" at lower system levels facilitated communication of situation and task-specific information upwards within the work system regarding safe system functioning, in terms of identifying the need for SOPs, undertaking direct task observation, and providing continued support for the return to work of an injured worker. This demonstrates communication and feedback was present across the work system, which is central to establishing Vertical Integration. The results, therefore, concur with previous research regarding the importance of establishing Vertical Integration to support effective safety leadership practices (Donovan et al., 2017, 2018). In doing so, the results provide understanding of the core characteristics of safety leadership which underpin Vertical Integration across a mining work system to support every-day safe system functioning.

Second, the findings provide improved understanding of the factors which influence safety leadership decision-making and behavior, with specific reference to the nature of the tasks undertaken, and work system level at which they occurred. In examining how safety leadership occurred across the work system, the analysis revealed decision-making and associated behavioral engagement requirements were influenced by task type. The analysis showed overall, structured tasks were more frequently engaged in, particularly at higher system levels (i.e., Regulatory, Company, and Management), while unstructured tasks occurred more frequently at occurred the lowest system level only. The structured tasks examined demonstrated lower decision-making requirements and lower associated safety leadership behaviors. In contrast, the unstructured tasks examined reflected increased decision-making requirements and associated engagement in leadership behaviors. These findings are consistent with two classes of tasks outlined in Rasmussen's Skills, Rules and Knowledge framework (Rasmussen, 1983). According to the framework, participants engaged in structured tasks on a "rule-based" approach. Rule-based behavior is said to be goal-oriented and planned whereby the execution of tasks is typically controlled by a rule or procedure (Rasmussen, 1983). This appears true of the structured tasks examined, particularly at higher system levels, as "*Goal Specification*" and "*External Influences*" were prominent for these tasks, with participants noting procedure or process underpinned their execution. Further, as the structured tasks examined were frequently undertaken, knowledge regarding their effective execution may have been gained over multiple previous executions. This suggests for these tasks, problem-solving, decision-making, and behavior may be pre-planned, thus potentially further reducing or consolidating associated decision-making and behavioral engagement requirements associated with such tasks. This is further reinforced by the prominence of the Leader-Member Exchange behavioral attribute of "*Obligation*," which was found to be related to the participants' understanding of job-related challenges faced by individuals and teams associated with the tasks being undertaken. Thus, familiarity with the task and scenario at hand may have influenced decision-making and behavioral engagement requirements associated with structured tasks. In contrast, "knowledge" based performance for unfamiliar or infrequent tasks requires explicit thinking (Rasmussen, 1983), which was evident in the execution of the unstructured tasks relating to "Task Observation" and "RTW coordination." While still goal-oriented, higher decision-making and behavioral engagement requirements were evident for these tasks, indicating explicit thinking and action was required. This is evidenced, for example, by the prominence of the decision-making element of "*Situation Assessment*," particularly at the lowest system level where engagement in unstructured tasks was more frequent, and the need for intervention was increased to ensure safe system functioning was maintained. While these results provide improved understanding of the inputs and cues which support safety-related decision-making (Wang et al., 2019), the findings have a number of implications for optimizing effective safety leadership across tasks and work system levels. First, they reinforce the importance of establishing Vertical Integration as the key mechanism by which continuously assessing, integrating, and communicating information underpins effective safety leadership decision-making as a key factor in maintaining safe performance. In an abnormal operational context, safety leadership decision-making is required to be dynamic and flexible to positively adapt and respond to situations as they evolve (Donovan et al., 2018). The same must be said for the conduct of regular tasks during normal operational context. An opportunity, therefore, exists to prompt the active and dynamic assessment of decision-making inputs and cues which enable Vertical Integration, particularly in association with regularly occurring structured tasks, to minimize the potential for complacency and system-level influences having a negative impact on performance (Årstad & Aven, 2017; Hyten & Ludwig, 2017).

The current findings also go considerably beyond existing models of safety leadership in a mining context (e.g., Du & Sun, 2012; Paul & Maiti, 2008), by providing new insight into the concept of safety leadership itself. By applying the CDM and behavioral prompts to directly explore safety leadership from the viewpoint of leaders themselves, an integrated perspective is developed whereby clear relationships are established between key decision-making elements, and supporting behaviors associated with the execution of regular tasks across the work system. This concurs with Rasmussen's assertion that safe performance is influenced by the decisions and behaviors of actors across the work system (Rasmussen, 1997). Moreover, the findings provide further evidence to demonstrate decision-making must be considered as an integral component of the safety leadership concept (Donovan et al., 2017, 2018). Central to this was the prominence of the decision-making elements relating to "*Goal Specification*," "*Information Integration*," and "*External Influences*" across the work system. Each task was reported as being associated with a specific goal ("*Goal Specification*") relating to the continued safe functioning of the work system. This was linked with the ability to integrate available information ("*Information Integration*") to ensure continued congruence with individual goals and alignment with "*External Influences*," such as regulation, standards, rules, and procedures with reference to task execution. Thus, the findings provide an important understanding of decision-making as an integral component of the safety leadership concept.

In terms of behavioral engagement, Empowering leadership practices and Leader-Member Exchange behaviors were the most frequently engaged in across the work system, however, different patterns of prominence were evident at different system levels. This is significant as it provides important insight into the patterns of behavior across the work system required to support every-day task execution and maintain safe functioning. From a top-down perspective, Regulatory officials engaged most frequently in the Empowering leadership practice of "*Coaching*" towards a desired outcome (i.e., compliance with regulation). In line with Zhang et al. (2017), this affirms the role external factors have in helping shape performance and safety leadership practices within an organization (Zhang et al., 2017). Within the organizational structure, leaders at the Company level frequently sought to engage individuals and teams in problem-solving to address the presence of hazards (*Participative Decision-Making*), while leaders at the Management system-level sought to establish "*Trust*" with teams and individuals through their interactions. In comparison, leaders at the frontline supervisory level (PPAA) engaged most frequently in the Transactional leadership behavior of "*Management by Exception*," in which leaders at this level regularly felt the need to intervene to stop observed unsafe acts.

These findings provide a level of agreement with previous research, specifically, regarding the relationship between Empowering leadership and Leader-Member Exchange practices in terms of promoting workforce participation (Martínez-Córcoles et al., 2012) and the importance of establishing trust between leaders and teams to foster open communications and exchanges of information (Conchie et al., 2012; Hofmann & Morgeson, 1999; Michael et al., 2006). However, the results do not replicate findings specifically in relation to Transformational and Authentic leadership practices as frequent and influential in supporting improvements in safety performance under normal performance scenarios (e.g., Akselsson et al., 2012; Conchie & Donald, 2009; Conchie et al., 2012; Du & Zhao, 2011; Fruhen et al., 2014; Lu & Yang, 2010). An explanation may lie in the advantage of the methodological design of the current study, whereby insights into leadership behavior were provided directly by leaders' themselves, instead of representing worker perceptions of effective safety leadership practices. As such, the results indicate capturing data directly from leaders provides an enhanced understanding of the key decision-making elements and behaviors associated with the execution of core safety-related tasks across mining work systems.

A number of practical implications are offered for organizations seeking to invest effort in the development of safety leadership capability. First, the results show benefit in ensuring Senior and Executive leaders engage directly in the five tasks explored, as well as Regulatory agencies outside of formal interventions. In doing so, the safety leadership decision-making and behavioral capability requirements identified can be formally embedded within competency frameworks and organizational learning and development content targeted for specific leadership levels. This will serve to not only support effective task execution but through the nature of the engagement profiles identified, will actively support the development of distributed safety leadership capability across work systems. Moreover, it will focus efforts on optimizing the effectiveness of safety leadership to better support and manage safety and risk across the mining industry. Second, the results also suggest that further education is required at the frontline level with regard to hazard identification and risk management activities. The frequency of leadership engagement in transactional leadership practices with respect to observing frontline workers indicates a potential gap in the safety and risk management capability of workers at the "sharp end." Building awareness of critical risk exposure at this system-level would seek to promote Supervisory level leaders to engage more frequently in the supportive behaviors indicative of higher system levels rather than transactional, intervention-based behaviors.

In terms of future research, studies should seek to examine safety leadership in a real-time, scenario-driven, and observation-based context. This will provide a further understanding of the process of decision-making and associated selection of behavioral engagement, with the immediate ability to assess effectiveness and impact on safety, particularly within the context of every-day safe functioning. This approach may also consider examining other regular tasks, for example, specific maintenance or risk management activities, which have not been explicitly explored in the current research. The findings from such research would help lessen the disconnect between how work is defined within work systems ("Work As Imagined") and how it is actually performed (Erik Hollnagel, 2005; Hollnagel, 2012). Work As Imagined refers to the assumptions made regarding how work should be done within complex sociotechnical systems (Hollnagel et al., 2011, 2012). As such, Work As Imagined typically takes the form of defined systems, processes, and procedures, which exist as the basis of organizational, or regulatory safety management systems. The prominence of structured tasks in the present research indicates a reliance on current Work As Imagined mechanisms to deliver optimal safety leadership. However, an improved approach would be to embed the identified safety leadership decision-making and behavioral capability requirements within Work As Imagined efforts to facilitate better alignment between procedures and actual practice in an every-day context (Back et al., 2017). Moreover, the findings of the present study implore future approaches to defining Work As Imagined to be less concerned with specifying action-based requirements, for example, through proceduralisation and focus more on promoting the key attributes of safety leadership identified to effectively support system functions and goals (Back et al., 2017). Such an approach would align with current thinking regarding adaptation and emergence (Dekker, 2011; Reiman et al., 2014; Wachs et al., 2016), which are both prominent concepts in systems theory, but less so in the practice of safety management.

As an alternate perspective, future research may wish to consider the role of intuition in decision-making (Alter et al., 2007), which assumes decision-making is based on years of practical experience and occurs at a subconscious level (Dane & Pratt, 2007; Hogarth, 2001; Kahneman, 2003; Klein et al., 1989). Although, Rasmussen's Skills, Rules and Knowledge framework (Rasmussen, 1983) does offer a position for understanding experience and skill in decision-making for structured and unstructured tasks, the unstructured tasks explored in the present study may be suited to understanding from an intuition perspective (Hammond et al., 1987). However, an explicit link would need to be made with subsequent leader behaviors to provide an integrated perspective of any intuition-based component of safety leadership. Further inquiries could also seek to understand the specific processes which underpin decision-making in the safety leadership context. This could be achieved through the application of additional systems-based methods, such the Control Task Analysis and Decision Ladder phase Cognitive Work Analysis (Vicente, 1999).

A number of limitations are acknowledged. First, in terms of the effectiveness of the decision-making elements and behavioral attributes identified, future studies should seek to make a direct connection between these elements and the presence or absence of incidents. As the tasks explored in the current study were not linked to injuries or incidents, it can be argued that they provide a measure of effectiveness in terms of maintaining safety equilibrium. However, this proposition would need to be further tested in situ to ensure confirmation. Second, for future studies, it is suggested sample size be increased to allow capture of safety leadership decisions and behaviors across a wider work system, which would further refine the critical decision elements and behaviors required of leaders across all levels to support safe functioning. Third, potential limitations of retrospective interviews could be addressed through real-time data capture of both leaders and followers to determine the equivalence of perspectives. Lastly, as the focus of this study was specifically on understanding safety leadership during regular tasks in a mining context, the generalizability of the results should be made with caution. To test applicability across other high-risk industries for similar tasks, additional research would need to be conducted using the same methodological approach to determine congruence.

5 | CONCLUSION

There is little argument that considerable progress has been made towards improving safety in the mining industry. However, this has largely been achieved through the application of a framework of regulation, underpinned by management systems that place emphasis on the conduct of specific tasks to effectively manage safety and risk. Continued reliance on such systems and processes alone will not give rise to marked improvement in current safety levels within the industry. The findings of the current study suggest that safety leadership plays an integral role in supporting regular safety-related tasks to help maintain safe performance. Key to this conclusion is the application of systems-thinking, which enabled new insight to be gained into not only the concept of safety leadership but also, how it occurs in an every-day context across a mining work system. To advance safety in mining, it is recommended that organizations invest effort in integrating the safety leadership capabilities identified into existing work practices and ensuring their application across the leader and work system levels. By doing this, effective safety leadership practices can be optimized to support key functions, thus further contributing to towards reductions in workplace injuries and incidents across the industry.

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ORCID

Sarah-Louise Donovan http://orcid.org/0000-0001-6452-5875
Paul M. Salmon http://orcid.org/0000-0001-7403-0286
Tim Horberry https://orcid.org/0000-0002-3453-0216
Michael G. Lenné https://orcid.org/0000-0003-1671-6276

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7.2 Discussion

The aim of this study was to apply Rasmussen's RMF and the CDM-SL (extended CDM) to examine safety leadership decision-making, behaviour and actions across a mining work system during regular safety-related tasks and activities. Specifically, the aim was to identify the key characteristics of safety leadership decision-making and behaviours that support safe performance across the work system, as a function of tasks executed in an every-day context. The findings revealed a core set of decision-making elements and behavioural attributes were associated with the five tasks examined, with additional profiles of decision-making elements and behavioural engagement requirements evident for different tasks and levels within and across the work system.

The findings add to the knowledge base relating to safety leadership in the following ways. Specifically, the analysis shows how safety leadership occurs at different levels of the work system to support ongoing safe performance during regular safety-related task execution. By examining safety leadership during regular safety-related tasks that aren't associated with any incident, the analysis reaffirms the findings presented in Chapters 4 & 5 relating to Vertical Integration. The presence of Vertical Integration was confirmed by the prominence of the decision-making elements relating to '*Goal Specification*', '*Information Integration*' and '*External Influences*', in conjunction with the EL practice of '*Informing*', and LMX behaviour associated with '*Obligation*'. The relationship between these decision-making elements and behaviours strongly aligns with the definition of safety leadership outlined in Chapter 2, whereby the common goal regarding the achievement of safe performance is reinforced through the decisions and behaviours leaders engage in across the work system. Fundamental to this is the gathering, integration and sharing of information across the work system. Collectively, these findings are novel, as they demonstrate the principal capacities across the work systems that can be developed to optimise safety leadership to effectively support safe performance during regular safety-related task execution.

A related important outcome of the study indicates that safety leadership is influenced by task type. Structured tasks showed less inputs to decision-making and subsequent corresponding behavioural requirements, while unstructured tasks were associated with higher average engagement in associated decision-making elements and behaviours. The frequency of structured tasks reported across the work system (n = 10) suggested these tasks to be core responsibilities in which effective safety leadership practices may be learned over repeated exposure, therefore lessening the requirement for decision-making and behavioural engagement. In contrast, unstructured tasks were less frequently engaged in and required considerable variability in performance to adapt and respond to changes in the situation (i.e., Task Observation, Return to Work coordination activities), which placed higher demands on decision-making and corresponding behavioural engagement. This aligns with the findings presented in Study 1 in terms of increased decision-making and corresponding behavioural engagement required by leaders during non-routine task execution (i.e., responding to the critical incident scenario) (Donovan et al., 2018). Figure 5 provides an overview of the key learnings and factors that influence safety leadership as derived from Study 2.

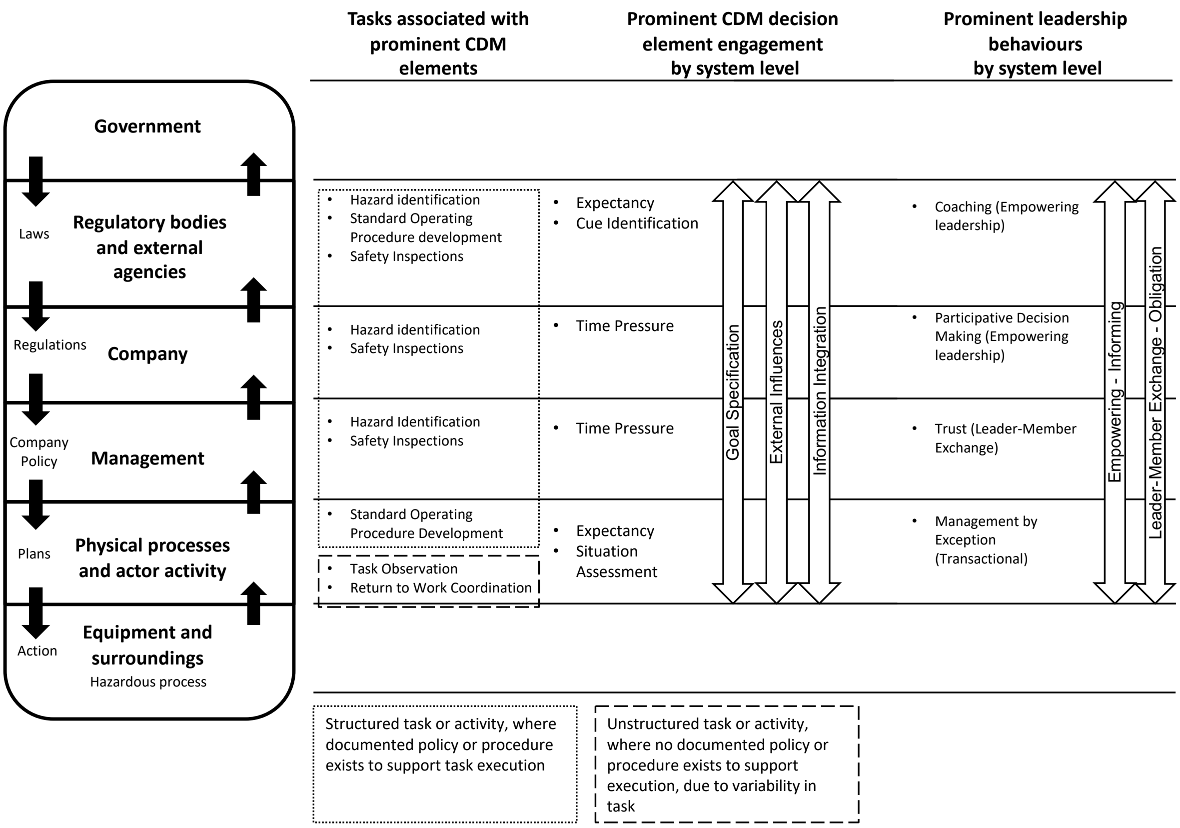

Figure 5. Factors that influence safety leadership during regular safety-related tasks

7.2.1 Limitation

Both studies described thus far have provided an in-depth analysis of how safety leadership occurs across a mining work system to support safe functioning, by identifying the factors that influence decision-making and behaviour during both normal and abnormal operational contexts. However, a consolidated perspective is not yet presented that can assist in defining a path forward for integrating the key factors identified into the development of targeted strategies to optimise safety leadership. To achieve this, an important next step of the current research relates to the design of such strategies to support practical application of the key findings. CWA has been used extensively to facilitate the design and development of interventions to improve safety and performance within complex socio-technical systems (e.g., (Cornelissen et al., 2015; Naikar, 2006; Niskanen, 2018; Read, Salmon, Lenné, & Stanton, 2016; Salmon et al., 2016; Stevens & Salmon, 2014), and as outlined in Chapter 3, it presents as a good candidate method for applying in the safety leadership context to move towards achieving this.

7.3 Conclusion

Chapter 7 described Study 2, which involved the application of the methodological extension to the CDM developed and described in Chapter 6. Chapter 7 outlined further important new knowledge regarding safety leadership, by showing how safety leadership decision-making and behaviour occurs across different levels within a work system in association with regular safety-related task execution. It also added to the knowledge base of what factors support and influence safety leadership across the work system to help maintain safe performance.

Chapter 7 also highlighted the need to consolidate the findings and factors identified in Studies 1 and 2 in order to move towards the design of strategies to enhance effective safety leadership across mining work systems. CWA is proposed to achieve this aim.

Chapter 8 therefore introduces Study 3, which applies three phases of CWA. Consolidating the factors and findings identified in Studies 1 & 2, first, a WDA is developed, which describes a series of 'means-end' links to model the affordances and constraints that govern the functions of safety leadership. Next, a CTA is undertaken, in which a consolidated DL is developed to understand the generic information requirements, inputs and outputs associated with achievement of the functions of safety leadership. Lastly, a WCA is performed to extract the key SRK-based behaviours required of leaders during normal and abnormal operational contexts to support continued safe system functioning. The key outcomes of Study 3 were used to inform the development of a systems-based safety leadership competency development framework, as a strategy to enhance and optimise safety leadership capability and performance across mining work systems.

8 Applying Cognitive Work Analysis to develop a model of safety leadership to support the development of strategies to enhance performance

8.1 Introduction

The initial studies described in this thesis have provided an in-depth assessment of safety leadership, how it occurs across a mining work system, and what factors and interact to support safe performance. While this has enhanced the knowledge base on safety leadership, the methodology applied thus far has not been sufficient in isolation to recommend a path forward for organisations to integrate and practically apply the learnings described. Thus, further analysis was required to support the development of strategies designed to translate the findings described, to enhance appropriate and effective safety leadership across the mining industry.

Chapter 8 presents Study 3, in which Cognitive Work Analysis was applied to further examine safety leadership, with the aim of moving towards the development of strategies to enhance and optimise safety leadership. CWA has been used extensively in other domains to support the design of interventions to optimise safety and performance (Lundberg et al., 2018; Naikar, 2006; Read, 2019; Salmon et al., 2016).To the author's knowledge, CWA has not yet been applied to examine safety leadership, nor to drive the development of strategies to support stakeholders to optimise safety leadership across mining work systems. As such, the application of CWA in the current context not only demonstrates an important extension of the use of the CWA method, in doing so it also provides a novel contribution to the research on safety leadership.

In Study 3, Work Domain Analysis was first applied to develop a model of safety leadership to identify and better understand the functions, values and priorities, objects and processes that afford and constrain effective safety leadership. Next, a Control Task Analysis was conducted to understand when and where functions currently occur as examined in Studies 1 and 2 with relation to safety leadership. A consolidated Decision Ladder was then developed that represents the generic information requirements, and inputs and outputs associated with achievement of the functions of safety leadership decisions, related to the tasks examined. Finally, a Worker Competency Analysis was performed to identify the underlying Skill, Rule and Knowledge-based competencies and behaviours required of leaders across mining work systems to support achievement of the functions of safety leadership.

The analysis presented in Chapter 8 provides an in-depth analysis of safety leadership as well as insights to support the design of a framework for safety leadership competency development. The analysis also provides evidence to address the following research questions:

> RQ 4: Can systems-based ergonomics methods be used to develop a useful model of safety leadership?
>
> RQ 5: How can organisations in the mining industry best encourage appropriate and effective safety leadership?

8.2 Applying Cognitive Work Analysis

As outlined in Chapter 3, three phases of CWA (Vicente, 1999) were applied, specifically:

- Phase 1 – Work Domain Analysis (WDA)
- Phase 2 – Control Task Analysis (CTA)
- Phase 5 – Worker Competencies Analysis (WCA).

The remaining two phases (Strategies Analysis and Social Organisation and Co-operation Analysis) were not applied in the present study. It was felt the output from the three phases applied would provide sufficient depth to achieve the study intent and provide a basis for the design and development of a targeted strategy to enhance safety leadership.

8.3 Method

A number of data collection activities were undertaken. The data gathering activities outlined below were previously granted ethics approved by the Monash University Human Research Ethics Committee as part of the studies outlined in Chapters 4, 5 and 7. Three analysts with considerable experience in applying CWA in a range of areas (e.g. Defence (Jenkins, Stanton, Salmon, Walker, et al., 2008), transport (Cattermole-Terzic & Horberry, 2019; Read, Salmon, & Lenné, 2014; Salmon et al., 2016)) were involved in conducting and reviewing the analysis. The data used by the analysts to perform the CWA was gathered during the various data collection activities described below. These activities have been previously established as appropriate data collection activities for the purpose of conducting CWA (Mulvihill et al., 2016).

8.3.1 Document review

A review was undertaken of the Safety Management System (SMS) documentation for the organisations involved in Studies 1 & 2. This was conducted by the author who has considerable expertise in both mining and the development, implementation, review and continuous improvement of SMS documentation. The review covered key standards and elements embedded within each SMS and specifically covered:

- Safety-related policies
- Hazard identification and risk management processes and procedures
- Organisational accountabilities and responsibilities
- Learning and development
- Communication and consultation
- Operational control including, management of change and business resilience and recovery requirements
- Incident reporting, investigation and action management
- Performance assessment and auditing requirements
- Monitoring and measuring activities; and
- Management review and governance.

The review was used to identify references to safety-related tasks or activities required to be undertaken by leaders, and any reference to safety leadership decision-making or behavioural capability requirements within key management system elements to support successful task or process execution. An example of relevant content within the SMS for one organisation was extracted from the top level Safety Policy, and stated "…sites must develop, implement and maintain an integrated approach for the management of health and safety, including policies that directly reference "*encouraging employee participation and promoting employee awareness of health and safety threats and opportunities…*"*.* An additional example in the SMS element relating to 'Communication and Consultation cited "…sites must have an accompanying process to encourage the participation of employees and contractors in activities that promote improvements in health and safety performance. This must include "*employee's specific involvement in hazard identification activities, risk analysis and the determination of controls…*". Both examples provide reference to attributes of safety leadership in terms of behavioural engagement (encouraging employee participation), and aspects of decision-making (risk analysis) associated with required tasks (i.e., hazard identification).

The document review provided input to three levels of the WDA, specifically; the physical objects, object-related processes and purpose-related functions levels. The document review also provided input to the CTA and DL in terms of identification of key safety-related tasks required to be executed across the work system (i.e., the regular or non-routine tasks examined), and any associated goals that may underpin them.

8.3.2 Critical Decision Method Interview data

The CDM interview data collected from twenty-one participants during the studies described in Chapters 4, 5 and 7 was reviewed and consolidated into categories of data to contribute to Study 3. The average age of participants at the time of the interviews was 45.9 years (SD = 9.29), with an average time in role of 2.4 years (SD = 2.39).

8.3.3 Cognitive Work Analysis

8.3.3.1 WDA

For the WDA, where references to factors and elements aligning to objects, processes, functions and priorities were identified in the CDM transcripts, these were extracted and classified as 'nodes' by the primary analyst and were placed on the appropriate level of the WDA abstraction hierarchy. Similarly, where an object, process, function or priority was referenced in the SMS documentation reviewed, this was also classified as a node and placed at the appropriate level on the abstraction hierarchy. For example, where a participant made a reference to a 'procedure' or 'work instruction', that data point was categorised as a 'physical object' and was placed at the lowest level of the WDA. Where a reference was made to 'ensuring procedures or work practices were followed', that was categorised as a 'purpose-related function'. Similarly, where SMS documentation referenced the need for a standard, policy or procedure for example, this was classified as a node at the physical object level of the WDA. Where a relationship was established between a node and a higher or lower order node on the abstraction hierarchy, a means-end link was created between the two. For example, at the 'Physical Object' level, 'Training content and materials' was linked to 'providing safety leadership training' at the 'Object-related process' level. This facilitated the mapping of the interrelationships, affordances and constraints that impact safety leadership.

8.3.3.2 Control Task Analysis and Decision Ladders

The CDM interview data from the twenty-one participants was also used to inform a CTA. This involved the development of a CAT and consolidated DL, whereby the tasks (regular and non-routine) examined in Chapters 4, 5 and 7 were mapped against the functional purposes and the purpose-related functions of safety leadership in a tabular fashion. This enabled consolidation of which tasks were performed with respect to achieving the individual high-level functions, and purpose-related functions associated with safety leadership. For example, all control tasks were associated with the function of ‘Ensuring and maintaining a safe working environment’, while not all control tasks were associated with ‘Fulfilling requirements of law and regulation’, or ‘Producing product or service safely’. Similarly, all tasks and scenarios were related to ‘Safety Leadership Decision-Making Competency’ and ‘Safety Leadership Behavioural Competency’, however not all tasks were linked to the function of ‘Ensuring Compliance’.

Following development of the CAT, the CDM interview transcripts were again reviewed with reference to the DL structure (see Figure 3 in Chapter 3), with information requirements, inputs and outputs derived from the CDM queries mapped against the relevant step in the DL. For example, participant responses that referenced perception of physical elements in the environment (i.e., visual observation, auditory cue, alert or alarm from technical systems), were all coded as input to the ‘Alert’ level of the ladder. Information inputs coming from cues relating to observing data or scanning for detail was coded at the ‘Information’ level. Goal-related information was coded at the highest ‘Goal’ level, while specific task related information (i.e., regular or non-routine, structured or unstructured) were coded at the ‘Task’ level.

8.3.3.3 Worker Competencies Analysis

The two previous phases (WDA and CTA) provided direct input into the development of the final phase of the CWA; the WCA. The WCA was performed by creating SRK inventory. The SRK inventory template was populated by first importing each of the individual steps from the DL down the left-hand side of the table. In a minor modification to the WCA approach, the analysis also included reference to the object-related processes identified in the WDA, mapping their correspondence against the individual decision steps. For example, at the ‘alert’ step in the DL, actors were required to ‘collect’ information on hazards, near misses, risks and compliance, while at the ‘options’ step, they were also required to ‘analyse’ the same information in order to determine options. Mapping the object-related processes was done to ensure the SRK-based competencies identified were able to be linked back to purpose-related functions of safety leadership and understand the subsequent link these have with respect to achieving the associated values and priorities, and overall functional purposes of safety leadership.

Next, following guidance provided in Kilgore & St-Cyr (2016) , the associated SRK-based behaviour elements of the analysis were derived from the CDM interview data and populated for each step in the DL. The information requirements, inputs and outputs described in the DL were individually reviewed and categorised to identify the high-level SRK competencies required. SBB (as introduced in Section 3.3.4.3) identified related to automated sensorimotor input such as visual or auditory information and outputs such as the act of communicating. For example, at the 'information' step in the DL, where an actor referenced the need to read or review written information, provide written notification, or verbally communicate with individuals and teams to advise of a situation, this was coded at the SSB level. It is important to note that the content of communications occurred at a Rule or Knowledge-Based level, while the actual act of communicating (not considering content) was considered the primary skill.

RBB (also introduced in Section 3.3.4.3) were related to following a specific procedure or step as required by the control tasks identified. For example, at the 'task' level, actors perceived information coming from various sources (internal and external) and followed required standards and procedures to support task execution. KBB (also introduced in Section 3.3.4.3) was noted where an actors' decision-making or behavioural response was based on conscious or explicit reasoning, or the application of expertise. For example, at the 'chosen goal' level, actors may vary decision-making and behaviour based on previous knowledge of a situation, and therefore act in accordance with individual and organisational goals, values and priorities.

The product of this phase of the CWA is a description of the activity elements associated with the different modes of cognitive processing and behavioural competencies required of actors to successfully complete the identified control tasks. The completed SRK inventory can be used to generate profiles of specific safety leadership competencies that actors must possess to effectively perform the control tasks examined. In this manner, it will be used to directly inform the design and development of a systems-based safety leadership competency development framework as a key strategy to enhance effective safety leadership across mining work systems.

8.3.4 Subject Matter Expert (SME) Review of Cognitive Work Analysis

The following section describes the review activities undertaken for each of the CWA outputs.

8.3.4.1 WDA

A draft of the WDA represented the safety leadership system within a mining organisation was presented to six SMEs for review to ensure its accuracy and completeness. Individual review sessions were held by the primary analyst with the six SMEs from within the mining industry and related regulatory bodies. One female and five male SMEs were involved in the review and represented four levels from within the work system; Regulatory (n=1), Company (n=1), Management (n=2) and Physical Processes and Actor Activities (n=2). To protect anonymity, the role descriptions within the industry for each SME is not disclosed. The average years of industry experience was 12.66 years (SD = 8.06).

During each session, SMEs were walked through the purpose of the WDA and stepped through an example of how the elements link across the analysis to afford or constrain safety leadership. Participants provided feedback and refinements in terms of purpose, values, functions and objects across the WDA to ensure its accuracy and completeness. Live updates were made to the WDA based on the feedback received. Table 10 shows the changes made to the WDA as a result of the review process undertaken with the SMEs.

Table 10. Changes made to the WDA based on reviews conducted with SMEs

WDA level	**Changes to nodes at review**	**Changes to connections at review**
Functional Purpose	• Node for 'Ensure/ maintain safe working environment' updated to 'Ensure and maintain a safe working environment' • Node for 'Produce product safely' updated to 'Produce product or service safely'	• All existing links tested and retained
Values & priority measures	• Node for 'Minimise injuries and fatalities' updated to 'Minimise or eliminate incidents, injuries and fatalities' • Node for 'Engage in effective safety leadership behaviours' updated to 'Engage in effective safety leadership decision-making and behaviours' • Node for 'Worker perceptions/ subjective rating assessment of safety leadership' removed, as not considered part of current safety leadership system	• Links added for 'Minimise exposure to hazards and risk' and 'Performance monitoring', 'Safety leadership behavioural competency' and 'Safety leadership decision-making competency'.
Purpose-related functions	• Nodes for individual safety leadership behaviours separated into two nodes 'Safety leadership decision-making competency' and 'Safety leadership behavioural competency' • Node added for 'Performance monitoring' • Node for 'Safe work practices' updated to 'Ensure safe work practices are followed' • Node for 'Compliance' updated to 'Ensure compliance' • Node for 'Assessment of safety leadership by workers for leader performance' removed as not considered part of current safety leadership system	• All links for 'Performance monitoring' node established • All existing links tested and retained
Object-related processes	• Node 'Analyse information on incidents and hazards' updated to include 'Analyse information on hazards, near misses, incidents, risks and compliance' • Node 'Provide safety leadership training for workers' updated to 'Provide safety leadership training' • Node 'Provide safety leadership information for workers' updated to 'Provide safety leadership information' • Node 'Provides standards for certification' updated to 'Meets required standards for certification' • Node 'Provides tools and equipment for work execution' updated to 'enable execution of work' • Node 'Provides real-time data monitoring' updated to 'enables real-time data capture and monitoring' • Nodes for 'collection', 'storage' and 'analysis' all updated to include 'information on hazards, near misses, incidents, risks and compliance' • Node for 'Auditing work practices' removed on account of presence of 'assessments, tools and checklists' at Physical object level and 'collects', 'stores' and 'analyses' nodes to meet purpose related function (above) of 'ensure compliance'	• All existing links tested and retained

WDA level	Changes to nodes at review	Changes to connections at review
Physical Objects	• Node for 'workspace tools and equipment' separated out into two nodes 'workspace or work environment' and 'tools and equipment' • Node for 'Incident/ hazard reporting system' updated to represent 'Integrated Safety Data Management System' • Minor amendments made to naming of nodes, for example 'training materials' broadened to training content and materials', education materials broadened to 'education and awareness raising materials' • 'Auditing software node removed' as deemed covered by 'integrated safety data management system'.	• Links added between 'Standards', 'Policies' and 'Procedures' and 'Analyse information on hazards, near misses, incidents, risks and compliance'.

8.3.4.2 Control Task Analysis, Decision Ladder and Worker Competencies Analysis

Two separate review sessions were held with an additional two SMEs from within the mining industry to review the CTA, consolidated DL and WCA. First, the CTA was reviewed by discussing the individual functions with reference to the work or task situations with which they occurred. Agreement was sought regarding the boundaries or extent to which the function occurred for each control task. This generated discussion regarding the constraints associated with particular tasks and situations in which alignment with the functions was not achieved. Both SMEs agreed with the CAT presented, with no changes suggested.

Next, a number of worked examples were stepped through in the DL to demonstrate the inputs and flow of steps executed for particular tasks. For example, the whole sequence of decision steps was reviewed for the structured tasks of 'inspection' and 'hazard identification', and also the unstructured task of 'task observation'. Discussion centred around the potential for 'leaps' and 'shunts' to occur across the ladder, particularly for structured tasks where experience was shown to influence decision-making requirements. The content for the final DL was agreed by the two SMEs, with no further changes suggested.

Last, the WCA was reviewed. Each of the object-related processes associated with individual steps in the DL were reviewed for accuracy in mapping and agreed completeness. Then the consolidated high-level SRK-based behaviours required to underpin the tasks and work situations were reviewed. For example, for the task of Standard Operating Procedure (SOP) development, at the 'Chosen Goals' level, the object-related processes were reviewed for accuracy and completeness, while the corresponding SRK-based behaviours were reviewed to ensure they adequately supported achievement of the chosen goal. Minor amendments were incorporated into the WCA based on the review activity and mostly focused on grammar or wording of the competency detail, rather than actual the competency requirements themselves.

It was noted that not all SRK-based behaviours extracted were linked to all tasks or steps in the DL. However, the consolidated WCA was agreed as the most appropriate means to provide an overall representation of the core high-level competencies required to execute the control tasks examined.

8.3.4.3 Final review of output from Cognitive Work Analysis

All outputs from the three phases of CWA applied were reviewed by three senior researchers associated with the study with considerable experience in the application and review of output from the various phases of CWA (Cornelissen, Salmon, McClure, & Stanton, 2013; Read et al., 2016; Salmon et al., 2016; Salmon, Williamson, Lenné, Mitsopoulos-Rubens, & Rudin-Brown, 2010; Xiao et al., 2015). Disagreements were resolved through discussion, with minor clarifications and adjustments made to the analyses throughout.

8.4 Results and Analysis of Cognitive Work Analysis

8.4.1 WDA – model of safety leadership

The WDA abstraction hierarchy model of safety leadership is presented in Figure 6.

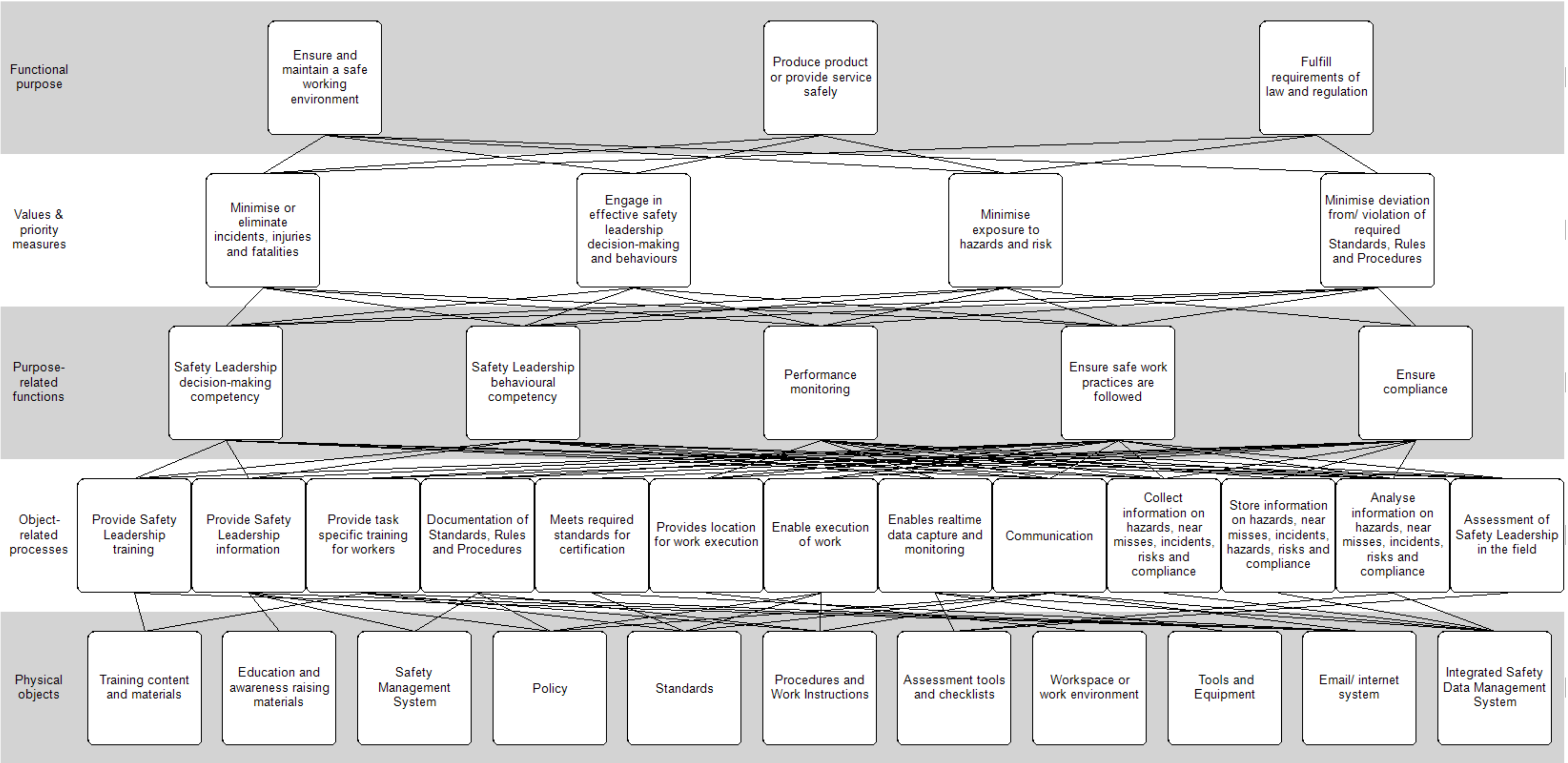

Figure 6. WDA of safety leadership

8.4.1.1 Functional Purpose of Safety Leadership

At the functional purpose level, three different functional purposes were identified; 'ensure and maintain a safe working environment', 'produce product or provide service safely' and 'fulfil requirements of law and regulation'. Each of the functional purposes identified were complimentary, rather than in conflict with one or another purpose, as is sometimes evident in other domains (Salmon et al., 2016). The concurrence strongly aligns with the definition and underlying intent of engaging in effective safety leadership decision-making and behaviour to support such goal-driven purposes.

8.4.1.2 Values and Priorities of Safety Leadership

The values and priorities measures level of the WDA shows the features that can be used to assess progress towards achieving the functional purposes of safety leadership. Four core values and priorities measures were identified; 'minimise or eliminate incidents, injuries and fatalities', 'engage in effective safety leadership decision-making and behaviours', 'minimise exposure to hazards and risk' and 'minimise deviation from/ violation of required standards, rules and procedures'. Of note, while each of the measures aligns with good-willed, moral and ethical intentions, it is debateable whether any of the values and priorities measures identified are currently being fully achieved. A key consideration in this regard lies in the extent to which achievement of each of the values and priority measures is able to be accurately quantified. For example, each represents a potential lead performance indicator of overall safe system performance however, there is currently no industry standard to determine what full achievement 'looks like'. While most mining organisations may collect information relating to observed hazards and near misses present in the work environment, or compliance figures relating to adherence to standards, there is currently no defined approach to relate data captured against the number of potential negative outcomes prevented. While logic may suggest an inverse relationship between safe and unsafe outcomes would indicate successful achievement of each stated measure, the current reality is that the values and priorities identified provide only an approximation towards affording the functional purposes described, since there is no existing model or criterion that permits measurement of absolute achievement.

8.4.1.3 *Purpose-related functions of Safety Leadership*

The purpose-related functions level shows the functions that need to be achieved for effective safety leadership. At this level, decision-making and behavioural competencies are recognised as playing an important role in helping to meet the value and priority measures and thus overall functional purposes of safety leadership. Identifying the need for safety leadership competency requirements at this level supports the proactive and positive performance shaping focus of the safety leadership concept. For example, the functions associated with compliance and monitoring indicate a focus on measuring performance 'after the fact' as a way to achieve the values and priority measures identified. By 'ensuring compliance', the value measure of 'deviation from or violation of required standards' is necessarily minimised, which translates into that priority measure being 'partially met' on account of no definitive criterion to determine outright achievement. Similarly, 'ensuring safe work practices are followed' also supports compliance efforts and towards 'minimisation of exposure to hazard and risk'. In comparison, demonstrating effective safety leadership decision-making and behaviour competencies at this level acts as a proactive precursor to the other purpose-related functions listed, with the potential to positively shape performance towards achieving the values and priorities.

8.4.1.4 *Object-related processes and physical objects*

An important observation of the WDA relates to the lack of support available from the two lower levels to help achieve the purpose-related functions. It becomes apparent that object-related processes and physical objects are may not provide adequate development and support to the purpose-related functions with reference to safety leadership competency development. While extensive objects and processes exist to support the other purpose-related functions associated with, for example, compliance and monitoring, these are clearly lacking with regard to developing safety leadership decision-making and behavioural competencies. This is evident in the number of nodes in the form of systems and processes at the object-related processes level, which typically form the backbone of modern approaches to safety and risk management. It is clear from the analysis that the physical objects and object-related processes identified appear more focused towards supporting compliance related activities and functions than developing safety leadership capability.

8.4.2 CTA – CAT and consolidated DL

Figure 7 shows the CAT developed for the higher-order and purpose-related functions associated with safety leadership, as taken from the WDA (see Figure 6).

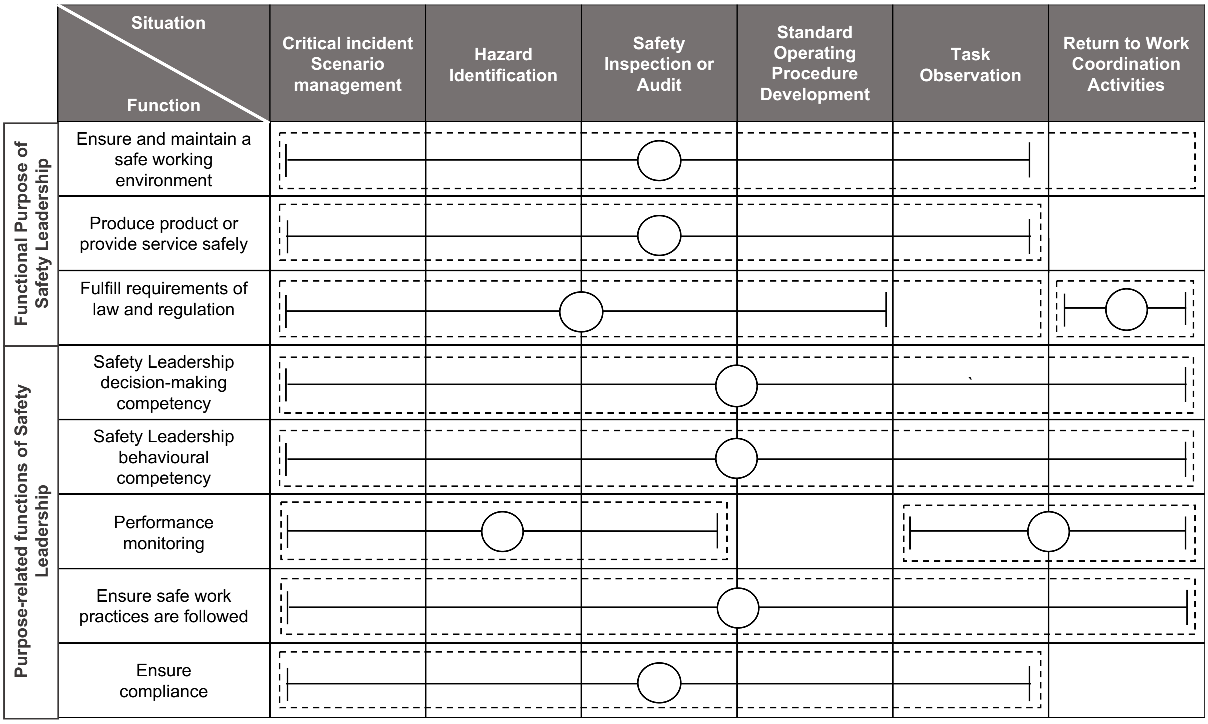

Figure 7. CAT for functions of safety leadership and related tasks or situations

The CAT shows that the functional purposes of safety leadership (left-hand column) were associated with the majority of tasks explored during the CDM interviews, with the exception of 'Task Observation' and 'Return to Work' (RTW) coordination activities. Task Observation was found to be not directly associated with the purpose of 'Fulfilling requirements of law and regulation', as it was classified as an unstructured task, which was performed by actors outside of any specified regulatory obligation, requirement, or process. It was recognised however, that performing Task Observation could assist in meeting regulatory requirements, thus indicating a current constraint evident within the safety leadership work system. Similarly, RTW coordination was not shown to be functionally linked to 'Producing product or providing service safely'. As this task was one step removed from the source of work being performed, it was not explicitly linked to the safe production of a product or service, even though the intended outcome of the task was to ensure this was achieved. Additionally, the function of 'Ensuring and maintaining a safe working environment' was not fulfilled by the RTW coordination activity, however similar to Task Observation, performance of this task could meet the espoused function, thus indicating another constraint within the current system.

In terms of the purpose-related functions of safety leadership, the majority of tasks were associated with the achievement of the functions of safety leadership described. Two exceptions were noted, the first being SOP Development, which was not directly associated with performance monitoring. This was deemed such as the requirement to monitor performance would be dependent on the SOP being developed, and then the subsequent following of that SOP. Further, the function of 'performance monitoring' was noted as being met by all other tasks (both structured and unstructured). Second, the task of RTW coordination did not fulfil the function of 'ensuring compliance' as again, this task was one step removed from the source of work being performed and was also met by all other tasks. These boundaries were not viewed as significant constraints impacting the achievement of the functions of safety leadership, as ultimately all functions were linked to all other tasks.

With the CTA complete, a DL was constructed by consolidating the generic decision relevant information identified with reference to the control tasks identified. The DL presented in Figure 8 represents a consolidated overview of the possible decision-making processes adopted by actors with regard to safety leadership during execution of the regular and non-routine control tasks explored.

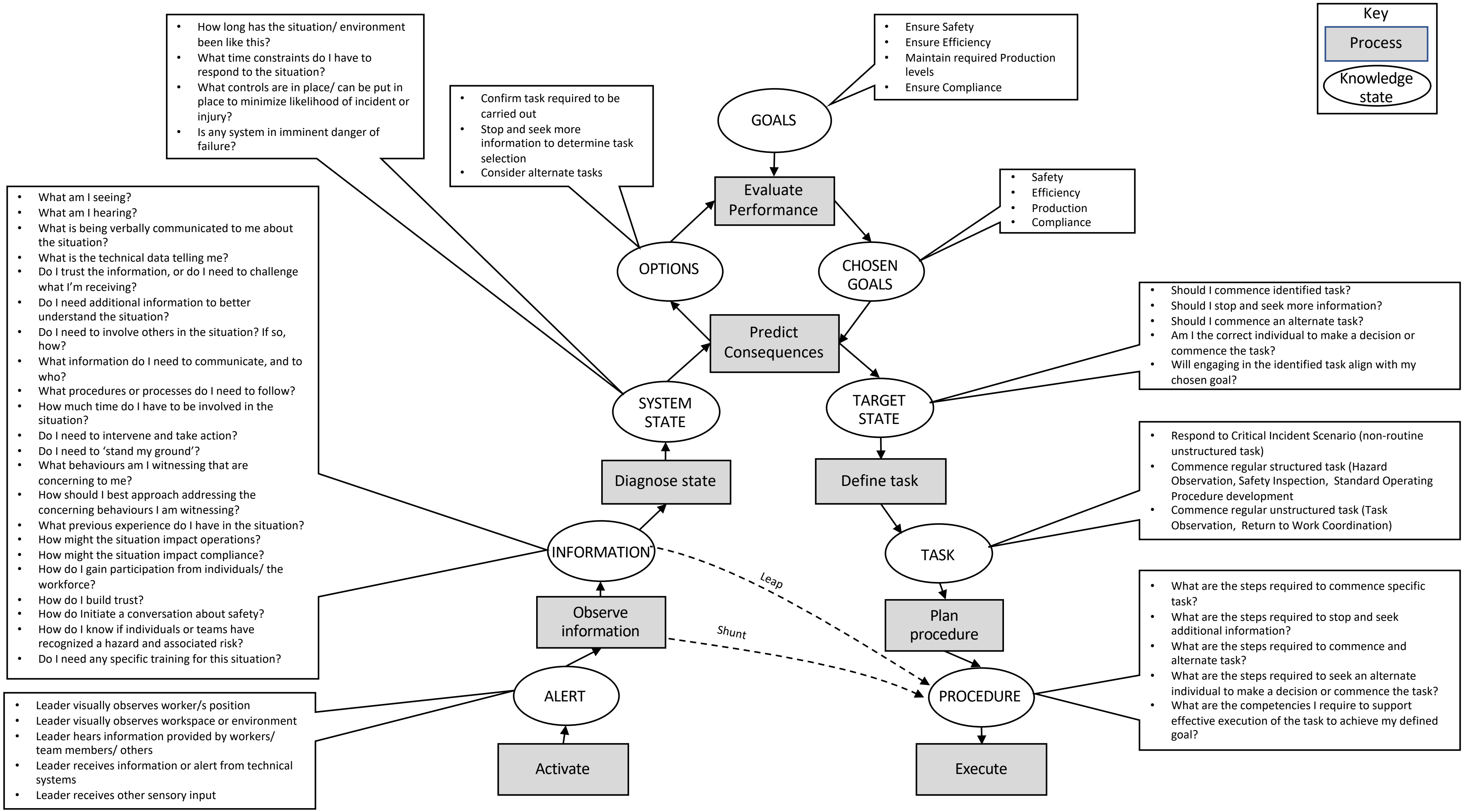

Figure 8. Consolidated safety leadership Decision Ladder associated with regular and non-routine task execution for all participants

The consolidated DL shows the many sources of information actors reported using to aid decision-making associated with safety leadership. For example, in terms of ‘activation’, sensory information such as visual perception of worker position, the workspace and environment, as well as auditory input featured prominently to provide initial recognition and context regarding the situation actors were required to respond to, or engage in. At the ‘information’ component level of the ladder, actors also indicated a range of inputs, including consideration of underpinning goals associated with the situation, an initial consideration of what processes may need to be followed or consulted and consideration of potential behavioural engagement requirements most appropriate to the situation.

While actors generally demonstrated following a linear sequence of information processing steps, there were instances where leaps and shunts occurred across the ladder. For example, structured tasks were typically pre-planned (i.e., Inspections and Audits, Hazard Observation) and tended to result in a reduced number of steps through the ladder to task execution. This is substantiated by the findings presented in Chapter 7 whereby reduced engagement in decision-making and behaviours was observed for structured tasks. In addition, engagement in structured tasks was predominantly based on a pre-determined goal and an actors’ previous experience or familiarity with the task or situation. This also resulted in a reduced number of steps through the DL, which raised a question regarding the potential for information to be missed, or not actively attend to and processed relevant to a situation as it developed. This may have implications for the reduced effectiveness of safety leadership associated with regular task execution in that while the associated outcomes may satisfy the requirement to ensure safe performance is maintained, decision-making and behaviour may not be fully optimised to drive improved performance and outcomes. In this sense, currently safety leadership may be merely ‘satisficed’ during regular, structured task execution (Vicente, 1999), which represents a key constraint for determining and optimising effective safety leadership practices.

With reference to unstructured tasks, decision-making typically followed a linear sequence through the ladder, with actors indicating heavier reliance on information inputs and active processing of information to guide task execution. This generated increased engagement in subsequent decision-making and associated behaviours for unstructured tasks, as reported in Chapter 5 and Chapter 7. As the unstructured tasks examined were less frequently engaged in (e.g., critical incident scenario response, RTW coordination), this meant actors were less able to draw on and apply previous experience readily. In addition, the absence of procedures relating to unstructured tasks suggests actor responses were formative in nature, whereby information from the environment was actively attended to, processed and reviewed as part of the decision-making and behavioural response progression. Decision-making and behavioural response was therefore adaptive and responsive with respect to the unstructured or non-routine control tasks executed, thus indicating a more thorough account of the range of inputs and behavioural outputs available for actors to engage to support achievement of functions and purposes.

A key feature of the unstructured and non-routine tasks examined in Studies 1 & 2 related to a direct interaction or engagement with teams and individuals regarding the individual situations encountered. It is suggested that this interaction not only drove VI and the open exchange and feedback of information across the work system, it also facilitated the adaptive and responsive nature of safety leadership required to support achievement of the functions described. This formative approach demonstrated variability whereby actors were required to draw on a range of decision-making and behavioural attributes relevant to the situation as it developed, rather than responding in a pre-learned, skill-focused manner which as indicated, may limit optimisation of safety leadership particularly during structured regular task execution. Thus, to continue to support VI and promote the open flow and exchange of information across mining work systems, the analysis suggests a formative approach to safety leadership may be more effective than constraining decision-making and behaviour through prescribing normative requirements.

8.4.3 Worker Competencies Analysis

The WCA represents a consolidated analysis of the high-level safety leadership related competencies identified relevant to the execution of both the regular and non-routine tasks executed across a mining work system. The WCA is presented in Table 11 below.

Table 11. Worker Competencies Analysis for safety leadership

Worker Competencies Analysis for Control Tasks

Information processing step	**Object-related processes associated with decision step**	**Skill-based behaviour**	**Rule-based behaviour**	**Knowledge-based behaviour**
Alert	• Collect information on hazards, near misses, risks and compliance	• Visual observation and monitoring of workspace or environment • Visual observation of behaviours of individuals or teams • Auditory input or communication from individuals / team members, or systems	• Perceive subsequent need to become involved in a situation	• Apply knowledge and experience of situation to determine if safety concern exists • Assess whether imminent safety concern exists based on prior expertise regarding potential risk exposures • Determine whether to assist situation
Information	• Collect information on hazards, near misses, risks and compliance • Communication	• Notify or advise individuals and teams of situation relevant information (written) • Communicate with individuals and teams to advise / notify of situation (verbal) • Read / review written information	• Check and review accuracy of any information received or obtained • Perceive information coming from physical systems, documentation or verbal communications	• Critical and analytical thinking required of information obtained to determine system state • Foster open communications and feedback to 'test' understanding of information and encourage continued supply of relevant information • Understand social and contextual factors surrounding provision of information, based on experience and skill
System State	• Analyse information on hazards, near misses, incidents, risks and compliance • Communication • Enables real-time data capture and monitoring	• Visually monitor system state • Receive communications regarding current system state • Communicate current system state to individuals and teams	• Confirm subsequent need to become involved in situation	• Perceive and interpret information to develop Situation Awareness • Apply knowledge and experience to determine if imminent safety concern exists (time constraints) • Understand system state, or behaviours exhibited by individuals or teams which may negatively impact safety
Options	• Collect information on hazards, near misses, risks and compliance • Analyse information on hazards, near misses, incidents, risks and compliance	• Visually monitor information, situation, task or environment for cues regarding safety concerns • Communicate options to individuals and teams	• Logically reason what options are available to safely become involved in situation • Logically reason whether subsequent involvement can occur safely considering any time constraints	• Determine options for engagement with individuals or teams • Demonstrate adaptability and flexibility to be able to respond appropriately
Goals	• Provide safety leadership information • Communication	• Continue to monitor information or system state for changes which may impact goals	• Engage / interact with individuals and teams in alignment with goals • Safety focused goal - clearly define individual goal/s relating to the maintenance of safety	• Understand social and contextual factors which motivate individuals and teams towards achievement of goal/s
Chosen Goals	• Provide safety leadership information • Communication	• Communicate safety focused goals to individuals and teams	• Follow required procedures in line with supporting chosen goal	• Act in accordance with individual and organisational goals, values and priorities
Target state	• Collect information on hazards, near misses, risks and compliance • Analyse information on hazards, near misses, incidents, risks and compliance • Communication	• Continue to monitor information or system state for changes • Read / review information obtained	• Perceive and interpreting information coming from all sources (internal and external)	• Build trust through meaningful interactions and open sharing of information and communications • Build quality interpersonal relationships by demonstrating concern for individuals and teams welfare and safety • Act with integrity, in accordance with chosen goal • Understand the importance and role of motivation in achieving safe outcome associated with tasks
Task	• Provide task specific training for workers • Provide safety leadership training • Assessment of safety leadership in the field	• Continue to monitor information or system state for changes • Communicate required information to individuals and teams	• Perceive information coming from various sources (internal and external) • Follow required standard and procedures	• Apply previous experience and skill in executing required tasks (no formal training other than learning On The Job) • Demonstrate trust through supporting and enabling migration of work practices to occur • Apply coaching principles and techniques to create a learning opportunity for individuals and teams • Assess safety through application of previous knowledge regarding situation
Procedure	• Meets required standards for certification • Provides location for work execution	• Continue to monitor information or system state and work environment for changes • Communicate required information to individuals and teams	• Perceive information coming from various sources (internal and external) • Follow required standards and procedures	• Apply previous experience and skill in executing required tasks (no formal training other than learning On-The-Job)

With respect to the division of types of behaviours, Vicente purports SBB comprises automatic responses and neuro-muscular control (Vicente, 1999). Thus, SBB is said to be performed without conscious attention and typically consists of anticipated actions involving direct coupling with the environment. As such, the corresponding safety leadership SBB identified were associated with, for example, visually observing hazards in the environment, visually observing specific behaviours of individuals and teams, reading and reviewing written communications and information, receiving auditory input in the form of verbal communications with individuals and teams, or monitoring systems for alarms or status prompts.

In the present context, the WCA revealed an inherent assumption associated with safety leadership SBB in that actors within the system are expected to implicitly 'know' what to be looking and listening for to be able to recognise or identify hazards or unsafe situations and behaviours. At each of the information processing steps associated with SBB, actors were required to observe, monitor, review, or communicate information to individuals and teams in line with the identified object-related processes. This suggests an antecedent requirement for actors to have previously developed an existing knowledge base relating to the situation in order to effectively engage in those SBB. For example, it may be possible for an actor to visually observe a work environment or workspace and yet not 'see' hazards that are present. Similarly, it may be possible for an actor to observe workers engaged in unsafe behaviours, but not detect them as such if no prior rule or knowledge base exists with regard to what is considered safe or unsafe behaviour. Therefore, it logically follows that SBB associated with safety leadership cannot be adequately developed without first establishing a sound and accurate knowledge or experience base, which is essentially indicative of RBB and KBB (Vicente, 1999).

In line with the DL analysis, it is therefore argued that the competencies representative of effective safety leadership are more closely aligned with a need to develop RBB and KBB. While it is acknowledged that SBB may be the preferred competency in other domains and control tasks, for example, involving direct operation a system or piece of equipment (Vicente, 1999), competency development in line with RBB or KBB in the current context provides greater opportunity to optimise safety leadership capabilities. This is not to suggest that SBB in the safety leadership context is not appropriate or useful, rather that, by enhancing the range of possible behaviours and decision-making approaches available to support safe performance, RBB and KBB competencies may better assist in achieving the functions of safety leadership. This would support an adaptive approach to safety leadership engagement that takes into account the variability of situations leaders may face, particularly in relation to non-routine task execution or safety critical scenario response. Further, focusing on developing such competencies would correspond to supporting a formative approach to safety leadership whereby constraints that shape behaviour are recognised and actively analysed, such that decision-making and behaviour is flexible and adaptive to respond to emerging situations. An actor is therefore not 'locked in' to performing narrow SBB, which give rise to non-adaptive patterns of behaviour (Lintern, 2010). This becomes important in the safety leadership context due to the inherent interaction requirements associated with facilitating the open flow and exchange of information indicative of VI. Further, it is important to create an environment where "Trust" is established whereby decision-making and behaviour is explicitly linked to safety-focused goals at both the personal and work system level and communicated across the work system.

An acknowledged drawback of RBB and KBB is that they tend to be slower due to the conscious focal attention required (Vicente, 1999), which can be somewhat problematic in certain contexts due to a need to respond quickly. In the current analysis however, time pressure was not noted as negatively impacting safety leadership in either regular or non-routine task execution (Chapter 4 and Chapter 7), thus not penalising the need to respond in a Rule or Knowledge-Based way.

It is worth noting that the competencies analysis did not link any of the behaviours to two object-related processes, specifically;

- Storing information on hazards, near misses, incidents, risks and compliance and;
- Documentation of standards, rules and procedures.

Rather than being considered as a constraint and potentially problematic, this result is recognised as reflecting the need for specific systems (i.e., SMS, incident reporting databases etc.,) to prescribe and capture information relating to achieving the functions of safety leadership described, which occur outside of the actual engagement in decision-making and behaviour.

8.5 Discussion

The aim of this chapter was to apply CWA to examine safety leadership, in order to assist in moving towards the design of strategies to optimise safety leadership across mining work systems. The key findings of Study 3 are now discussed with reference to the research questions outlined in section 8.1.

8.5.1 Key outcomes

8.5.1.1 WDA of Safety Leadership

The WDA was successful in producing a useful model of safety leadership across a mining work system, thus providing positive support for Research Question 4. The resulting model was able to demonstrate the functional purposes of safety leadership are well defined, however a clear implication from the output relates to a current lack of ability to optimise the identified factors that both support and enable effective safety leadership. While objects and processes exist at the lower levels of the hierarchy relating to safety leadership (e.g., training content and materials, etc.,), it is clear that the purpose-related functions are not well defined in terms of what constitutes the required safety leadership competencies to support safe performance. This suggests that currently training and development artefacts at lower levels of the hierarchy may not support development of the right safety leadership competencies. Further, the ill-specified criterion for achieving the values and priorities measures also constrains development of effective safety leadership decision-making and behavioural competencies in that there exists nothing to 'measure' effectiveness against. The result is in the current system, there is little impetus towards developing the physical objects and object-related processes such as training, education and awareness raising in line with effective safety leadership competency requirements. This impacts overall achievement of the functional purposes of safety leadership. A potential explanation may lie at the regulatory level of mining work systems, where the clear focus of current regulatory instruments is on prescribing compliance requirements and limited requirements relating to achieving effective safety leadership (e.g., Mine Safety and Inspection Regulations 1995 of Western Australia, Western Australian Government, 2017; Mining and Quarrying Safety and Health Regulation, Queensland Government, 2017; Work Health and Safety (Mines and Petroleum Sites) Regulation, New South Wales Government, 2014). This in turn drives a minimalist approach to defining safety leadership requirements and how they should be executed and supported in line with system functions to support safety performance across mining work systems.

8.5.1.2 Control Task Analysis and Decision Ladder

A key outcome from this phase of CWA relates to the reduced information processing steps associated with the completion of structured tasks. Structured tasks were more frequently engaged in and tended to be rule or procedurally based. This suggested a degree of consistency in how these tasks were performed and the associated safety leadership practices engaged in. Actors may have deferred to previous experience in terms of 'what worked' to successfully complete structured tasks, which indicates currently, decision-making and behaviour may not be fully optimised to drive improved performance and outcomes. In this sense, safety leadership may be merely 'satisficed', particularly with regard to structured tasks (Vicente, 1999). This represents a constraint for determining and optimising effective safety leadership practices as the completion of structured tasks becomes normative in nature (Lintern, 2019), whereby actors draw on existing behaviour rather than considering all possibilities of behaviour available to optimise performance (Read et al., 2016).

In contrast, unstructured tasks showed an increased number of steps through the DL and thus, higher decision-making inputs, outputs and associated behaviours. This resulted in a broader range of elements and attributes available to be drawn upon and indicated a formative approach to engagement in effective safety leadership for such tasks. This is important from the perspective of supporting VI, given communication and interaction-based requirements are key to supporting quality interpersonal relationships, trust and the open exchange of information across the system. By utilising a fuller range of decision-making inputs and associated behaviours, leaders demonstrated adaptability and flexibility, thus moving towards optimisation of safety leadership to support task execution and performance.

8.5.1.3 Worker Competencies Analysis

The final phase of CWA identified the high-level consolidated SBB, RBB and KBB that are required to support the control tasks, with reference to achievement of the functions associated with safety leadership. In line with the results for the CTA and DL, the analysis showed an inclination towards RBB and KBB as the key mechanisms through which to promote and achieve effective safety leadership and its associated functions. However, noted within this, was an inherent requirement on having a previously developed a repertoire and understanding of effective inputs to support decision-making and corresponding behaviours. Yet, how leaders obtain sufficient exposure to the sort of experience they need to develop that repertoire during regular and non-routine tasks is variable, with most 'learned on the job'. Thus, it is clear that without appropriate guidance on what sort of behaviours or competencies best support the achievement of goal-driven outcomes under varying conditions, and a structured way in which to develop this experience, it is largely up to individual learning and adjustment to develop those capabilities through trial and error. Thus, a need exists to define the effective safety leadership competencies identified in a way that can be integrated into formal learning and development mechanisms to facilitate development of leaders across the work system.

8.5.2 Factors influencing safety leadership

In concurrence with findings presented in Chapter 7, the nature of the tasks undertaken (structured vs unstructured) may have influenced safety leadership, acting as both a constraint in the case of structured tasks and an affordance in the case of unstructured tasks. While structured tasks occurred more frequently across the work system, they involved less information processing steps through the DL, which indicated actors may be drawing on previous experience to support execution, rather than actively attending to and processing all relevant information to optimise decision-making and behaviours. In contrast, unstructured tasks exhibited increased information processing steps through the DL, with actors drawing on a broader range of information and appropriate behavioural responses to support effective task execution. With this in mind, consideration should be given to the potential influence of task type on engagement in effective safety leadership practices, particularly relating to the promotion of VI. In order to optimise safety leadership in supporting task execution, the analysis indicates leaders should be encouraged to engage in a fuller range of decision-making elements and behaviours irrespective of task type. This would also seek to foster VI, the open flow and exchange of information and communications to develop trust through the nature of the decision elements and behaviours engaged in.

An additional influence is present in the identified values and priorities of the work domain, which reference the extent to which safety leadership is able to be developed. While 'engagement in effective safety leadership decision-making and behaviours' is recognised as a value, the current safety leadership system showed little focus or importance is currently placed on developing or enhancing safety leadership at the lower purpose-related function level. This is largely driven by the limited object-related processes and physical objects available to support development of effective safety leadership, which consequently constrains the ability to achieve the core values and priorities of the safety leadership system. With this in mind, it is unclear how safety leadership can be fully optimised to support safe performance if there is little support mechanisms available to build and sustain such capability across mining work systems. As such, a remaining concern relates to the lack of definition regarding effective safety leadership competencies required at the 'purpose-related' level to drive integration of learning, development and coaching across the work system. This leads to a situation whereby achievement of the values, priorities and functional purpose of safety leadership cannot be fully achieved.

8.6 Implications for optimising Safety Leadership

The application of CWA revealed a number of implications for optimising safety leadership across mining work systems. Addressing Research Question 5, Table 12 provides an overview of the key affordances and constraints identified and includes detail on number of targeted strategies organisations can implement to optimise the effectiveness of safety leadership in supporting safe system performance.

Table 12. Implications for optimising safety leadership from the CWA analysis

CWA PHASE	CONSTRAINTS AND AFFORDANCES	TYPE	RECOMMENDED OPTIMISATION STRATEGY
WDA	Limited object-related processes and physical objects exist to support the development of safety leadership. Therefore, safety leadership competencies are not well defined in terms of what constitutes effective decision-making and behavioural capability requirements across the work system to support safe functioning. Without clear definition of competencies required, this constrains the ability to meet the overall values and priorities of safety leadership, and corresponding functional purposes.	Constraint	1. Define safety leadership decision-making and behavioural competency requirements at the ‘purpose-related’ level, and develop and integrate corresponding learning, development and coaching mechanisms at the 'object-related' and 'physical objects' level to support development of required capabilities.
	The values and priorities associated with safety leadership are well defined however, it is unclear if they are being fully met as currently there is limited ability to quantify or measure actual achievement.	Constraint	2. Establish appropriate Key Performance Indicators for measuring achievement of values and priorities relating to engaging in effective safety leadership.
	At the functional purpose level, there is a clear imperative towards the achievement of safe and compliant performance. This strongly aligns with the definition of safety leadership applied throughout and underlying intent of engaging in effective safety leadership decision-making and behaviour to support such goal-driven purposes.	Affordance	3. Ensure any Key Performance Indicators established provide a clear link to the functional purposes of safety leadership as defined.
CTA/ DL	The completion of structured tasks typically involved a reduced number of steps through the DL, indicating safety leadership may be 'satisficed' for such tasks, rather than optimised.	Constraint	4. Ensure targeted learning and development mechanisms integrate appropriate Human Factors learning content, including coverage of individual/ internal factors that may influence decision-making (i.e., attention and memory capabilities), as well as remediation strategies for managing non-adaptive heuristics and cognitive biases which may give rise to less optimal safety leadership practices.
	Structured tasks were underpinned by pre-determined goal, and an actors’ previous experience or familiarity with the task or situation.	Affordance	5. Ensure targeted learning and development outcomes are clearly linked to the values and priorities, and functional purposes of safety leadership to preserve alignment with individual and organisational goals.
	The completion of unstructured tasks typically followed a linear sequence through the DL, indicating increased reliance on information inputs and active processing of information to support effective safety leadership associated with task execution.	Constraint	6. Ensure targeted learning and development mechanisms promote a formative approach to optimising decision-making and behavioural engagement associated with task execution. This will encourage learners to recognise and actively analyse constraints that shape decision-making and behaviour, such that safety leadership is flexible and adaptive to respond to emerging situations. It will also serve to develop a range of safety leadership competencies for learners to draw on relevant to a situation, rather than constraining decision-making and behaviour to pre-learned, skill-focused engagements.
WCA	The analysis indicates the competencies indicative of effective safety leadership to underpin successful task execution are more closely aligned with Rule-Based and Knowledge-Based Behaviours.	Affordance	7. In line with above, ensure learning content focuses on the development of Rule and Knowledge-Based Behaviours which provide greater opportunity to optimise the effectiveness of safety leadership across the work system. This should be underpinned by content which promotes and supports Vertical Integration (the open flow, exchange and communication of information across the work system), and the creation and maintenance of 'trust' through decision-making and behaviours, which are linked clearly to the values and priorities and functional purpose of safety leadership at both an individual and work system level.

In terms of the key constraints identified, a priority need is apparent regarding the need to define the specific decision-making and behavioural competency requirements associated with the purposes of safety leadership, for each level of the work system. Defining such competency requirements will provide a path forward for addressing the remaining constraints (i.e., development of appropriate Key Performance Indicators, development of training and assessment, etc.) and where appropriate, also leveraging the affordances (i.e., enhancing RBBs and KBBs, linking to functional goals, and promoting VI).

8.7 Study Limitations

The application of CWA has provided important understanding of the affordances and constraints associated with safety leadership across mining work systems. However, the output from the CWA in its current form is not summarised in a way for organisations to easily and practically apply, particularly regarding the specific decision-making and behavioural competencies of leaders required to be developed across the work system.

Therefore, in line with the first constraint outlined in Table 12, a necessary next step is to define the required competencies in a way that can be practically used by organisations to support development of safety leadership capability. By integrating the affordances and constraints identified within the CWA, the combined findings of the research thus far will now be used as the basis for the development of a systems-based safety leadership competency framework. The framework, developed and outlined in the following chapter, will define the underlying safety leadership competencies required of leaders at each system level to support safe system functioning.

8.8 Conclusion

Chapter 8 provided further important new knowledge regarding safety leadership and how it can be supported. Through the WDA, a new perspective was gained regarding the functional purposes, values and priorities and purpose-related functions associated with safety leadership. The analysis provided insight into the affordances and constraints that influence the effectiveness of safety leadership, with a key finding relating to a lack of defined decision-making and behaviour competency requirements to support development of successful and effective safety leadership across mining work systems. The CTA and consolidated DL points to a further constraint relating to the influence of task type on the ability of leaders to optimise safety leadership, particularly for structured tasks. This is impacted by the lack of available learning and development mechanisms at lower levels of the safety leadership system to adequately foster development of a range of safety leadership capabilities and ensure it is optimised for key tasks, irrespective of type (i.e., structured or unstructured). Lastly, the WCA identified a greater need for leaders to engage in RBBs and KBBs as a function of effective safety leadership. However, an apparent challenge remains in terms of how leaders grow rule and knowledge-based experience and capability in the absence of these specific skills being defined, and appropriate development mechanisms to support learning.

The priority outcome from the CWA points to a need to develop a systems-based framework for effective safety leadership competency development. The framework must leverage and address the affordances and constraints identified and promote the RBBs and KBBs identified, in association with regular and non-routine task execution. Such a framework would necessarily link safety leadership decision-making and behavioural competencies to the identified functions, values and priorities of safety leadership.

To address this need, the following chapter presents a systems-based safety leadership competency development framework. The framework integrates the key outcomes identified throughout the current research, and results in a design appropriate to underpin learning and development mechanisms to optimise safety leadership to support safe performance across mining work systems.

9 Development of a systems-based competency framework for effective safety leadership development

9.1 Introduction

Chapter 8 outlined the need to clearly define the safety leadership decision-making and behavioural competency requirements required of leaders across mining work systems to support safe functioning. The aim of Chapter 9 is therefore to integrate the core findings from the research presented in this thesis to develop a systems-based competency framework for effective safety leadership development.

The framework presented in this chapter describes five core competencies of safety leadership derived from this research, and includes the skills, knowledge, decision-making and behaviours leaders must competently perform across a mining work system to support safe system functioning. The framework was developed to link directly to the functions, values and priorities and purposes of safety leadership as defined in the WDA presented in Chapter 8. The behavioural indicators for each competency were mapped onto Rasmussen's RMF to distinguish specific requirements and focus of development required at each system level.

The systems-based competency framework described in the current chapter directly addresses the following research question:

> RQ 5: How can organisations in the mining industry best encourage appropriate and effective safety leadership?

9.2 Method

To develop the competency framework, a blank representation of Rasmussen's RMF was mapped out in large form on 3.5m x 2.5m collaborative wall space. Next, each of the influencing factors, prominent decision-making elements and behaviours identified in Studies 1 and 2 were extracted and placed onto the framework at the system level at which they were identified. For example, the decision-making element of *Cue Identification*, and AL behaviour of *Relational Transparency* were placed at the *Regulatory* system level. The decision-making element of *Goal Specification*, and EL behaviour of *Participative Decision Making* were placed at the *Company* system level. Where a factor, decision-making element or behaviour was identified as residing across multiple levels, it was noted as having a system-wide influence (e.g., Vertical Integration, the importance of Trust, etc.), and was mapped across the relevant system levels. This initial mapping produced a consolidated representation of all of the factors, prominent decision-making elements and behaviours that supported safety during both critical incident scenario response, and regular safety-related tasks as undertaken at each level of the work system.

Next, the SRK-based behaviours described in the WCA (Chapter 8) were reviewed and grouped in terms of the object-related processes they related to. Linking the SRK-based behaviours to the object-related processes was considered important as it provided a first step towards identifying the underpinning developmental needs of physical objects and processes at that system level, in order to inform the development of required competencies at the purpose-related functions level. Grouping of the SRK inventory content was performed for all object-related processes in the DL to identify the high-level consistencies and similarities in underlying SRK requirements. The grouping identified over 80% of the high-level SRK-based behaviour requirements to be related to three object-related processes; "*Collect information on hazards, near misses, risks and compliance*", "*Analyse information on hazards, near misses, risks and compliance*" and "*Communication*". For example, the "Skills" relating to "*Collect information on hazards, near misses, risks and compliance"* were consistently associated with visual observation, monitoring of information, reading information or receiving auditory inputs. At the "Rule" level of the inventory, the consistent behaviours associated with "*Analyses information on hazards, near misses, risks and compliance"* related to perception and interpretation of information received from various sources (i.e., systems, processes, teams and individuals both internal and externally). At the "Knowledge" level, the high-level behaviours associated with "*Communication*" consisted of fostering open communications to build trust through meaningful interactions, recognising social and contextual factors that influenced how information was shared, and acting in accordance with individual and organisational goals.

Once the grouping of the SRK inventory content was complete, the next step involved linking the high-level SRK based behaviours with the factors, prominent decision-making or behavioural elements mapped across each level on Rasmussen's RMF. For example, the CDM decision-making element of "*Information Integration"* was linked to the high-level RBB associated with the perception of information coming from physical systems, documents or comprehending verbal communications received. The LMX behavioural attribute relating to *Trust* was linked to the KBB that represented meaningful interaction, and the open sharing of information and communication with individuals and teams. The linking of factors, decision-making elements and behaviours was conducted for all high-level SRK requirements in the WCA. The result was a matrix that mapped the relationships between the high-level SRK requirements that underpin the key object-related processes associated with safety leadership, and the corresponding influencing factors, decision-making and behavioural elements indicative of effective safety leadership across the work system.

An inter-reliability analysis was conducted by a second analyst with considerable experience in coding safety-related data. The same linking task was performed for the RBB and KBB associated with the object-related processes of "*Communication*" and "*Collect information on hazards, risks and compliance*", which were identified as two of the three object-related processes which was associated with the highest number of SRK-based behavioural requirements. A percentage agreement of 80.76% was achieved for the linkages, which is considered acceptable in the literature (Goode, Salmon, Taylor, Lenné, & Finch, 2017), with disagreements resolved through discussion between the analysts.

Whilst at this point, Rasmussen's RMF was fully populated, not all of the behavioural indicators within the SRK inventory were written in a way that would facilitate actual measurement, qualification or assessment. This is a key requirement of any competency framework, and also a constraint identified within the findings from Study 3 relating to the measurement of the values and priorities of the safety leadership system (Chapter 8). To address this, the SRK behavioural indicators were amended where required in line with the underlying intent of the associated factor, decision-making or behavioural element to define each as a measurable attribute against which performance could be assessed. For example, the RBB of "*Following required standards and procedures*" was linked to the decision-making element of '*External Influences*', with the behavioural indicator expressed as "*Understands and actively applies required safety systems, policies, standards, procedures and frameworks* *in line with supporting values and functions".* The KBB of "*Critical and analytical thinking required of information obtained to determine system state*" was linked to the underpinning decision-making elements of '*Basis of Choice*', and '*Situation Awareness'*. The resulting behavioural indicator was subsequently expressed as the ability to "*Demonstrate (s) critical thinking, adaptability and flexibility in identifying and responding to safety-related information and situations".* Inheriting an important constraint identified during Study 2 and also the WCA from Study 3, a key focus was on clearly articulating the behavioural indicators for development of the required RBB and KBB, whilst ensuring the fundamental SBB identified in the WCA were also preserved and embedded within each descriptor.

Finally, the behavioural indicators were required to be meaningfully linked to the values, priorities, and functional purposes of safety leadership as identified in the WDA. To achieve this, the content in the framework was grouped one final time according to the key factors identified throughout this research. For example, behavioural indicators at each system level associated with building trust, and the open sharing and exchange of information were considered indicative of competencies that support and promote Vertical Integration as described in Chapters 4, 5 and 7. Further, to "actively apply safety systems and policies" and "ensure the correct understanding and consistent implementation safety systems and frameworks" were related to creating a culture of unconscious compliance (Chapters 5 and 7). This final grouping of competencies resulted in the emergence of five core overarching safety leadership competencies, which grouped the behavioural indicators in terms of supporting and promoting Vertical Integration, developing a leaders' ability to demonstrate behaviours that represent safety as a core value (at both an individual and organisational level), the development and coaching of genuine expression of the same behaviours in others, the creation of an environment where compliance is achieved instinctively, and the ability to lead and decide effectively under all operational contexts.

This final grouping deliberately took a dual 'bottom-up' and 'top-down' approach to deriving the overarching core competencies by connecting the behavioural indicators to the prominent factors across the work system, and then linking those groupings to the values, priorities and functional purposes of safety leadership. This meant the resulting overarching five competencies were defined by the requirements of the safety leadership system and thus, the purpose-related functions associated with defining safety leadership decision-making and behavioural competency was achieved to meet the priority recommended optimisation strategy outlined in Table 12 (see Chapter 8).

9.2.1 SME review

The framework and its content were reviewed by four senior researchers associated with this research, each with significant experience in reviewing systems-based representations of safety-related factors and performance characteristics, the development of frameworks to support improvements in safety, and also, experience in researching variables associated with safety leadership, and mining industry research experience (Burgess-Limerick, Joy, Cooke, & Horberry, 2012; Goode et al., 2017; Newnam & Goode, 2019; Newnam, Griffin, & Mason, 2020). Minor clarifications and modifications to language were made based on feedback received, with the final version of the framework presented in 9.3 below.

9.3 A Systems-based Safety Leadership Competency Framework

The developed framework provides a comprehensive systems-based representation of the core attributes of effective safety leadership required across a mining work system to achieve the functions of safety leadership to support safe performance. The five core competencies that support achievement of the values, priorities and functional purposes of safety leadership are defined as:

- **Foster and promote Vertical Integration**
  Recognised throughout this research as a key factor that influences and supports safety, the ability to foster and promote VI is contingent on a leaders' ability to create and sustain relationships based on Trust. This is achieved by leaders practicing open and transparent communications and the flow and exchange of information across all system levels. The associated behavioural indicators described in the framework seek to build and reinforce these attributes both up and down the work system, from the frontline leader level up to the regulatory leader level and back down again.

- **Lead and decide effectively in all operational contexts**
  This competency focuses on development of the attributes required of leaders across the work system to make effective decisions and take action based on the integration and analysis of information. Closely linked to the competency of 'Foster and Promote VI, this competency describes the requirement to apply critical analysis, the ability to seek out and verify the accuracy of information as it is received, the process of making decisions, keeping them under review, and changing them as required to effectively adapt and respond to operational circumstances as they evolve.

- **Exemplify a safety-focused mindset**
  This competency focuses on development of the RBB and KBB indicative of leading in a way that unconditionally demonstrates safety is of principal importance. The behavioural indicators are built on a leaders' ability to define and regularly communicate clear safety-focused goals, with connection to organisational values and priorities and ensuring execution of visible behaviours in line with those values and priorities. This competency also requires a leader to build quality interpersonal relationships by demonstrating care for the safety of individuals and teams across all levels and through seeking out and actively listening to all concerns related to safety. This in turn builds trust through in demonstration of genuine support for team members, executing courageous decisions that reflect a 'safety before production' value, and taking accountability of one's own performance to build an environment where this type of behaviour is valued and encouraged.

- **Lead and develop a safety-focused mindset in others**
  A complementary competency to leaders individually exemplifying a safety focused mindset, this competency was designed to optimise the capabilities of leaders to develop and motivate individuals and teams to achieve exceptional safety performance. This is achieved through increasing ownership and empowerment by engaging individuals and teams in participative decision-making and encouraging collaboration to solve problems together. Further, a key aspect of this competency relates to identifying and developing individuals to build their own safety competence through interaction, goal setting, development planning, feedback and coaching.

- **Create a culture of unconscious compliance**
  Acknowledging a core function of the safety leadership system is to 'fulfil requirements of law and regulation', this competency seeks to define behaviours that actively promote and embed a culture where compliance with required standards is achieved unconsciously. Accordingly, the behaviours required of leaders relate to understanding and ensuring consistent implementation of required safety systems, policies, standards and procedures in line with supporting values and functions and ensuring adequate accountability, governance and oversight for all situations where safety concerns may impact business objectives. Such behaviours will promote compliance and improvement safety performance by effectively and proactively managing and addressing safety-related risks.

The systems-based Safety Leadership Competency Development Framework, with the behavioural indicator relevant to each system level is now presented in full in
Figure 9 and Figure 10.

FUNCTIONAL PURPOSES

- **Ensure and maintain a safe working environment**
- **Produce product or provide service safely**
- **Fulfil requirements of law and regulation**

VALUES AND PRIORITIES

- **Engage in effective safety leadership decision making and behaviours**
- **Minimise exposure to hazards and risk**
- **Minimise or eliminate incidents, injuries and fatalities**
- **Minimise deviation from / violation of required standards, rules and procedures**

	Example role groupings	Foster and promote vertical integration	Exemplify a safety-focused mindset	Lead and develop a safety-focused mindset in others	Create a culture of unconscious compliance	Lead and decide effectively in all operational contexts
		Create and sustain relationships based on trust and respect by practicing open and transparent communications, and the sharing of information sharing across all levels.	Lead in a way that unconditionally demonstrates safety is of principal importance.	Develop and motivate individuals and teams to achieve exceptional safety performance through commitment, personal engagement and collaboration.	Actively embed a culture where compliance with required regulation and standards is achieved unconsciously.	Makes decisions and takes action based on integration and analysis of information, and keeps decisions under review to effectively adapt and respond to changing circumstances.
Government	**Integrate a formative approach to defining safety leadership requirements within regulatory instruments:** • Define and reference safety leadership in regulatory instruments to ensure consistent understanding, and set expectation regarding minimum standard • Create opportunity for connection between organisational priorities and objectives, and engagement in effective safety leadership practices to achieve espoused system functions and purposes • Embed requirements for organisations to develop a formative approach to safety leadership, and delivery through development of capability and competency					
Regulatory	**Head of Function (e.g., Technical Operations)** **Regional Manager or Area Manager** **Functional Specialist (e.g., Inspector)**	Understands social and contextual factors which influence the open sharing of information, and actively works to create *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Obligation'*	Openly explains own decisions, and shows support for organisational decisions to individuals and teams, clearly *Knowledge Based Behaviour, linked to factor 'other decisions', and Empowering Leadership attribute of 'Informing'*	Actively listens to concerns about safety, and encourages individuals and teams to solve problems together *Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Individualised Concern'*	Explains and ensures standards are set and understood by stakeholders and industry personnel *Skill and Knowledge Based Behaviour, linked to factor 'Organisational Processes', and decision elements of 'External Influence' and 'Expectancy'*	Makes decisions based on, and demonstrates actions consistent with, own values and beliefs regarding safety *Knowledge Based Behaviour, linked to decision element 'Basis of Choice', and Authentic Leadership attribute of 'Internalised Moral Perspective'*
		Builds trust through communicating and sharing safety-related information with individuals and teams in an open and transparent manner *Skill and Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Informing', and Leader-Member Exchange attribute of Trust (system wide factor)*	Regularly talks about personal values and beliefs regarding the importance of safety, and goal to eliminate incidents, injuries and fatalities in the workplace *Skill and Rule Based Behaviour, linked to decision element of 'Goal Specification', and Transformational Leadership attribute of 'Idealised Influence'*	Uses and adapts appropriate influencing and coaching strategies to achieve individual and organisational goals without compromising safety *Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Coaching'*	Reviews and monitors performance in line with adhering to standards to achieve compliance *Skill Based Behaviour, linked to decision element of 'Cue Identification' and 'Situation Assessment'*	Actively seeks sufficient information and different points of view for greater understanding of a problem or system state to determine potential impact on safety *Rule Based Behaviour, linked to Authentic Leadership attribute of 'Balanced Processing'*
		Demonstrates respects for individual and team skills and experience by listening carefully to points of view *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Respect'*	Motivates individuals and teams to achieve clearly defined organisational goals by demonstrating enthusiasm and interest in safety-related activities and matters *Knowledge Based Behaviour, linked to Transformation Leadership attribute of 'Inspirational Motivation'*	Provides honest feedback related to safety with individuals and teams across all levels in a constructive manner, and coaches for improvement *Skill and Knowledge Based Behaviour, linked to Authentic Leadership attribute of 'Relational Transparency'*	Displays commitment to achieving and maintaining a safe working environment through visible support for standards, safety systems and associated requirements *Rule Based Behaviour, linked to factor 'Compliance Requirements'*	Make decisions comfortably and calmly when dealing with elements of ambiguity, without compromising safety *Rule and Knowledge Based Behaviour, linked to decision element of 'Influence of Uncertainty'*
		Establishes good relationships across all levels by adapting communication style to meet the needs of the audience, and seeks feedback to ensure understanding *Knowledge Based Behaviour, linked to decision element 'Situation Assessment'*	Understands stakeholder job problems and needs, through acquiring knowledge and expertise *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Obligation'*	Shares knowledge generously related to standards, safety systems and requirements to develop understanding and expertise in individuals and teams *Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Coaching'*	Regularly challenges individuals and teams to critically evaluate organisational performance with respect to matters of compliance *Rule Based Behaviour, linked to factor 'Organisational Processes' and Empowering Leadership attribute of 'Coaching'*	Applies critical thinking and analysis to safety-related situations and information received to inform decisions *Skill and Knowledge Based Behaviour, linked to decision elements 'Basis of Choice', 'Situation Awareness' and 'Information Integration'*
Company	**Managing Director/ President** **Chief Executive Office or Chief Operating Officer** **Senior Vice President or Vice President** **Head of Function at Group level (e.g., Health, Safety & Environment)**	Build trusting relationships with individuals and teams across all levels (both internal and external) through role modelling open, honest and transparent communications *Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Informing' and Leader-Member Exchange attribute of 'Trust' (system wide factor)*	Demonstrates commitment to safety by regularly communicating personal values aligned with organisational goal to eliminate incidents, injuries and fatalities in the workplace *Rule Based Behaviour, linked to decision element 'Goal Specification', and Transformational Leadership attribute of 'Idealised Influence'*	Increases ownership by engaging individuals and teams in participative decision making, and empowers by encouraging collaboration to solve problems together *Knowledge Based Behaviour, linked to factor 'Planning and Organising' and 'migration of work practices', and Empowering Leadership attribute of 'Participative Decision Making'*	Ensures adequate governance and oversight exists for all situations where safety concerns may impact business objectives *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Obligation', and Transactional Leadership attribute of 'Manage by Exception'*	Actively seeks out further information and different points of view for greater understanding of a problem or system state to determine potential impact on safety, and inform decisions *Knowledge Based Behaviour, linked to Authentic Leadership attribute of 'Balanced Processing'*
		Regularly communicates functional objectives, values, priorities and goals of the organisation in an authentic and clear manner, across all levels *and Authentic Leadership attribute 'Relational Transparency'*	Regularly talks about personal values and beliefs regarding the importance of safety, and motivates individuals and teams to align behaviours with own values *Skill and Rule Based Behaviour, linked to Transformational Leadership attribute of 'Inspirational Motivation'*	Generously shares time and knowledge related to skills and experience to develop understanding and expertise in individuals and teams *Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Coaching'*	Commits required resources to ensure compliance with organisational safety systems, policies, standards, procedures and frameworks is achieved *Rule Based Behaviour, linked to factor 'Organisational processes', and decision element 'Cue Identification'*	Actively seeks accurate and sufficient information from various sources (written, data, verbal and visual), and integrates effectively to inform decisions *Skill and Rule Based Behaviour, linked to decision element 'Information Integration'*
		Adjusts communication style, uses simple language to meet the needs of the audience and seeks feedback to ensure understanding *Knowledge Based Behaviour, linked to decision element 'Situation Assessment'*	Demonstrates active care for the safety of individuals and teams across all levels by seeking out and actively listening to concerns related to safety *Knowledge Based Behaviour, linked to Transformational Leadership attributes of 'Individualised Consideration' and 'Shows Concern'*	Shows respect through willingness to learn and understand team job problems and needs, and provides support through ensuring adequate resourcing *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Respect', and Authentic Leadership attribute of 'Self Awareness'*	Influences safety policy, systems and related instruments through participation in industry networks and external stakeholder groups *Rule and Knowledge Based Behaviour, linked to decision element 'External Influences'*	Considers available options, and makes decision based on personal values and organisational goals aligned with safety *Rule and Knowledge Based Behaviour, linked to decision elements 'Basis of Choice' and 'Goal Specification'*
		Demonstrates integrity by sharing information with teams and individuals in a way that can be verified *Rule Based Behaviour, linked to Authentic Leadership attribute of 'Relational Transparency' and Leader-Member Exchange attribute of 'Trust' (system wide attribute)*	Sets high standards for performance through own behaviours, ensuring visible alignment with individual and organisational values and priorities *Rule and Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Lead by Example' and Authentic Leadership attribute of 'Internalised Moral Perspective'*	Actively seeks out individual and team members feedback and ideas on how to achieve organisational goals, and improve safety performance *Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Intellectual Stimulation' and Empowering Leadership attribute of 'Participative Decision Making'*	Continuously reviews and monitors safety performance and compliance in order to achieve common goal to eliminate incidents, injuries and fatalities in the workplace *Skill and Rule Based Behaviour, linked to decision elements 'Situation Assessment' and 'Goal Specification'*	Makes prompt, clear decisions which includes consideration of risks relevant to the operational context *Rule and Knowledge Based Behaviour linked to decision elements 'Influence of Uncertainty', 'Time Pressure' and 'Situation Awareness'*
Equipment and surroundings		Systems Data (UPWARDS) Environmental conditions (Changes in operational environment, situation, task or scenario - UPWARDS)				

Figure 9 Systems-based Safety Leadership Competency Framework for Government, Regulatory and Company system levels

FUNCTIONAL PURPOSES	**Ensure and maintain a safe working environment**	**Produce product or provide service safely**	**Fulfil requirements of law and regulation**	
VALUES AND PRIORITIES	**Engage in effective safety leadership decision making and behaviours**	**Minimise exposure to hazards and risk**	**Minimise or eliminate incidents, injuries and fatalities**	**Minimise deviation from / violation of required standards, rules and procedures**

	Example role groupings	**Foster and promote vertical integration**	**Exemplify a safety-focused mindset**	**Lead and develop a safety-focused mindset in others**	**Create a culture of unconscious compliance**	**Lead and decide effectively in all operational contexts**
		Create and sustain relationships based on trust and respect by practicing open and transparent communications, and the sharing of information sharing across all levels.	Lead in a way that unconditionally demonstrates safety is of principal importance.	Develop and motivate individuals and teams to achieve exceptional safety performance through commitment, personal engagement and collaboration.	Actively embed a culture where compliance with required regulation and standards is achieved unconsciously.	Makes decisions and takes action based on integration and analysis of information, and keeps decisions under review to effectively adapt and respond to changing circumstances.
Management	**General Manager, Senior Manager, or Manager** **Leader of individual function (e.g., Safety or Risk Management)** **Senior Director or Director** **Chief Advisor or Principal Advisor**	Listens carefully to different points of view, and responds quickly to the needs of an audience, their reactions and feedback *Skill and Knowledge Based Behaviour, linked to decision elements 'Cue Identification' and 'Time Pressure', and Authentic Leadership attribute of 'Balanced Processing'*	Regularly communicates personal values and establishes clear safety-focused goals, with connection to individual and organisational values and priorities *Skill and Rule Based Behaviour, linked to factor 'other decisions', decision element 'Goal Specification' and Transformational Leadership attribute of 'Inspirational Motivation'*	Actively involves others in decision making, through encouraging individuals and teams to express ideas and opinions about safety at work *Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Intellectual Stimulation' and Empowering Leadership attribute of 'Participative Decision Making'*	Communicates effectively with individuals and teams across all levels to ensure clear understanding and application of required safety systems, policies, standards, procedures and frameworks *Rule Based Behaviour, linked to factor 'Organisational Processes', and decision element 'External Influences'*	Makes decisions in a timely manner, and constantly reviews and changes them if required to ensure continued safety *Knowledge Based Behaviour, linked to decision elements 'Time Pressure' and 'Expectancy'*
		Understands social and contextual factors which influence the open sharing of information, and actively works to create an environment where it is safe to share *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Obligation'*	Builds quality interpersonal relationships by demonstrating concern for individual and team wellbeing, listens and takes the time to discuss concerns patiently *Knowledge Based Behaviour, linked to Transformational Leadership attributes of 'Individualised Consideration' and 'Shows Concern'*	Understands teams job problems, needs and situations through application of previous knowledge, and spends time sharing knowledge regarding the safest way to complete tasks *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute of 'Respect', and Empowering Leadership attribute of 'Coaching'*	Continuously strives to improve safety performance by effectively planning and proactively managing safety-related risks *Rule Based Behaviour, linked to factor 'Planning and Organising'*	Effectively adapts decision making and behavioural responses when faced with unforeseeable or non-routine circumstances to achieve the safest outcome *Knowledge Based Behaviour, linked to decision element 'Influence of Uncertainty'*
		Actively role models the open and transparent sharing of safety-related information across all levels, and seeks feedback on performance *Knowledge Based Behaviour, linked to Empowering Leadership attribute of 'Informing' and Authentic Leadership attribute of 'Self Awareness'*	Takes accountability for own performance and understands the impact of own behaviour on others *Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Idealised Influence' and Empowering Leadership attribute of 'Lead by Example'*	Identifies talented safety leaders and encourages them to build their own safety competence through interaction, goal setting, development planning, and feedback *Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Individualised Consideration' and Empowering Leadership attribute of 'Coaching'*	Applies knowledge and experience to prevent and interrupt risky behaviours constructively, and ensure compliance is achieved *Rule and Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Manage by Exception'*	Demonstrates critical thinking, adaptability and flexibility in identifying and effectively responding to safety-related situations and information *Knowledge Based Behaviour, linked to decision elements 'Basis of Choice' and 'Situation Awareness'*
		Demonstrates trust and encourages organisational learning through supporting the migration of work practices *Knowledge Based Behaviour, linked to factor 'migration of work practices' and Leader Member Exchange attribute of 'Trust' (system wide factor)*	Communicates expectations regarding safety and related behaviours, and holds individuals and teams to account for own behaviours, with constructive feedback and coaching *Skill and Rule Based Behaviour, linked to Authentic Leadership attribute 'Relational Transparency'*	Encourages individuals and teams to identify own values and beliefs, and demonstrate actions consistent with them *Knowledge Based Behaviour, linked to Authentic Leadership attribute of 'Internalised Moral Perspective'*	Provides positive affirmation to individuals and teams for visible efforts of compliance *Skill and Rule Based Behaviour, linked to Transformational Leadership attribute 'Contingent Reward'*	Effectively integrates, analyses and verifies information from various sources (written, verbal and system data) to make informed decisions *Knowledge Based Behaviour, linked to decision elements 'Situation Assessment' and 'Information Integration'*
Physical Processes and Actor Activities	**Supervisor** **Superintendent** **Team Leader** **Senior Advisor or Advisor** **Technical or Functional Specialist (e.g., Geologist or Operations)**	Uses simple language to communicate to ensure the message meets the needs and understanding of the audience *Skill and Rule Based Behaviour, linked to Leader-Member Exchange attribute of 'Obligation'*	Regularly and clearly communicates individual and organisational goals and objectives, and explains the role individuals and teams play in achieving them *Rule Based Behaviour, linked to decision element 'Goal Specification'*	Applies knowledge and experience to recognise, prevent and interrupt risky behaviours constructively, with feedback and coaching *Skill and Knowledge Based Behaviour, linked to decision elements 'Cue Identification' and 'Expectancy', and Transactional Leadership attribute of 'Manage by Exception'*	Understands and actively applies required safety systems, policies, standards, procedures and frameworks in line with supporting organisational values, functions and goals *Rule Based Behaviour, linked to factor 'Organisational Processes', and decision element 'External Influences'*	Integrates and analyses information from various sources (written, verbal and system data) to understand system state and potential impact on safety *Rule and Knowledge Based Behaviour, linked to decision elements 'Situation Assessment' and 'Information Integration'.*
		Shares information with individuals and teams regarding company goals, decisions and performance in an open and transparent manner *Skill and Rule Based Behaviour, linked to Empowering Leadership attribute of 'Informing'*	Speaks openly with individuals and teams regarding safety performance to promote awareness and empowerment to identify and express opportunities for improvement *Skill and Knowledge Based Behaviour, linked to Transformational Leadership attribute of 'Intellectual Stimulation'*	Identifies and supports individual and team member needs for development of required safety-related competencies and experience *Knowledge Based Behaviour, linked to Transformational Leadership attribute 'Individualised Consideration' and Leader-Member Exchange attribute of 'Respect'*	Explains and ensures correct understanding and consistent implementation of safety systems to achieve compliance *Rule Based Behaviour, linked to Empowering Leadership attribute of 'Informing'*	Demonstrates adaptability and flexibility in identifying and effectively responding to safety-related situations to ensure safe outcomes are achieved *Knowledge Based Behaviour, linked to decision elements 'Basis of Choice', 'Situation Assessment' and 'Influence of Uncertainty'*
		Establishes good relationships with individuals and teams, and takes time to listen, discuss concerns and receive feedback *Rule and Knowledge Based Behaviour, linked to Empowering Leadership attribute 'Shows Concern'*	Motivates individuals and teams by providing encouragement and communicating belief that safety can be achieved *Knowledge Base Behaviour, linked to decision element 'Situation Assessment' and Transformational Leadership attribute 'Inspirational Motivation'*	Supports migration of work practices through empowering individuals and teams to own decisions regarding safety and performance *Knowledge Based Behaviour, linked to factor 'Migration of work practices'*	Adequately plans for and leads compliance related activities, to ensure safety requirements are consistently met *Rule Based Behaviour, linked to factor 'Planning and Organising'*	Applies specialist technical expertise and knowledge to recognise and assess risks, and acts or escalates where required *Skill and Knowledge Based Behaviour, linked to Transformational Leadership attribute 'Idealised Influence' and Empowering Leadership attribute 'Informing'*
		Builds trust through consistent communications with individuals and teams, expressing information clearly *Knowledge Based Behaviour, linked to Leader-Member Exchange attribute 'Trust' (system wide factor)*	Consistently behaves in a way that displays visible commitment to safety, acting in accordance with personal values *Knowledge Based Behaviour, linked to Transformational Leadership attribute 'Idealised Influence'*	Provides positive affirmation to individuals and teams for visible safe behaviours and safety improvement efforts *Skill and Rule Based Behaviour, linked to Transactional Leadership attribute 'Contingent Reward'*	Consistently encourages individuals and teams to identify system improvement opportunities, and promotes ownership for implementing change *Rule and Knowledge Based Behaviour, linked to factor 'Organisational Processes'*	Constantly reviews information from various sources to ensure own correct understanding of system state, and adjusts decisions in a timely manner as required *Skill and Rule Based Behaviour, linked to decision elements 'Time Pressure' and 'Balanced Processing'*
Equipment and surroundings		Systems Data (UPWARDS)				
		Environmental conditions (Changes in operational environment, situation, task or scenario - UPWARDS)				

Figure 10 Systems-based Safety Leadership Competency Framework for Management, Physical Processes & Actor Activities and Equipment and Surroundings system level

The framework consists of role groupings according to the system levels present within Rasmussen's RMF. Each system level and corresponding role grouping has four specific behavioural indicators relating to the decision-making and behavioural capabilities for each of the five core competencies. The embedded behavioural indicators are applicable developmental requirements for both leaders of teams, as well as individual contributor leaders across the work system.

The framework was designed to support progression of developmental needs within and across system levels. While the intent is to apply the competency development framework vertically, the behavioural indicators have been designed such that a horizontal banding of each system level will reinforce the matrix of behaviours required across the work system. For example, behavioural indicators relevant to leaders at the Physical Processes and Actor Activities level (i.e., Supervisors, Superintendents, Technical Specialists etc.,) focuses primarily on the direct application of knowledge, systems, and direct communications, whilst also a developing leaders ability to support the same in others within the work system. Similarly, indicators relevant to leaders at the Company level (i.e., Chief Executive Officers, Heads of Functions, etc.,) primarily relate to building quality interpersonal relationships by communicating functional and organisational objectives, and setting high standards for performance, whilst supporting the development of the same traits for leaders at lower system levels through active involvement and engagement of individuals and teams.

Structuring of the behavioural indicators in this way allows for a range of safety leadership capabilities to be developed for leaders to draw on across the work system and ensures consistency and alignment of the competencies to support achievement of the values, priorities and functional purposes of safety leadership. This is particularly important with regard to the promotion of VI, as it supports the appropriate migration of work, and flexible and adaptive safety leadership practices whilst still ensuring safe functioning is maintained. The approach also has benefits in relation to the execution of structured tasks whereby leaders can develop RBB and KBB required at other system levels by enabling flexible and adaptive patterns of behaviour to be drawn upon from within system levels (Lintern, 2010). This opens up a range of possible behaviours available to leaders to optimise performance (Lintern, 2019; Read et al., 2016), rather than constraining developmental needs to focusing only on capabilities applicable to the relevant system level.

Further, the majority of the behavioural indicators are described in a context-independent manner and focus on strengthening the required RBB and KBB under both normal and non-routine or abnormal operational contexts. By encouraging RBB and KBB across the work system, this optimises the capacity of safety leadership and the identified influencing factors within the work system to support achievement of the functions of safety leadership under a range of conditions. This is important due to the range of situations leaders may encounter (i.e., critical incident scenario response or regular safety-related task execution), so promoting development and engagement in the full range of competencies described will provide the greatest opportunity to optimise safety leadership across the work system.

9.3.1 Updated WDA

The development of the systems-based competency framework provided a direct means to improve the current safety leadership system, as described in Chapter 8. An updated representation of the WDA is provided in

Figure 11 to demonstrate the new physical objects, object-related processes and purpose-related functions afforded by the development of the systems-based Safety Leadership Competency Framework.

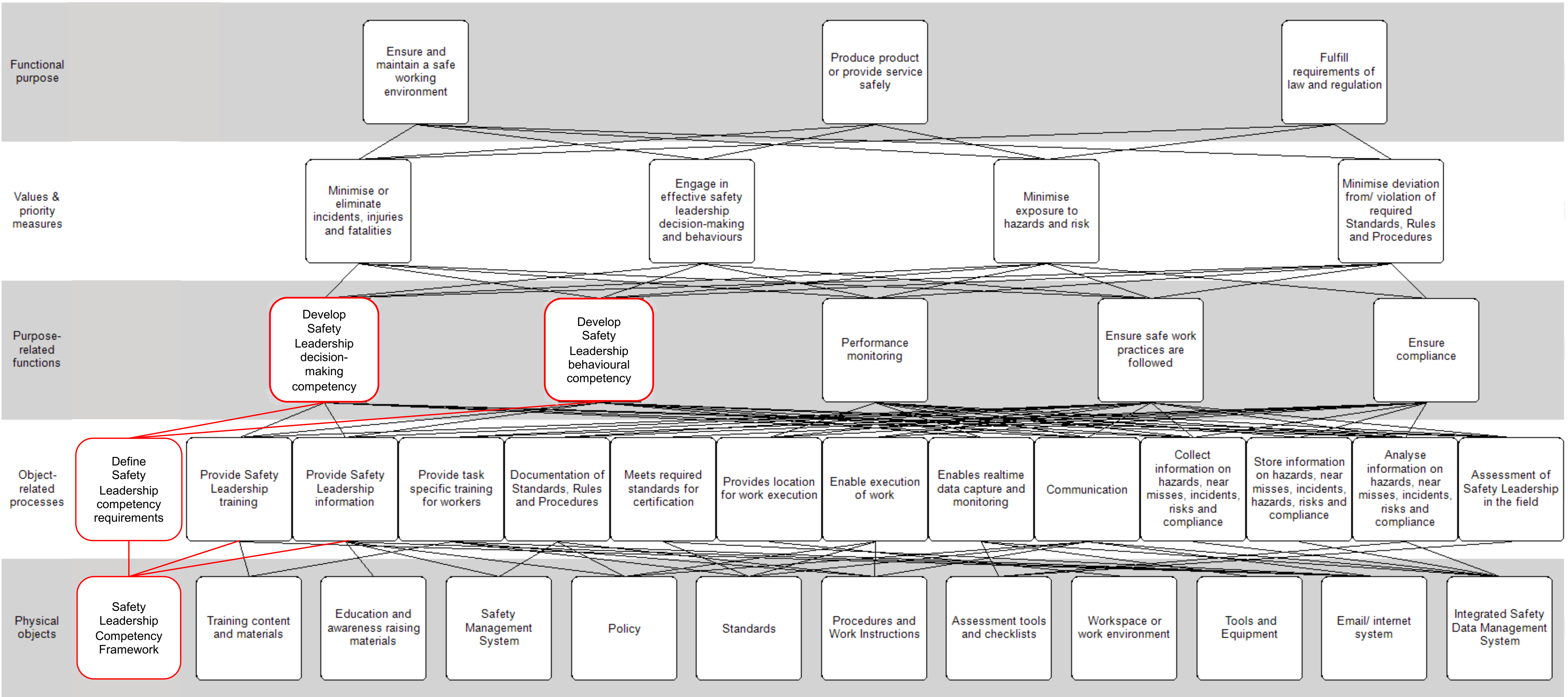

Figure 11. Updated WDA to include safety leadership system improvements

In terms of improvements to the safety leadership system, the developed competency framework serves as a standalone physical object at the lowest level of the WDA. At the object-related process level, the framework defines the required competencies in terms of both decision-making and behaviours. This in turn, supports the purpose-related functions of developing safety leadership decision-making and behavioural competency, in order to achieve higher order values and priorities and the overall functional purpose of the safety leadership system.

9.4 Discussion

The aim of this chapter was to present a systems-based competency framework for effective safety leadership development. This was developed by integrating the key findings from the overall program of research presented in this thesis. The framework is underpinned by five core safety leadership competencies that comprise the skills, knowledge, decision-making and behavioural engagement requirements leaders must competently perform across a mining work system to support safe system functioning. The competencies and behavioural indicators defined are designed to link directly to the functions, values and priorities and purposes of safety leadership by focusing on supporting and promoting Vertical Integration, make effective decisions, developing a leaders' ability to demonstrate behaviours that represent safety as a core value, developing and coaching the same behaviours in others, and create a culture where compliance is achieved instinctively. The behavioural indicators associated with each competency were designed to be independent of task type or scenario, however, do focus on promoting RBB and KBB as the central feature of effective safety leadership capability, and the ability to adapt and respond effectively to a range of operational contexts.

As discussed in Chapter 1, there exists a paucity of research which defines competency requirements associated with 'good' and effective safety leadership (Griffin & Talati, 2014). Therefore, the framework presented directly addresses the priority need detailed in Table 12 (Chapter 8) by defining decision-making and behavioural competency requirements associated with the 'purpose-related' functions of safety leadership. In doing so, it directly improves the safety leadership system (as described in

Figure 11), by providing a comprehensive framework and starting point for mining organisations to adopt, and against which to develop and integrate corresponding learning, development and coaching content and approaches to competency development at the 'object-related' and 'physical objects' level. The intention is to encourage development of the appropriate and effective safety leadership competencies described and required across mining work systems to support safe functioning. The remaining recommended optimisation strategies can also be appropriately progressed as part of a comprehensive and sustainable approach to building and improving safety leadership capability and safety performance within the industry.

9.4.1 Limitation

A limitation of the framework is acknowledged regarding development of safety leadership capability at the governmental system level. While specific behavioural indicators are not described for role groupings at the government level of Rasmussen's RMF, consideration has been provided regarding how best to integrate growth and sustainment of effective safety leadership at this system level. The framework provides a way forward for this to be achieved by outlining the need for safety leadership to be defined and referenced in regulatory instruments. However, rather than dictating the need to specify the current competency framework within existing regulation, it is suggested that a formative approach to defining and referencing safety leadership be adopted. This would entail the amendment of regulatory instruments to define the requirement for organisations to explicitly create a connection between organisational priorities and objectives and engagement in effective safety leadership practices to achieve espoused functions and purposes (Carden, Goode, Read, & Salmon, 2019; Carden, Goode, & Salmon, 2018). This, in turn, would set an expectation regarding a minimum standard for organisations to commit to development of the safety leadership competencies outlined in this thesis across an organisation, as well as establishing a consistent understanding of the definition of safety leadership across the industry, with links to the importance of the concept in supporting safe performance.

9.5 Conclusion

Chapter 9 outlined a systems-based competency framework for development of effective safety leadership capability across mining work systems. Five core safety leadership competencies are defined, which comprise the skills, knowledge, decision-making and behavioural engagement requirements leaders must competently perform across a mining work system to support safe system functioning. The framework links directly to the functions, values and priorities and purposes of safety leadership, with the behavioural indicators for each competency providing a pathway for competency development across the system.

The competency framework can thus be utilised by mining organisations to commence shaping learning and development approaches that ensure alignment with the functional purposes, values and priorities of safety leadership across mining work systems. Further, the framework also provides a way forward for the integration of safety leadership competency requirements within mining regulatory instruments, which would seek to reinforce the importance of the concept in supporting safe system performance.

The final chapter of this thesis (Chapter 10) will provide a synopsis of the contribution of this thesis to theory, method and practice. In addition, Chapter 10 will provide further detail regarding implementation of the recommended optimisation strategies to ensure mining organisations can effectively integrate the output from this research to build safety leadership capability and support safe performance.

10 Discussion, recommendations and conclusions

10.1 Introduction

There is little argument in contemporary research that the provision of safety depends on the activities and interactions of actors, both human and non-human, at every level of a work system (Vicente & Christoffersen, 2006; Woo & Vicente, 2003). With this in mind, the major thread of this thesis has asserted that approaches from the discipline of systems-thinking provide appropriate methods through which to study safety leadership in order to optimise its effectiveness. At the onset of this research, this argument was based on the notion that few research, if any, had applied such approaches in the safety-leadership context. Applying systems-thinking to safety leadership has supported the identification of factors that both influence and support effective safety leadership across a mining work system. This information has subsequently been used to develop a competency framework that aims to improve safety leadership in mining, with potential application across other high-risk industries.

In this final chapter, the findings and theoretical, methodological and practical implications of the research are discussed. A set of recommendations are tabled, which provide the basis for targeted improvements in safety leadership in line with the principles of the systems-based theory, frameworks and methods applied throughout this research. Implications for practical implementation within the mining industry are discussed and avenues for further research are recommended.

10.2 Addressing the research aim and research questions

The overall aim of the research presented in this thesis was to examine safety leadership from a systems perspective in order to establish how the mining industry can best enhance the likelihood of effective safety leadership to support safe performance. To achieve this aim, this thesis proposed the following five research questions:

RQ 1: Has safety leadership been conceptualised and analysed from a systems perspective and, if not, is this perspective appropriate?

RQ 2: Can the application of a systems perspective expand understanding of safety leadership within a complex socio-technical mining system?

RQ 3: What factors influence safety leadership within a complex socio-technical mining system and how do these factors interact?

RQ 4: Can systems-based ergonomics methods be used to develop a useful model of safety leadership?

RQ 5: How can organisations in the mining industry support appropriate and effective safety leadership?

The methodology applied throughout was structured in such a way to naturally progress through addressing each of the research questions in sequence. The body of research will now be discussed in terms of how it has answered the research questions, and how this has resulted in improved understanding of safety leadership to assist advancement of contemporary approaches to improving safety within the mining industry.

Chapter 2 presented the results of a comprehensive review of the safety leadership literature and found that existing theories, concepts and methodologies used to study safety leadership are not underpinned by a systems perspective. The review demonstrated considerable gaps existed in the knowledge base regarding what constitutes effective safety leadership. Moreover, it was concluded that it is not clear what factors interact with and influence safety leadership across work systems to support safe performance. *Research Question 1* was addressed by applying a systems perspective to examine safety leadership, as presented in Chapters 4, 5, 7 and 8. In doing so, the results from the body of work presented demonstrated the utility of applying a systems perspective to examine safety leadership to elicit improved understanding.

Research Questions 2 and *3* were answered through the application of the systems-based methodology throughout, which enabled new insight and understanding to be gained regarding safety leadership, and how it occurs across mining work systems to support safe performance. The use of Rasmussen's RMF and AcciMap Method (Rasmussen, 1997), the CDM interview technique (Klein et al., 1989) and CWA (Vicente, 1999) enabled improved understanding of safety leadership as a concept, and importantly identification of the range of factors that both influence and support, afford and constrain safety leadership decision-making and behaviour across a mining work system.

Research Question 4 was answered through the application of CWA in Study 3, with Chapter 8 presenting the first application of CWA to this problem domain. The comprehensive application of the three phases of CWA applied were able to effectively model safety leadership, define the decision-making processes and inputs associated with the control tasks examined, and subsequently derive the competency requirements in terms of SBB, RBB and KBB indicative of effective safety leadership. The SBB, RBB and KBB identified were key to understanding safety leadership in terms of how to support achievement of the overall functions, values and priorities of safety leadership within a mining work system.

A key outcome of Study 3 was the identification of affordances and constraints that shape how mining work systems currently support and develop effective safety leadership. Collectively, the findings pointed to a need to develop a systems-based competency development framework, which could be utilised by the industry to promote ongoing development of appropriate and effective safety leadership capabilities, as identified in this program of research. *Research Question 5* was answered with the application of CWA and subsequent development and presentation of a systems-based Safety Leadership Competency Framework that can be used as a means to develop effective safety leadership capability across the industry. In adopting the competency framework and setting in place formal mechanisms to develop the competencies outlined, the true benefits of safety leadership as a positive performance shaping factor may be realised to help maintain safe performance.

The body of research presented in this thesis therefore comprehensively answers the research questions posed to achieve the overall stated aim. In doing so, the program of research gave rise to number of specific theoretical, methodological and practical contributions to research and practice, which will now be discussed.

10.3 Contributions to research and practice

This thesis has made an original contribution to the research relating to safety leadership in a number of important ways. These contributions are outlined in Table 13 below and are discussed in detail in sections 10.3.1 to 10.3.3.

Table 13. Key contributions as an outcome of this thesis

Key contributions	*Chapter/ Study link*
Theoretical contributions	
• *First application of systems-thinking methodology to examine safety leadership from a systems perspective*	• Chapters 4 & 5 (Study 1) Chapter 7 (Study 2) Chapter 8 (Study 3)
• *Defining a systems-based conceptualisation and definition of safety leadership*	• Chapter 2 (literature review)
Methodological contributions	
• *Development and application of a systems-based methodology for improved examination of safety leadership*	• Chapter 3
• *Development and application of an extension to the Critical Decision Method to elicit information regarding safety leadership behaviour*	• Chapter 6 & 7 (Study 2)
Practical contributions	
• *Identification of the factors that influence and support effective safety leadership across a mining work system*	• Chapters 4 & 5 (Study 1) Chapter 7 (Study 2) Chapter 8 (Study 3)
• *Establishment of a systems-based competency framework for development of appropriate and effective safety leadership.*	• Chapter 9

10.3.1 Theoretical Contributions

10.3.1.1 First of type application of systems-thinking methodology to examine safety leadership from a systems perspective

A systems perspective is the dominant approach to safety management in complex socio-technical systems such as defence, aviation and transport (Branford, 2011; Cornelissen et al., 2013; Hulme, Stanton, Walker, Waterson, & Salmon, 2019; Mulvihill et al., 2016; Naikar, 2005, 2006; Read et al., 2016; Salmon et al., 2020; Salmon et al., 2016; Salmon et al., 2012), however its application has rarely been extended to other high-risk domains or phenomena, despite calls for this to occur (Davis, 2014).

The research presented in this thesis is the first to apply systems-thinking theory, concepts and methods to the study of safety leadership, with a number of key outcomes realised. First, the concepts, frameworks, methods and models applied enabled a more in-depth understanding to be gained of safety leadership as a concept. By taking an integrated approach that encompassed exploration of decision-making, behaviours and actions, the methods facilitated improved insight into the role of safety leadership plays in supporting safe system functioning, particularly during a critical incident scenario.

Importantly, the use of the CDM generated new and unique insight into safety leadership, by demonstrating the importance of decision-making as a key component of the safety leadership concept under both normal and abnormal operational contexts. The use of the CDM allowed decision-making and subsequent behaviour to be examined in terms of their cognitive basis, and with reference to the factors across the work system that informed and influenced them. This confirmed the concept of safety leadership itself is much broader, and more complex than its representations in the existing literature (e.g., (Clarke, 2013; Conchie, 2013; de Souza Costa Neves Cavazotte et al., 2013; Hofmann et al., 2003; Martínez-Córcoles et al., 2011)). Further, the application of the AcciMap Method to examine the Bingham Canyon Highwall Failure incident demonstrated the presence of factors and interactions across the work system and how the interactions between the factors identified propagated both upwards and downwards through the work system to support continued the incidents safe outcome.

Improved understanding was also exemplified through the establishment of safety leadership as an emergent property of the interactions between factors across multiple levels of a mining work system. This was achieved in two ways; as visualised through the application of Rasmussen's RMF (Rasmussen, 1997) and; each of Rasmussen's predictions for the performance of systems phenomenon was confirmed for safety leadership, which provided the necessary confirmation of the merits of applying a systems perspective to study safety leadership. These are key outcomes, as in terms of supporting future research agendas, they demonstrate the importance of examining and understanding safety leadership from a systems perspective.

Last, the application of CWA in Study 3 provides a new perspective in terms of the functional purposes, values and priorities and purpose-related functions associated with safety leadership. Through the WDA, new insight is gained into the affordances and constraints that influence the effectiveness of safety leadership, with a key finding relating to a lack of defined safety leadership competency requirements to support development of successful and effective safety leadership across mining work systems. The CTA and consolidated DL demonstrate further constraints specific to the influence of task type on the ability of leaders to optimise safety leadership, particularly for structured tasks. This is further impacted by the lack of available learning, development and coaching mechanisms within the safety leadership system to adequately underpin development of the identified capability requirements to ensure safety leadership is optimised. Finally, the WCA shows a greater need for leaders to engage in RBB and KBB as a function of effective safety leadership with a shortcoming identified in terms of how leaders currently grow such experience and capability. The priority outcome from the CWA pointed towards the need to develop a systems-based framework for effective safety leadership competency development, which leverages and addresses the affordances and constraints identified, and promotes the key RBB and KBB identified to support successful task execution and ongoing safe system functioning.

10.3.1.2 Defining a systems-based conceptualisation and definition of safety leadership

In Chapter 2, the current conceptualisation and definition of safety leadership popularised within the existing literature was found to be inadequate (e.g., Chemers, 1997) to describe the emergent, complex and adaptive nature of the concept to support safe performance within high-risk, complex socio-technical systems. To address this, a new definition and conceptualisation of safety leadership was developed to align with a systems perspective to describe the role of safety leadership in supporting safe system functioning across a mining work system. This thesis re-defined safety leadership in the following way:

"Safety leadership comprises the emergent decisions, behaviours and actions of actors across all levels within a work system, which combine and interact to support achievement of the common goal of safe performance".

The definition developed reflected the need to understand safety leadership as an emergent system property, which was created by the decisions, behaviours and actions of actors across all levels within a work system and how they combine and interact to support achieving safe performance. Conceptualising and defining safety leadership from a systems perspective provided two important contributions. First, it allowed a clear relationship to be established between decision-making and behaviour in the safety leadership context, which was not evident in the existing literature, despite such a link being well recognised in other domains (Rogers & Blenko, 2006). The relationship was confirmed as presented in Chapters 4, 5 and 7. Second, it demonstrated clear link between safety leadership and subsequent safe performance, in terms of supporting achievement of the common goal of safety across the work system under both normal and abnormal operating contexts.

Thus, the contribution of defining safety leadership from a systems perspective provided a necessary extension and foundation to explore the relationship between decision-making and behaviour in the safety leadership context. This goes beyond existing theories evident within the literature (Clarke, 2013; Gerstner & Day, 1997; Martínez-Córcoles, Gracia, Tomás, Peiró, & Schöbel, 2013; Walumbwa, Avolio, Gardner, Wernsing, & Peterson, 2007) which focus on examining and understanding safety leadership from the perspective of followers, rather than seeking to understand it as an integrated concept, and from the perspective of leaders themselves. Further, the present research demonstrates a range of decision-making and behavioural attributes are indicative of safety leadership. This shows the concept is not constrained to one or several 'styles' of leadership in isolation, rather a wide range of styles and attributes underpin key decision-making elements and behaviours to comprise effective safety leadership. The research presented in this thesis has presented a number of studies which demonstrate the importance of considering safety leadership as an integrated concept, with the definition applied throughout an important contribution to theoretical understanding in this regard.

10.3.2 Methodological Contributions

10.3.2.1 Development and application of a systems-based methodology for improved examination of safety leadership

Chapter 2 provided a comprehensive perspective on the limitations of current conceptual and methodological approaches for studying safety leadership. To date, existing research have predominantly relied on the use of retrospective questionnaire-based methodologies (Birkeland Nielsen, Eid, Mearns, & Larsson, 2013; Du & Sun, 2012; Yagil & Luria, 2010), which limits understanding for a number of reasons and thus the ability to optimise safety leadership for improvements in safety. First, as described in Chapter 2 and section 10.3.1, the favoured conceptualisation of safety leadership present within the existing literature is vastly inadequate. This has driven existing research towards the use of out-dated approaches, which assume safety leadership is a simplistic function, and which is examined primarily through obtaining follower ratings of leader behaviours and their perceived effectiveness in supporting safety. This approach, which is symptomatic of the existing literature, not only ignores the dynamics of leadership itself in terms of decisions, behaviours and actions, it also fails to consider the context in which leadership occurs (i.e., regular and non-routine tasks, scenarios or situations). Second, the application of such methods has typically focused on understanding an isolated dyad of the leader-follower relationship, whereby the frontline worker and immediate supervisor are the focus of interest. In concert, these limitations have important implications for understanding and optimising safety leadership as a positive performance shaping factor.

The conceptualisation and methodological approach applied in the current research addressed these shortcomings in the following ways. First, by defining safety leadership from a systems perspective, myriad methods become available through which to examine the concept. This in turn, facilitates a natural movement away applying from narrow, static, retrospective questionnaire-based approaches, to embracing methods that allow an integrated perspective of safety leadership to be obtained. In addition, understanding the contextual factors that both influence and support safety leadership during a range of operational contexts can be achieved. Second, the use of systems-based methods and concepts supports understanding of safety leadership directly from the viewpoint of leaders themselves, rather than solely being based on the perceptions of followers. Third, importantly it opens up the ability to gather data across a work system; from the frontline up to and including regulators and the governmental level. This is key to gaining a holistic perspective on how identified factors interact within and across multiple levels of the work system to support and influence safety leadership in order to optimise its effectiveness. The existing out-dated methods favoured by many for studying safety leadership (Christian et al., 2009; Clarke, 2013; de Koster et al., 2011; de Souza Costa Neves Cavazotte et al., 2013; Kath, Marks, & Ranney, 2010; Walumbwa, Peterson, Avolio, & Hartnell, 2010) fail to offer the same depth of understanding, which limits understanding considerably.

The methodological approach developed and applied throughout provides improvement in how to examine, analyse and understand safety leadership across mining work systems. As the underpinning framework, Rasmussen's RMF offered a foundation structure for designing data capture activities to encompass all levels of the work system. In applying the AcciMap Method to examine a critical incident scenario, interconnections and relationships between identified factors were able to be mapped against the framework in order to build a comprehensive picture of the mechanisms by which effective safety leadership occurred. By applying the CDM in both its original and extended form to interview participants from across each level within the Rasmussen's framework, enhanced understanding of the relationship between decision-making and behaviour in the safety leadership context was achieved. In addition, the use of the CDM further allowed the identification of factors and their interactions across the work system and visibility of how they combined and interacted to support safety leadership. Last, through applying CWA, all of the findings and factors and their interrelationships were brought together to draw out the specific behavioural and decision-making capabilities required of leaders to support achievement of system functions, goals and priorities. This enabled a core set of safety leadership competencies to be identified and developed into a systems-based competency development framework.

By applying a systems-based methodological and conceptual underpinning, the research presented in this thesis goes beyond existing representations and understanding of safety leadership, to provide a strong foundation for defining what constitutes good and effective safety leadership (Glendon & Clarke, 2015) within the mining industry.

10.3.2.2 Development and application of an extension to the Critical Decision Method to elicit information regarding safety leadership behaviour

A further contribution of this thesis lies in the development of an extension to the CDM (Klein et al., 1989) to create a new method that enabled examination of safety leadership behaviours in association with decision-making. The application of the standard CDM interview as presented in Chapter 5 revealed limitations in the ability of the technique to identify safety leadership behaviours. As such, a modified version was developed to incorporate cognitive probes that specifically aimed to elicit information on the behaviours leaders engaged in as associated with decision-making. The extension developed aligned with current thinking regarding the application of cognitive interviewing (Beatty & Willis, 2007; Dickinson et al., 2019), with each probe phrased as an open-ended question that allowed participants to respond to and elaborate on.

The development and application of the extended method is presented in Chapters 6 and 7 respectively examined safety leadership during regular task execution. The CDM – SL was shown to produce data of sufficient quality, depth and detail across the work system to support improved understanding of the link between safety leadership decision-making and behaviour during regular and non-routine safety-related task execution.

It is recognised however, that further application of the CDM-SL is warranted to prove the effectiveness of the method in examining safety leadership behaviours in conjunction with decision-making during a critical incident scenario. Even so, the development and embedding of behavioural specific probes within the standard CDM interview technique approach provided a new method to apply across work systems to enable an integrated perspective of safety leadership to be obtained.

10.3.3 Practical Contributions

10.3.3.1 Identification of the factors that influence and support effective safety leadership across a mining work system

This research provides an original contribution to practice through the identification of a set of factors that influence and support effective safety leadership across a mining work system, during both regular and non-routine task execution. Through the improved understanding of these factors, and their interactions across the work system, targeted strategies can be pursued by organisations within the industry to optimise the effectiveness of safety leadership to support safe performance and outcomes. Figure 12 provides a consolidated summary of the key factors identified across this research that influence and support effective safety leadership across the work system.

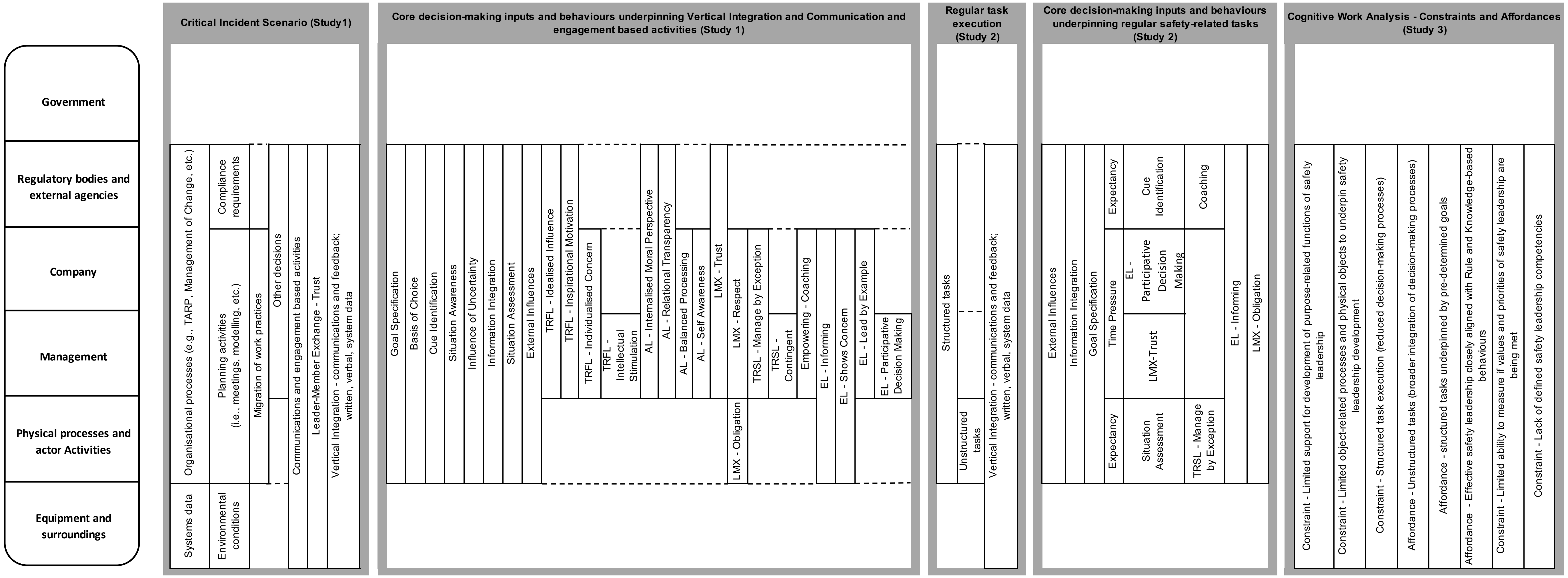

Figure 12. Summary of factors that influence and support effective safety leadership

In terms of the discrete factors as described in Chapters 4, 5 and 7, the majority represented; organisational processes (standards and procedures), compliance requirements, planning activities, the communication, flow and feedback of information (verbal and written communications and systems-data) between actors (human and non-human), systems data and environmental or task-specific workspace conditions. With reference to Rasmussen's predictions as tested in Chapter 4, the migration of work practices and prior 'other' decisions and actions executed across the work system also influenced safety leadership.

Vertical Integration was identified as having the greatest impact on supporting and enabling effective safety leadership during both a critical incident scenario and also regular safety-related task execution. Communications and information sharing between actors was strong across the work system, with feedback further strengthening interactions and interconnections between leader decision-making and behavioural response. The LMX attribute of 'Trust' was a key factor in supporting positive interactions between leaders, individuals and teams, with the present research highlighting the significance of trust in interpersonal interactions, and the quality of these relationships with respect to promoting VI to support, influence and enhance safety leadership.

Task type was shown to influence safety leadership and acted as both a constraint in the case of structured tasks and an affordance in the case of unstructured tasks. While structured tasks occurred more frequently across the work system, they exhibited less intensive decision-making and behaviour. The analysis found this may have implications in terms of optimising safety leadership whereby leaders may be 'satisficing' safety leadership for structured tasks rather than optimising its effectiveness. In contrast, unstructured tasks exhibited higher average engagement in decision-making and behavioural engagement requirements. This meant leaders drew upon and integrated a broader range of inputs to inform effective safety leadership decision-making and behaviour to support task execution. With this in mind, it is argued that the competencies representative of effective safety leadership are more closely aligned with a need to develop RBB and KBB (see Chapters 7 and 8), thus leaders should seek to integrate a fuller range of inputs to decision-making and behavioural responses regardless of task type, which would further seek to foster VI and Trust development through the nature of the decision-making elements and behaviours engaged in. The present research does not suggest that SBB in the safety leadership context is not appropriate or useful, rather that, by enhancing the range of possible behaviours and decision-making approaches available to support safe performance, RBB and KBB competencies may better assist in achieving the functions of safety leadership.

Study 3 identified a significant constraint in relation to how the current work system is structured to support achievement of the values, priorities and functions of safety leadership. Currently, there exists little focus on developing or enhancing the purpose-related function of safety leadership across the work system. This is symptomatic of the limited object-related processes and physical objects to support development of effective safety leadership. With little support mechanisms evident to build and sustain safety leadership capability across the work system, a priority concern related to the lack of definition regarding effective safety leadership competencies required at the 'purpose-related' system level to drive integration of sustainable learning and development opportunities.

An important observation related to efforts to optimise safety leadership, the majority of factors identified were present at levels within the work system over which leaders, organisations and regulatory bodies within the mining industry can exert some influence. Factors were identified from the 'Regulatory' level, down to and including the 'Equipment and Surroundings' level of Rasmussen's framework, with the knowledge of the factors outlined, their interactions and how they support and enable effective safety leadership has been distilled into the competency framework presented in Chapter 9.

The systems-based competency framework presented offers the industry a key starting point from which to develop targeted learning and development opportunities to build safety leadership capability across the work system. The core competencies outlined have been developed to leverage the key factors identified that influence safety leadership, with the framework structured as such that capability development can be strengthened across the work system from the top down and the ground up. The novel contribution of the competency framework is discussed in more detail in the following section.

10.3.3.2 Establishment of a systems-based competency framework for development of appropriate and effective safety leadership

A significant and exciting practical contribution of this research relates to the establishment of a systems-based competency framework for effective safety leadership development. Presented in Chapter 9, the framework represents the distillation of the findings from Studies 1, 2 and 3 to describe five core safety leadership competencies in terms of the decision-making and associated behavioural capabilities required of leaders across a mining work system to support achievement of the functions, values and priorities of effective safety leadership. Maintaining the systems perspective, the competencies are mapped against Rasmussen's RMF and emphasise the key factors and elements associated with effective safety leadership identified throughout this thesis. In particular, the framework focuses on the promotion of VI and communications and engagement-based interactions and requirements to build trust between leaders, individuals and teams.

The competency framework is considered formative in nature, whereby the specific competencies described acknowledge and account for variability within the system with regards to control task execution. This promotes development of a range of behaviours available to leaders to engage in to support safe system functioning. Aligned with this, the competencies and underlying behavioural indicators are designed to be context-independent and focus on promoting and strengthening RBB and KBB as key drivers of adaptability and flexibility to optimise safety leadership effectiveness. By encouraging RBB and KBB across the work system, this will encourage optimisation of safety leadership and the identified influencing factors within the work system to support achievement of the systems functions and purposes. Such a focus further accommodates the adaptive, flexible and responsive nature of safety leadership required across the work system to support safe functioning under the range of operational scenarios as examined in this thesis.

The competency framework presented therefore provides a unique and beneficial contribution to the industry that can be adopted by mining organisations to shape development pathways for leaders, which will enhance and optimise safety leadership for improved performance across the work system.

10.4 Recommendations for optimising effective safety leadership across the mining industry

With the improved understanding of safety leadership provided by the systems perspective applied throughout this research, a set of outcome recommendations are presented that provide the basis for targeted approaches to develop and optimise safety leadership capability across the mining industry. Implications for practical implementation are discussed, with the recommended optimisation strategies offering the potential to improve safety performance and outcomes.

The development of the systems-based safety leadership competency framework presented in Chapter 9 directly addresses the priority recommended optimisation strategy outlined in Table 12. The framework defines the safety leadership decision-making and behavioural competencies to be developed across mining work systems to support safe system functioning. The remainder of Section 10.4 focuses on providing a way forward to progress the other recommended optimisation strategies outlined in Table 12, with reference to adopting the systems-based competency framework.

10.4.1 Development of targeted learning and development content

For mining organisations already seeking to develop safety leadership competency, the findings presented in this thesis provide a foundation of content that can be used to develop scenario-based training. The majority focus of scenario-based training within the industry currently is largely reserved for roles that involve the direct operation of equipment, such as heavy machinery (i.e., haul trucks, drills, drag lines, excavators etc.), or operations control (i.e., centralised systems-monitoring and oversight). The competencies required for such roles typically focused on ensuring adequate spatial and numerical reasoning to detect and respond to safety concerns, as well as the coordination and control of equipment that moves within multiple planes of motion.

To adopt the fourth through seventh recommended optimisation strategies outlined in Table 12, a candidate approach may be to develop a range of safety leadership specific scenarios through which to assess individual and team performance against the competencies outlined. Such an approach would focus on enhancing capability in line with the core SRK-based behavioural requirements identified and associated types of decisions and behaviours executed for different tasks, at different levels within the work system. Such an approach would promote formative development of decision-making and behavioural competencies by encouraging learners to recognise and actively analyse constraints that shape decision-making and behaviour, to demonstrate flexibility and adaptability in response to emerging situations. It would also allow learners to develop a range of competencies to draw on relevant to a situation, rather than constraining decision-making and behaviour to pre-learned, skill-focused engagements. Further, it would ensure scenarios support development of the prominent RBB and KBB that underpin the majority of the competencies in the framework, to provide greater opportunity to optimise the effectiveness of safety leadership across the work system during dynamic situations. This candidate approach would be similar to that in other industries, for example, as in aviation where Evidence Based Training (EBT) is underpinned by assessment of specific decision-making capability and behavioural competency execution with reference to successfully undertaking key regular and also non-routine tasks (i.e., responding to a critical incident scenario) (*Manual of Evidence-based Training, International Civil Aviation Organization*, 2013) . As such, similar to the aviation industry, the mining industry may wish to invest effort in the development of check and training specialists that focus on assessing and coaching improvement in effective safety leadership practices during scenario-based simulation, or indeed real-time operations to identify further development opportunities.

An additional approach would see the development of self-paced learning content that provides foundational knowledge of key Human Factors concepts known to influence decision-making (i.e., attention and memory capabilities), as well assisting learners to develop remediation strategies for managing non-adaptive heuristics and cognitive biases which may give rise to less optimal safety leadership practices. This would assist in satisfying the requirement to develop sufficient object-related processes and physical objects to actively support and supplement safety leadership competency development. Further, learning and development outcomes associated with such content should be clearly linked to the values and priorities, and functional purposes of safety leadership to ensure alignment with individual and organisational goals is preserved. Ensuring a clear connection between physical objects, object-related processes and purpose-related functions of safety leadership will provide a solid foundation against which to afford achievement of the higher-level functions of the safety leadership system.

10.4.2 Defining key performance indicators (KPIs), metrics and continuous improvement activities

It is recommended that any organisation that adopts and integrates the systems-based safety leadership competency framework develops a set of related KPIs and metrics to measure the associated influence on safety and performance.

Such an approach would ensure efforts to develop safety leadership capability are measurably aligned with the functional purposes of safety leadership, as well as being capable of measuring achievement of the values and priorities associated with engaging in effective safety leadership. To achieve this, and in line with the targeted optimisation strategies outlined in Table 12, organisations may wish to develop and structure individual performance related goals and objectives around the three functional purposes of safety leadership; produce a product or provide a service safely, fulfil requirements of law and regulation, and ensure and maintain a safe working environment. Doing so would foster development of programs and initiatives that directly support and align with those functional purposes. For example, an individual leader may have a goal or objective related to the development and successful delivery of an audit plan to 'fulfil the requirements of law and regulation'. While it can be argued such a goal may be relatively easy to achieve, ultimately, successful achievement would be measured through assessment against the underpinning values and priorities, and engagement in associated safety leadership decision-making and behavioural competencies. For example, the degree to which the leader 'fosters and promotes vertical integration' as well as 'creating a culture of unconscious compliance' through delivery of the audit plan will influence achievement of the values and priorities associated with 'minimising exposure to hazards and risk', and the degree to which 'deviations from standards, rules and procedures are minimised'. A further example may be related to the development and delivery of targeted safety-related communications and awareness raising, as linked to the functional purpose of 'ensuring and maintaining a safe working environment'. Successful achievement of that objective may be measured through the degree to which the leader 'exemplifies a safety-focused mindset' and 'leads and develops a safety-focused mindset in others' to achieve the value of 'minimising or eliminating incidents, injuries and fatalities'. This bottom-up, top-down approach has two advantages; one, it drives development of programs of work to align with the functions of safety leadership, whilst ensuring safety leadership competency is developed to measurably achieve the values and priorities of the safety leadership system.

A final consideration relates to the development of metrics through which to measure the effectiveness of the individual safety leadership competencies and attributes defined. Such an approach may include self-assessment of engagement in the key components of safety leadership during every-day tasks and activities. This would provide visibility of the 'in situ' profile of decision-making and behavioural responses requirements across the work system in real-time and how such requirements may adapt and respond based on tasks executed. Further, capturing metrics in this way may provide insight into the effectiveness of safety leadership as a key operational risk control, which would provide a strong business case for other organisations within the industry seeking to invest effort in development of safety leadership capability to support improved performance. It would also allow further assessment to be made against achievement of the values and priorities of safety leadership through comparison with key safety-related data such as the number of hazards, incidents and injuries reported, and or the number and severity of findings and actions raised from audits and inspections.

In terms of continuous improvement, it is intended that the competency framework will be provided as an online resource for the mining industry to download for direct embedding within organisations or at the regulatory level. In conjunction with this, a website may be developed by the author of this research to enable users of the competency framework to provide feedback on its effectiveness in their organisations and the ability for users to suggest additions, amendments or variations for consideration. The website would also provide an avenue for collecting data about the use of the framework over time via online survey forms. This initiative will provide a benefit to continuous improvement efforts in that will enable the competency framework to be evaluated and further refined over time based upon the experiences of the users and facilitate adaption of the competency framework for emerging uses and requirements.

10.4.3 Integrating safety leadership competency requirements into recruitment and selection activities

A straightforward benefit that the industry can achieve with relative ease, would be to embed the competency requirements defined in this thesis within existing recruitment and selection activities. Doing so would allow for early identification of candidates to organisations with a natural inclination towards the engaging in the effective decision-making and behavioural competencies defined. A potential benefit of this would lie in the ability to identify and recruit individuals capable of responding in flexible and adaptive ways, particularly during non-routine safety-related tasks and activities, such as that of the Bingham Canyon Highwall Failure incident to ensure safe outcomes are achieved. With candidates able to demonstrate engagement in the range of decision-making elements and behavioural responses required of leaders to promote VI and support safe performance under such circumstances, organisations may establish a foundation in such candidates to further develop the identified competencies based on role definition. Further, embedding the competency requirements in recruitment and selection activities would allow for organisations to better identify candidates whose personal values and priorities align with those of the safety leadership system, which would necessarily support achievement of the overall function of safety leadership. It is suggested this approach may also have benefit for other high-risk industries to adopt, such as the aviation, construction or transport industries however, the underlying competency requirements outlined in this thesis would require further empirical testing relevant to these industries to ensure appropriate generalisability.

10.4.4 Influencing regulatory reform

It is recommended that regulatory bodies within the industry review the findings of the current research with a view to taking a formative approach to integrating safety leadership requirements into regulatory instruments. With the dearth of reference to safety leadership apparent within existing regulation nationwide, and the subsequent lack of support mechanisms apparent to develop appropriate capability across the industry as identified in the present research, development of safety leadership capability remains largely up to individual organisations to invest time and effort in pursuing. With the clear links between safety leadership and improved performance already established, it is considered short sighted of current regulatory approaches and instruments to fall silent on integrating associated requirements.

Rather than potentially constraining performance through stipulating specific requirements, a formative approach is recommended in the current context as it would allow requirements for safe system performance to be described in ways that acknowledge and account for variability indicative within mining operations (Salmon et al., 2016; Vicente, 1999). Such an approach would be consistent with the systems perspective applied in the present research, whereby defining formative performance requirements would focus on promoting optimisation of factors within mining work systems, such as those identified within this research with the capacity to support and enable safety leadership. This may include amending regulatory instruments to define the requirement for organisations to explicitly create a connection between organisational priorities and objectives and engagement in effective safety leadership practices to achieve espoused system functions and purposes. Importantly, this would set an expectation regarding a minimum standard for organisations to commit to developing safety leadership capability. In addition, it would establish a consistent understanding of the definition of safety leadership across the industry as defined in this research, with links to the importance of the concept in supporting safe performance.

Encouraging regulatory reform in this way would allow organisations to meet compliance requirements through development of the competencies and associated SRK-based behavioural requirements outlined in this thesis to support continued safe functioning.

10.5 Research Limitations

A number of limitations are acknowledged, which are discussed below.

10.5.1 Sampling and sample size

It is acknowledged the number of participants involved in both Studies 1 and 2 was somewhat constrained. In relation to Study 1, the critical incident scenario examined presented as a unique event through which to examine safety leadership due to the safe outcome associated with the incident. Given an incident of this type is exceedingly rare, there weren't other opportunities identified across the industry to include within the scope of Study 1. Hence, the sample size was constrained to 8 participants from within the organisation. Additionally, there was limited access to participants at levels outside of the organisational system to increase the sample size. However, even though the sample size was modest, representation of leaders across all levels within the organisational system was achieved, which is considered significant in the current context.

Likewise, it is acknowledged the number of participants involved in Study 2 could have been higher and also widened to involve additional organisations. However, in determining an adequate sample size, consideration was given to other studies in the literature that have used the CDM interview technique, particularly where the number of participants interviewed was less (Horberry & Cooke, 2010; Øvergård, Sorensen, Nazir, & Martinsen, 2015; Plant & Stanton, 2013; Wachs, Saurin, Righi, & Wears, 2016). Due to in-depth nature of the CDM interview technique, it is not uncommon for the number of participants in a study to be modest. With this in mind, the final sample sizes in both Studies 1 and 2 were considered adequate to achieve data saturation and was in line with other sample sizes used in the literature.

With the above constraints considered, the opportunity to interview key personnel involved in actively managing and responding to the incident to in Study 1 and subsequently have the same organisation support participation in Study 2 is a considerable achievement and sufficient for obtaining a systems perspective of safety leadership within the domain and context studied.

10.5.2 Methodology

In relation to the methodological design, it is noted that currently no data or input was obtained directly from the government level with regard to safety leadership practices, other than the review of regulatory instruments for identification of where safety leadership is referenced. As such, the studies presented focused on understanding safety leadership from a regulatory perspective and also within mining organisations where it is typically executed for most safety benefit. While this approach yielded important understanding at an organisational and regulatory level, it was unable to do so for decisions, behaviours and actions present at higher system levels (i.e., government) that may subsequently influence safety performance and outcomes. As such, future endeavours should seek to incorporate data capture and analysis from all levels within the work system, including participants at the government level who develop policy, to help better understand additional influencing factors and interactions across system levels that may be present.

There is also further opportunity to explore safety leadership from a systems perspective through the application of additional methods identified, but not applied in the present research. Chapter 3 outlines 9 methods not selected for application and the reasons for their exclusion. However, it is recognised that some of the methods may have applicability. For example, both the STAMP and HFACS methods may provide sufficient insight into causal and contributory factors such as decision-making and behaviour that can be associated with incidents, such that designing appropriate social and organisational control processes that account for and promote effective safety leadership may then form the basis of incident prevention strategies.

Overall, however, the application of the systems-thinking methods applied has led to improved understanding of safety leadership as a concept and the factors that influence it to support safe performance.

10.5.3 Generalisability

While some of the findings in this thesis provide agreement with those in other domains where safety leadership is studied (Fruhen, Mearns, Flin, & Kirwan, 2014) caution is urged when generalising findings to other domains. This is considered on account of both the sample size included in the studies undertaken and also the nature of operations in mining and relationships between leaders and team members, which may differ to those of other high-reliability environments. To determine ultimate generalisability, the same methodological approach may be applied to study safety leadership in other industries.

10.5.4 Design of specific interventions

While the present research provided a set of targeted strategies organisations can implement to optimise the effectiveness of safety leadership in supporting safe system performance (Table 12), it did not seek to design specific interventions based on the majority of the strategies proposed. While the systems-based safety leadership competency framework presented in Chapter 9 takes an important first step in this regard, it was considered out of scope to design interventions to support all of the remaining recommended optimisations presented. As a result, further work is encouraged to explore the specific design and evaluation of strategic interventions associated with the optimisation strategies proposed.

10.5.5 Validation of Cognitive Work Analyses

The three phases of CWA presented in Chapter 8 provide a comprehensive representation of a safety leadership system, associated control tasks and DL, and the SBB, RBB and KBB required of leaders of leaders across the system to support safe functioning.

While the analyses were reviewed by six SMEs and three senior researchers associated with the program of work, the current research did not formally validate the output from the CWA via an iterative process such as a Delphi study (Linstone & Turoff, 2011). Conducted over multiple evaluation rounds, the Delphi method is considered useful in areas of limited research, as it invites SMEs to provide opinions and apply expertise to reach a consensus regarding the content under review. As a result, The Delphi method is often used to validate systems analysis models (Hulme, Nielsen, Timpka, Verhagen, & Finch, 2017; Lane, Salmon, Cherney, Lacey, & Stanton, 2019; Read, Naweed, & Salmon, 2019). Given the involvement of multiple SMEs and researchers in the review of data collected across the program of research, a Delphi study was not undertaken. The review process applied was considered robust as it allowed for disagreements in opinion and evaluation to be resolved through discussion to ensure an acceptable level of agreement was achieved regarding the CWA output. However, it is recognised there may be benefit in conducting a Delphi study for similar research.

10.6 Future research directions

As the present research is the first to apply a systems perspective to the examination of safety leadership in mining, a number of exciting opportunities exist with regard to the direction of future research. First, the focus of the CDM interviews undertaken in Studies 1 and 2 was on understanding the systemic and contextual factors that supported safety leadership decision-making, as opposed to seeking to understand the step-by-step process of decision-making. While the application of CTA & DL phase in CWA (Study 3) did allow for high-level exploration of the process steps involved in safety leadership decision-making, potential future research directions could explore decision-making in depth during real-time operational context. A method such as Verbal Protocol Analysis (Stanton; 2013) may be employed during specific task execution to gain such insights however, any methodologies used should be underpinned by the systems perspective used herein to maintain theoretical validity and continued advancement of research related to safety leadership. This may involve the application of wider systems-thinking techniques identified as suitable in Chapter 3.

Second, in the early stages of the literature review, consideration was given to the potential influence of personality on decision-making and behaviour as linked to engaging in effective safety leadership practices. The current research did not explore such a link and the question remains outstanding. With this in mind, an opportunity exists to extend the current research to integrate consideration of personality traits to determine any potential influence or interaction with safety leadership effectiveness, or preference for engagement in certain practices over others.

A further variable that was not explicitly examined in the current research relates to resilience. The need to understand factors that support positive performance, as opposed to only examining scenarios with adverse safety outcomes (Hollnagel, 2004) is a key requirement within emerging areas of safety science, such as resilience engineering and Safety II (Hollnagel, 2014). While the presence of VI was recognised to enhance resilience and maintain safety during the critical incident scenario examined, further examination of normal behaviours such as safety leadership decision-making and behaviour, particularly within an accident scenario (Dekker, 2011; Leveson, 2004; Rasmussen, 1997), may provide a powerful opportunity to contribute to future research regarding the relationship between safety leadership and resilience.

And last, future empirical research is required to test and evaluate the effectiveness of the competency framework in application for development of safety leadership capability. This could involve either implementation and formal evaluation or modelling via systems HFE methods (e.g. Lane et al., 2019; Read et al., 2017). It is hoped that academic agendas will be extended to incorporate such, in efforts to further improve safety not only within the mining industry, but other high-risk industries that may also benefit from such research.

10.7 Conclusion

This thesis represents an important and exciting step forward for research relating to safety leadership. Through the application of a systems perspective, a paradigm shift was achieved that delivered an improved understanding of safety leadership from a theoretical, methodological and practical perspective.

In terms of theory, this thesis redefined safety leadership as an integrated concept, which is comprised of the decisions, behaviours and actions of actors across all levels within a work system that combine and interact to support safety. By defining safety leadership in this way, improved understanding of the concept in application was possible, through a methodological design underpinned by systems-thinking. By seeking to understand the factors and interactions that contribute to and influence safety leadership across a mining work system under both normal and abnormal performance scenarios, it was possible to identify what constitutes effective safety leadership in terms of decisions, behaviours and actions to support safe functioning.

In addition to the theoretical and methodological contributions described, this thesis has provided contributions to practice with the provision of a competency development framework and associated recommendations for integrating the key outcomes of this research within and across mining work systems to further support improvements in safety across the industry.

Throughout this thesis, the application of a systems perspective has yielded a deeper understanding of the factors and elements that underpin effective safety leadership across all levels within a mining work system. In doing so, this thesis has provided original insights into how mining work systems can best enhance the likelihood of effective safety leadership during both regular and non-routine operational situations to support continued safe functioning.

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12 Appendices

Appendix 1. Frameworks, models and methods not selected for application in the current research

For completeness, following section outlines the remaining methods not selected for application in the current research, and the justification for their exclusion. Consideration for future application of those below is provided in Chapter 10 of this thesis.

A1.1 Event Analysis of Systemic Teamwork (EAST)

The EAST approach was deemed not suitable for application for the current research as requires a high degree of training associated with the use of the various methods, it is very time consuming to apply and requires a high level of access to the domain, specific tasks and Subject Matter Experts.

A1.2 Functional Resonance Analysis Method (FRAM)

The FRAM approach was deemed not suitable for application for the current research, as it is judged as extremely complex to learn and apply and the outputs are considered difficult to decipher.

A1.3 Human Factors Analysis and Classification System (HFACS)

HFACS was not deemed suitable, as it is focused on failures and factors associated with accident analysis, which does not align with the intent of this thesis (i.e., to explore positive performance characteristics, as opposed to identifying failures).

A1.4 Human Factors Engineering Principles

While HF principles are applied throughout, the intent of HF engineering principles and concept are typically applied in isolation and as such, do not yield insight into the interactions between elements, nor across system levels.

A1.5 Interviews

For the purpose of application, the Critical Decision Method is considered an interview technique, negating the need to introduce or include an additional approach to interviewing.

A1.6 Observations

The use of observations was not deemed suitable in the current research due to requirements for a high level of access to the domain, specific tasks and Subject Matter Experts. Further, it may not be possible to physically observe certain aspects of safety leadership, such as decision-making, nor be present to observe safety leadership during management and response to a critical incident scenario.

A1.7 Questionnaires

Unless specifically designed as such, questionnaires are not deemed to be systems-thinking methods. Further, as a data capture method, questionnaires provide limited ability to extract emergent factors that influence or interact with safety leadership.

A1.8 Swiss Cheese Model

The Swiss Cheese Model was not deemed suitable as it is focuses on failures and factors associated with accident causation and analysis, which does not align with the intent of this thesis (i.e., to explore positive performance characteristics, as opposed to identifying failures).

A1.9 Systems Theoretical Accident Modelling and Processes (STAMP)

Similarly, STAMP was not deemed suitable, as it is focuses on failures and factors associated with accident analysis, which does not align with the intent of this thesis (i.e., to explore positive performance characteristics, as opposed to identifying failures). For completeness, following section outlines the remaining methods not selected for application in the current research, and the justification for their exclusion.

Appendix 2. AcciMap of the Bingham Canyon Manefay landslide reproduced in full