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The leading edge: A systems thinking methodology for assessing safety leadership

Sarah-Louise Donovan[a,]*, Paul M. Salmon[b], 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, School of Social Sciences, University of the Sunshine Coast, Queensland 4558, Australia

Abstract

Leadership is progressively being recognized as a key factor in supporting successful performance across a range of domains. This is particularly important when considered within the context of safety, with the now widespread acceptance that safety is an emergent property of overall work systems. As such, the decisions and actions that characterize safety leadership thus become important emergent properties in the prevention of incidents, which should be considered within the context of the broader organizational system and not merely constrained to understanding events or conditions that shape performance at the 'sharp end'. This paper presents a first-of-its-kind test application of a methodological approach, underpinned by systems thinking, to the examination of safety leadership. A case study incidentis examined using the Critical Decision Method, Rasmussen's Risk Management Framework and correspondingAccimap method to identify safety leadership decisions and actions, and their contribution to the incidents important safe outcome (no injuries or fatalities were incurred). The merits of the methodological approach utilized are discussed.

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*Keywords:*Safety leadership; Systems-thinking; Accimap; Critical Decision Method; Rasmussen's Risk Management Framework

*Corresponding author.Tel.: +61 3 9905 1913; fax: +61 3 9905 4364.
E-mail address: sarah-louise.donovan@monash.edu

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1. Introduction

Leadership is progressively being recognized as a key factor in supporting successful performance across a range of domains. Defined as 'the action of leading a group of people or an organization' [1], the characteristics that underlie different approaches to leadership manifest as both broad and varied. As such, understanding the influence leadership has on performance becomes particularly important when considered within the context of safety.

Over the two decades, a body of literature has emerged with a focus on examining the impact leadership has on safety performance and outcomes within high-risk industries, with support growing for a positive contribution inthe prevention of accidents and injuries [2, 3]. Within this, identifying and characterizing the specific influence safety leadership plays in the prevention or minimization of accidents offers some important opportunities for enhancement of traditional approaches to safety and risk management within high-risk industries.

A review of theliterature regarding safety leadership[4]revealed that much of the research to date has been applied within the manufacturing, construction and chemical industries[5-9],with a focus on examining the impact of leadership predominantly at the 'sharp-end' (i.e., at the frontline supervisory level). The review also showed that currently favored methodological approaches have tended to adopt single-level, one-directional data capture techniques, mainly involvingthe use of questionnaires and surveys [6, 10-14]. This approachis limited in that it restricts not only examination of safety leadership with regard to more distal system elements (e.g., company, regulatory and government influences),it furthermore restrictsthe exploration of different leadership behaviors at different levels within an organizational system and their relative influence; an important emerging piece of the performance puzzle [15, 16].With the now widespread acknowledgement that safety is an emergent property of multi-level work systems [17, 18], the decisionsand actions that characterize safety leadership thus become important emergent properties in the prevention of incidents and accidents. As such, theirshould be considered within the context of the broader organizational system and not merely constrained to examining events and conditions that shape performance at the sharp end. Only then can we begin to understand and characterize the true contribution of safety leadership in the prevention of incidents and accidents within high-risk industries.

Methodologically,the examination of safety leadership requires a new perspective. This paper discusses the value of applying systems-based methods to the examination of safety leadership. In a first-of-its-kind approach, a recent incident is analyzed through the application of the Critical Decision Method interview technique[19], Rasmussen's Risk Management Framework and Accimap[18]incident analysis methodto identify leadership decisions and actions that contributed to the important safety outcome in which no injuries or fatalities were incurred. The findings provide support for applying systems-based methods to the examination of safety leadership.

1.1. The systems approach

Over the past twenty years, the use of systems-based approacheshave become popular for examining safety within complex socio-technical systems, and in doing so haveprovided an important step forward for the safety science literature[17, 18, 20, 21]. The systems approach assertsthat safety is an emergent property, which is influenced by the interactions of actors and elements across every level of an organizational system [17]. As such, safety is viewed as a 'control problem' [22] with sub-optimal performance usually caused by multiple linked contributing factors across different system levels; not just a single catastrophic decision or action at one level alone. The systems approach therefore argues it is important to examine and understand the relationships that exist between different elements across different levels of an organizational system.

Rasmussen's Risk Management Framework (RMF) [18] (Figure 1) is a prominent systems-theory based model for describing work systems comprised of various levels, and argues that safety is impacted by the decisionsand actions of individuals across all levels (e.g., politicians, chief executives, managers, supervisors), not just by those of front line operators alone [23].

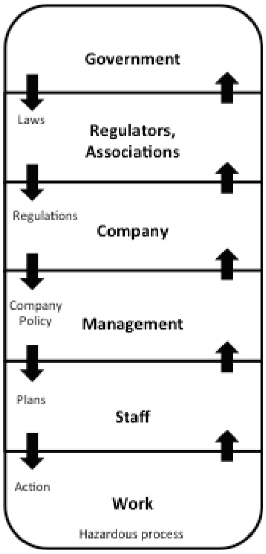

Fig.1. Rasmussen's Risk Management Framework.

Each level in the framework is considered connected by the flow of information, with decisions promulgated downward for example, as regulations and policies, while information about the current system status is propagated upwards to help inform decision-making and action at higher levels [18]. This flow and exchange, known as 'vertical integration', is recognized as essential for safety as it helps to exercise control over hazardous processes to ensure safety is maintained [18].

Underpinned by the framework, the Accimap method [18] provides an approach through which to describe the elements and interactions within and across an organizational system with regard to their contribution and connectedness to an incident outcome. While the framework and method are commonly applied to examine incidents from the point of view of 'what went wrong', both the method and framework are sufficiently flexible and adaptable to enable exploration of accident sequences across a range of different contexts [24-27]. In doing so, both the framework and method are considered equally applicable to allow description and examination of incidents in terms of 'what went right'. Indeed, Trotter et al.[28] recently applied Accimap to examine the factors enabling a successful outcome during the Apollo 13 lunar landing.As such, Rasmussen's Risk Management Framework and Accimap method offer both a useful structure and theoretical basis to be tested in a 'positive' sense;that is, to demonstrate the application of systems-thinking approaches to examinethe positive contribution of safety leadership in the prevention and minimization of incidents and accidents. Understanding events that had a positive outcome, particularly non-routine and emergency situations represents a critical line of inquiry for safety science generally [29, 30].

1.2. Case study analysis

On April 10th2013, a mining company in the U.S. experienced a significant landslide along a fault line of its north eastern wall. Dislodging more than 150 million tons of earth, the landslide is recognized as the largest of its type in history.

In the months leading up to the incident, the mining company had identified increasing ground movement on the north eastern wall, and had put in place measures to manage the safety risks associated with a potential landslide. These measures included relocating people, facilities and key infrastructure. Leading up to, and at the time of the slide, multiple layers of protection were in place that afforded considerable advanced warningto ensure operations were ceased and all personnel were evacuated well ahead of the landslide. With these layers of protection in place, the organization successfully stopped operations and evacuated all personnel from the Mine prior to the landslide,ensuring that no injuries or fatalities occurred as a result of the incident.Figure 2 below provides an overview of the incident timeline. The timeline presented runs from the point at which an increased rate of slope movement was identified until the point at which the north eastern wall failed.

2. Method

The case study was undertaken to explore the safety leadership decisions and actions evident throughout the landslide incident. Two methods, the Critical Decision Method (CDM) and Accimap, were used to gather and analyze data regarding safety leadership decisions and actions as they emerged within the context of the incident. CDM interviews [19] were held with eight participants across five leadership levels within the organizational system of interest. CDM is a semi-structured cognitive task analysis technique that is used to examine decision making and the associated influencing factors.The CDM interviews were conducted by a Human Factors researcher with experience in the application of the technique across different safety critical industries. A standard set of probes were used [31], in conjunction with supplementary items to extract additional information on influencing factors across different system levels. Each interview was audio taped and lasted for approximately two hours.The data for each participant was transcribed and coded into influencing and contributory factors [32]consistent with the six levels of Rasmussen's RMF [18].

An Accimap was then constructed from the data to describethe evolution of the incident and map the safety leadership decisions and actions enacted by leaders, across various system levels,over the course of the incident. The resulting Accimap was reviewed by two Human Factors researchers with considerable experience in the application of accident analysis methods, in addition to three Subject Matter Experts (SMEs) from the organization who were familiar with the incident. Any discrepancies or disagreements were resolved through discussion between the researchers and the SMEs until consensus was reached. Last, the final Accimapoutput wasreviewed against the formal incident investigation reportto determine commonality in the elements and contributing factors identified to furthersupport validation of the methodological approach used.

3. Results

3.1. Critical Decision Method

From the CDM data, sixteen key decision points were identified and spanned the incident timeline, with the CDM probes(extract provided in Table 1) allowing exploration of the specific cues that assisted and supported each decision.

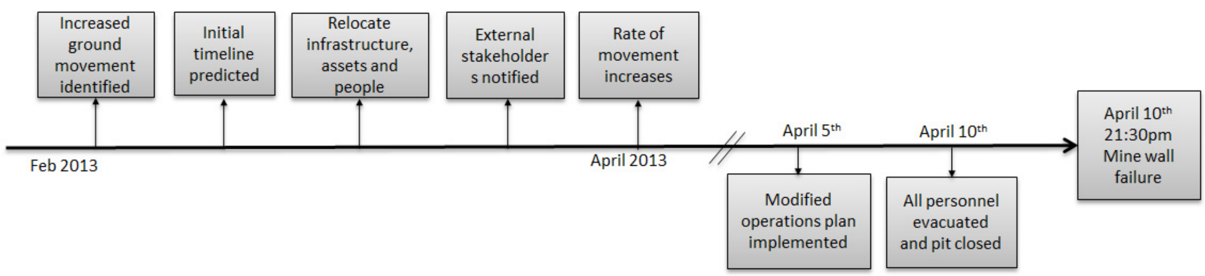

Fig.2. Incident timeline adapted from CDM interview data.

Table 1.Critical Decision Method interview probes.

Cue	Probe
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? Were there others involved in making the decision?
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 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?
Options	What other courses of action/ alternatives were considered or were available?
Decision making	How much time pressure was involved in making this decision? How long did it take to actually make this decision?
External influences	Did you at any time feel like the decisions and actions you were making were constrained by:standards/ rules/ procedures, higher organizational influences, Regulation (OSHA/ MSHA), Government considerations.

The analysis revealed each of the safety leadership decisions and actions identified was underpinned by a range of cues with the accuracy of information being provided (*influence of uncertainty*), the importance of information being shared (*information integration*) and ensuring the safety of personnel was maintained at all times emerging as a key goal (*goal specification*). As such, the communication and sharing of accurate information became important in influencing and supporting each safety leadership decision throughout the evolution of the incident. Furthermore, of the sixteen key decisions identified, 75% demonstrated direct connectedness with at least one other key decision, with the remaining decisions providing secondary support and informing through the execution of processes and or supporting activities.

3.2. The Accimapmethod

The Accimap analysis revealed the sixteen key safety leadership decisions identifiedthrough the CDM interviews spanned across four system levels; Physical actor and process activities, Management, Company and Regulatory bodies and external stakeholders. Of the decisions identified, over half (56%) occurred at the Management level, and demonstrated connectedness to at least 3 influencing factors and elements, which also spanned across multiple system levels (physical processes and actor activities, and equipment and surroundings). The safety leadership decisions identified at the Company level were connected to lower level system elements through communications based interactions, and focused on providing support and coaching to leaders and decisions executed at these lower system levels. The flow and exchange of information across different system levels was evident throughout the incident, exhibiting vertical integration.

While the analysis did not reveal any key safety leadership decisions at the highest system level (government) or the lowest system level (equipment and surroundings), this is not considered unusual as potential governmental influences may have not been apparent or known to the study participants, while the lowest system level elements were predominantly related to specific systems and equipment, rather than individuals.

Figure 3provides an extract of the Accimap analysis and highlights some of the key safety leadership decisions identified through the CDM interviews that occurred during the initial stages of the incident. Importantly, the Accimap analysis demonstrates key decisions were made and executed across multiple system levels. Common elementsidentified between the CDM interview data and investigation report are noted. Considerable agreement is evident between the findings of the present analysis and the investigation findings, thus providing support and validation for the utility of the methodological approach used.

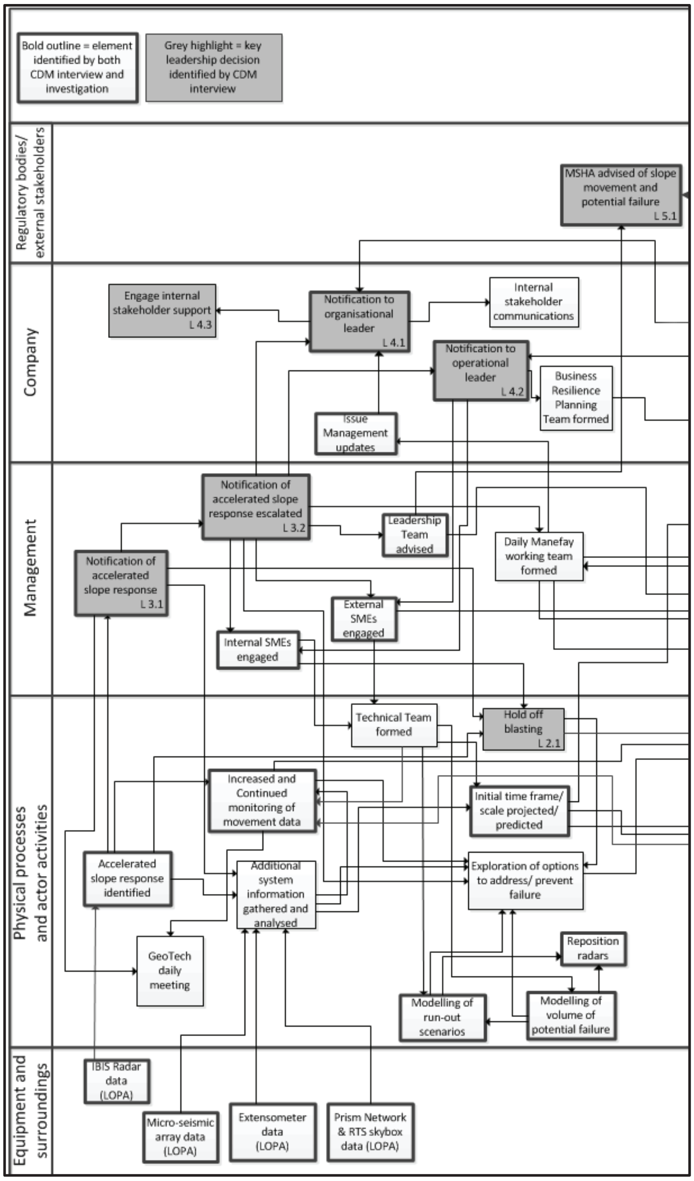

Fig.3. Extract of Accimap Analysis of Initial Stages of the Incident.

4. Discussion

The results of this study provide support for the value of applying systems-based methods to the examination of safety leadership.

The CDM interview technique was found to be a fitting method to allow identification and exploration of elements that contributed to key the safety leadership decisions and actions for each participant. Using the technique, key decisions were identified across different leader levels within the organization, with their contribution and connectedness able to be traced in terms of supporting the ultimately positive safety outcome. The use of the method in this way (i.e., to interview multiple leaders across multiple levels within an organization) allowed a level of insight and detail to be gained into important safety leadership decisions and actions that could not have been possible had traditional approaches (i.e., conventional survey methods or exploration of the investigation report alone) been used. Furthermore, use of the technique in this way demonstrated support for the application of the method in identifying and exploring safety leadership as a positive contributor to the ultimate safety outcome.

The Accimap method was also found to be afittingmethod to examine safety leadership decisions and actions within the incident. The method allowed the safety leadership elements extracted from the CDM interview data to be mapped according to their connectedness across multiple system levels, which allowed exploration of the interrelationships between elements across different levels. This provided important insight into the closeness and distance of specific factors and their influence and contribution to the safety outcome. For example, the early decision to notify the Mine leadership team of the increased ground movement was supported by information provided by lower system levels, which included individual actions and the timely provision of important system generated data. This decision was connected to the secondary decision to escalate and communicate the situation to higher levels within the organizational system, both of which were linked to the positive safety outcome of the incident in that they triggered the development of appropriate planning and response activities aimed at ensuring safety was maintained. Had, for example, the initial notification and escalation occurred later than they did, or had they not occurred at all, planning and response activities initiated at lower system levels may not have been afforded important resource and support elements (for example; forming of dedicated technical team, engagement of internal and external SMEs) which ultimately assisted in developing the response plans and activities which supported the safe outcome.

These findings provide support for the value in applying Accimap to examine safety leadership.The method allowed mapping of the interrelationships between elements which spanned multiple system levels, all of which contributed to the incidents safe outcome. Furthermore, within each safety leadership element identified, communication and information sharing was shown to play a vital role in supporting performance, demonstrating vertical integration across multiple system levels which further contributed to the safe outcome of the incident.

As such, the methodological approach applied provides support for the application of systems-based methodsto the examination of safety leadership.It is suggested that future research agendas interested in examining safety leadership would benefit from includingsystems-based methods to support data capture and analysis activities.

5. Conclusion

The results of the analysis presented demonstrate the value in applying systems-based methods to the examination of safety leadership. The analysis shows the usefulness of the CDM interview technique for extracting and exploring safety leadership decisionsand actions within the context of an incident, across multiple leader levels. In line with this, Rasmussen's RMF and corresponding Accimap method facilitated visual mapping of the elements identified, illustratingthe interrelations between safety leadership decisions and actions and the role these elements played in ensuring the positive safety outcome. Furthermore, the Accimap constructed from the CDM interview data demonstrated a high degree of concurrence with elements identified within the investigation report, providing further support for the validity of the methodological approach used.

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References

[1] Oxford Dictionary of English (2010) 3rd edition.
[2] Mullen, J.E. and Kelloway, E.K. (2009) Safety leadership: A longitudinal study of the effects of transformational leadership on safety outcomes. Journal of Occupational and Organizational Psychology, 82(2): p. 253-272.
[3] Zohar, D. (2002) The effects of leadership dimensions, safety climate, and assigned priorities on minor injuries in work groups. Journal of Organizational Behavior, 2002. 23(1): p. 75-92.
[4] Donovan, S.-L., Salmon, P.M., and Lenné , M.G. (2015) Leading with style: A literature review of the influence of safety leadership style on performance and outcomes. Journal of Safety Research (under review).
[5] Flin, R. and Yule, S. (2004) Leadership for safety. Industrial experience,p. ii45-ii51.
[6] Hofmann, D.A. and Morgeson, F.P. (1999) Safety-related behavior as a social exchange: The role of perceived organizational support and leader-member exchange. Journal of Applied Psychology, 84(2): p. 286-296.
[7] Kelloway, E.K., Mullen, J.E, and Francis, (2006) Divergent effects of transformational and passive leadership on employee safety. Journal of occupational health psychology, 11: p. 76-86.
[8] Michael, J.H., Guo, Z.G., Widenbeck, J.K., and Ray, C.D. (2006) Production supervisor impacts on subordinates' safety outcomes: An investigation of leader-member exchange and safety communication. Journal of Safety Research, 37(5): p. 469-477.
[9] Zohar, D. (2000) Modifying supervisory practices to improve subunit safety: a leadership-based intervention model. Journal of Applied Psychology,87(1): p. 156-163.
[10] Clarke, S. and Ward, K. (2006) The Role of Leader Influence Tactics and Safety Climate in Engaging Employees' Safety Participation. Risk Analysis: An International Journal, 26(5): p. 1175-1185.
[11] Kapp, E.A. (2011) The influence of supervisor leadership practices and perceived group safety climate on employee safety performance. Safety Science, 50(4): p. 1119-1124.
[12] Martínez-Córcoles, M., Gracia, F. J., Tomás, I., Peiró, J. M., and Schöbel, M. (2012). Empowering team leadership and safety performance in nuclear power plants: A multilevel approach. Safety Science, 51(1), 293-301.
[13] Nielsen, M. B., Eid, J., Mearns, K., and Larsson, G. (2013). Authentic leadership and its relationship with risk perception and safety climate. Leadership and Organization Development Journal, 34(4), 308-325.
[14] Zohar, D., and Tenne-Gazit, O. (2008). Transformational Leadership and Group Interaction as Climate Antecedents. Journal of Applied Psychology, 93(4), 744-757.
[15]Carmeli, A. and Schaubroeck, J. (2006). Top management team behavioral integration, decision quality, and organizational decline. The Leadership Quarterly, 17(5), 441-453.
[16] Reid, W. A. (2012). Development of an Instrument to Measure Level 5 Leadership. International Journal of Leadership Studies (IN PRESS).
[17] Leveson, N. (2004) A new accident model for engineering safer systems. Safety Science. 42(4): p. 237-270.
[18] Rasmussen, J. (1997) Risk management in a dynamic society: a modelling problem. Safety Science. 27(2–3): p. 183-213.
[19] Klein, G.A., Calderwood, R. and Macgregor, D. (1989) Critical decision method for eliciting knowledge. Systems, Man and Cybernetics, IEEE Transactions on. 19(3): p. 462-472.
[20] Leveson, N.G. (2011) Applying systems thinking to analyze and learn from events. Safety Science. 49(1): p. 55-64.
[21] Reason, J., Parker, D., and Lawton, R. (1998), Organizational controls and safety: the varieties of rule-related behaviour. Journal of Occupational and Organizational Psychology. 71(4): p. 289.
[22] Svedung, I. and Rasmussen, J. (2002) Graphic representation of accident scenarios: mapping system structure and the causation of accidents. Safety Science. 40(5): p. 397-417.
[23] Cassano-piche, A.L., Vicente, K.J., and Jamieson, G.A. (2009) A test of Rasmussen's risk management framework in the food safety domain: BSE in the UK. Theoretical Issues in Ergonomics Science. 10(4): p. 283-304.
[24] Salmon, P.M., Williamson, A., Lenné, M.G., Mitsopoulos-Rubens, E. and Rudin-Brown, C.M. (2010) Systems- based accident analysis in the led outdoor activity domain: Application and evaluation of a risk management framework. Ergonomics. 53(8): p. 927-939.
[25] Woo, D.M. andVicente, K.J.(2003) Sociotechnical systems, risk management, and public health: comparing the North Battleford and Walkerton outbreaks. Reliab. Eng. Syst. Saf. 80(3): p. 253-269.
[26] Goode, N., Salmon, P., Lenné, M.G. and Hillard, P. (2013) Systems thinking applied to safety during manual handling tasks in the transport and storage industry. Accident Analysis and Prevention.
[27] Salmon, P.M., Cornelissen, M. and Trotter, M. J. (2011) Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. Safety Science, 50. p.1158-1170.
[28] Trotter, M.J., P.M. Salmon, and M.G. Lenné (2014) Impromaps: Applying Rasmussen's Risk Management Framework to Improvisation Incidents. Safety Science. 64: p. 60-70.
[29] Dekker, S., (2011) Drift into failure : from hunting broken components to understanding complex systems. Farnham, England: Farnham, England : Ashgate.
[30] Hollnagel, E. (2012) FRAM, the functional resonance analysis method modelling complex socio-technical systems. functional resonance analysis method, ed. C. Ebooks. Farnham, Surrey ; Burlington, VT: Farnham, Surrey ; Burlington, VT : Ashgate.
[31] Stanton, N.A., Salmon, P.M., Walker, G.H., Baber, C., and Jenkins, D.P. (2005) Human Factors Methods : A Practical Guide for Engineering and Design. 2005, Aldershot, England ; Burlington, VT: Aldershot, England ; Burlington, VT : Ashgate Pub. Co.
[32] Hopkins, A. (2009) Learning from high reliability organisations.Sydney : CCH Australia.