CRANFIELD UNIVERSITY

Charles Cowley

The Paradox of Safety – Challenging the current paradigms of organization and leadership in the prevention of disasters from high hazard technology

School of Management
PhD Part Time – 2012 cohort

PhD
Academic Year: 2019 - 2020

Supervisor: Professor David Denyer
Associate Supervisor: Dr Elmar Kutsch
October 2020

CRANFIELD UNIVERSITY

School of Management
PhD Part Time – 2012 cohort

PhD

Academic Year 2019 - 2020

Charles Cowley

The Paradox of Safety – Challenging the current paradigms of organization and leadership in the prevention of disasters from high hazard technology

Supervisor: Professor David Denyer
Associate Supervisor: Dr Elmar Kutsch
October 2020

ABSTRACT

This qualitative empirical research project has examined the interplay between rule-following and adaptive practice in the safe operation of high hazard technology ('process safety') and especially the influence of leadership on the entanglement of these paradoxically different approaches, at three different operational oil & gas and petrochemical sites in the Middle East, Asia-Pacific and Europe. Interviews were conducted with 73 people directly involved in plant operations at these sites, firstly using Repertory Grid technique (Kelly, 1955) to elicit individuals' understanding of process safety through the lens of the unfolding of incidents. A second study used semi-structured interviews to focus on leadership and organization relating to process safety through the lens of Complexity Leadership Theory and Leadership-As-Practice. In a third study a critical review of accident analysis was conducted including the analysis of 194 documents relating to 117 process safety incidents, which was compared with that from the two interview-based studies, and also performed a pilot QCA (Ragin, 1987) to explore the application of this method to analysing process safety accidents. The repertory grid data showed that respondents regard both adaptive and administrative practices as important; however the interview data and analysis of incident investigation reports reflect a narrower range of factors, indicating an institutionalised predisposition towards administrative practices, which can be at odds with respondents' theory-in-use. There are practical implications for incident investigation processes, which may be overlooking the importance of adaptive practices, for individuals at the sharp end who may be coping with the gulf between what they believe is important and what they bring to the surface, share and document, and for managers who may be constraining the establishment of a climate of psychological safety; all of which may be inhibiting organizational learning that could improve process safety. The research contributes empirical findings that support theories of HRO, System Safety and 'Safety II' and support and extend theories of Leadership-As-Practice and Complexity Leadership Theory, and makes recommendations both for research and for management practice.

Keywords:
Complexity   Entanglement   HRO   Leadership Practice   Organizational Learning
Process Safety   Psychological Safety   QCA   Repertory Grid

ACKNOWLEDGEMENTS

I am very grateful for the support and guidance of my supervisor, Professor David Denyer. Throughout this programme, from its inception in the Research Methods course, the early discussions about the direction the research should take and the development of the project, through the fieldwork planning to the analysis and writing-up, David has been a steady guide and a constant source of inspiration and encouragement: an exemplar of adaptive and enabling leadership.

I am also very grateful to Dr Elmar Kutsch for his enthusiastic support and guidance, especially with the Repertory Grid study, for which his knowledge and experience was invaluable.

My thanks are also due to Professor Kim Turnbull-James, whose wise and gentle challenges and encouragement have given me much confidence.

I also extend my thanks and appreciation to all the various staff members and fellow students at the School of Management who have given me support and encouragement over the years, who are too many to mention all by name, but especially include Irena Pidlyskyj, Debbie Bramwell, Miles Hayman and Neha Tewari.

I also acknowledge with grateful thanks the support of my sponsor, the Energy Institute, in particular Stuart King, Rob Miles and Dr Robin Bryden, for their guidance and practical help in gaining access to carry out the fieldwork as well as for their financial support.

My appreciation, thanks and respect are also due to all the people who were interviewed and who otherwise helped provide the field data for this research, for their time and effort and for their frank expression of their views and ideas.

Finally, I want to express my deep gratitude for the loving and patient support of my wife, Fiona, my partner in everything, without whom I could not have completed this long journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

AI	Actual Incident
ALARP	As Low As Reasonably Practicable
ANV	Average Normalised Variability
BSCAT	Barrier-based Systematic Cause Analysis Technique
CCPS	Center for Chemical Process Safety
CIMO-Logic	Context – Intervention – Mechanism – Outcome Logic
CLT	Complexity Leadership Theory
COMAH	Control of Major Accident Hazards (UK Regulations)
COMPASSS	COMPArative Methods for Systematic cross-caSe analySis
CRM	Crew Resource Management
CSB	Chemical Safety Board
eMARS	(online) Major Accident Reporting System
ERT	Emergency Response Team
FMEA	Failure Modes and Effects Analysis
FRAM	Functional Resonance Analysis Method
H2S	Hydrogen Sulphide
HFACS	Human Factors Analysis and Classification System
HRO	High Reliability Organizing / Organization
HSE	Health and Safety Executive
HV	High Voltage
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
ILO	International Labour Organization
INUS	Insufficient but Non-redundant parts of a condition which is itself Unnecessary but Sufficient for an occurrence
IOGP	International Association of Oil & Gas Producers
IPIECA	International Petroleum Industry Environmental Conservation Association
ISO	International Standards Organization
JHA	Job Hazards Analysis
JRC	Joint Research Centre (European Commission)
JSA	Job Safety Analysis

LMX	Leader-Member Exchange
NAT	Normal Accident Theory
NM	Near Miss
NV	Normalised Variability
OECD	Organisation for Economic Cooperation and Development
OSHA	Occupational Safety and Health Administration
P&ID	Piping & Instrumentation Diagram
PI	Potential Incident
PPE	Personal Protection Equipment
PSV	Pressure Safety Valve
PTW	Permit to Work
QA/QC	Quality Assurance / Quality Control
QCA	Qualitative Comparative Analysis
csQCA	crisp set Qualitative Comparative Analysis
fsQCA	fuzzy set Qualitative Comparative Analysis
mvQCA	multi value Qualitative Comparative Analysis
QRA	Quantified Risk Assessment
SD	Shut Down
SMS	Safety Management System
STAMP	Systems-Theoretic Accident Model and Processes
TEG	Triethylene Glycol
TEM	Threat and Error Management
TSS	Total Sum of Squares
UF	Unique Frequency
VUCA	Volatility, Uncertainty, Complexity and Ambiguity

1 INTRODUCTION

1.1 Background to the research

The purpose of the research is to understand how adaptive as well as administrative working practices, sensemaking and expert improvisation as well as operational discipline and rule-following, can interact effectively to prevent major accidents arising from the use of high-hazard technology. How and under what circumstances can this paradox be reconciled?

The problem of interest that led to this research is the continued occurrence of major process safety incidents in the oil & gas and chemical industries, with the many repeat incidents indicating widespread ineffective organizational learning. Alongside this is the persistence in these industries of the traditional 'command and control, hierarchy and rule-following' paradigm of process safety, despite the growing body of academic literature emphasising the importance of adaptive processes with more flexible leadership and organizing practices for the safety of high hazard technology. These ideas challenge assumptions about the asymmetric power inherent in the traditional paradigm, suggesting that it may be inhibiting organizational learning.

Allowing flexibility and improvisation while also demanding compliance with rules and procedures can appear impossible; the two approaches seem to be mutually exclusive. Such tensions are often seen as a dualism, an 'either/or' choice, often informed by contingency 'if-then' theories (Jansen, Vera and Crossan, 2009; Mintzberg, 1980). But it is also possible to view these different approaches as an interdependent and mutually enabling duality (Farjoun, 2010) where compliance is the norm and procedures are adapted whenever necessary. In this view the paradox seems no longer to represent an organizational challenge. However many writers do see such paradoxes as enduring tensions, and how and under what conditions such tensions can operate as a duality to overcome the inherent paradox is not well understood (Jules and Good, 2014; Lewis and Smith, 2014; O'Reilly and Tushman, 2013; Turner, Swart and Maylor, 2013).

The need for adaptive as well as administrative processes and practices for high organizational performance is widely accepted (Gibson and Birkinshaw, 2004; O'Reilly and Tushman, 2008; Smith and Lewis, 2011) and the difficulty of meeting this need is emphasised in the literature of both ambidexterity (Birkinshaw and Gupta, 2013) and paradox (Smith and Lewis, 2011). There have been few studies of this in the field of high hazard technology safety though, and research in the wider field of avoiding and mitigating disasters remains fragmented (Buchanan and Denyer, 2013; Hallgren, Rouleau and de Rond, 2018).

Many forms of technology have inherent hazards with the potential for major accidents involving multiple fatalities, environmental disasters and big financial losses. Around the world, with terrible regularity, aircraft crash, ships sink, bridges collapse and chemical plants explode. In the process industries such as oil & gas and chemicals, the prevention of such major accidents is known as 'process safety' to distinguish it from 'personal safety' concerned with 'slips, trips and falls' and so on. In other industries the safety of their specific high-hazard technology is referred to as 'flight safety', 'maritime safety', 'nuclear safety' etc.

The safety of high hazard technology is of particular interest because of the intrinsic risk that using such technology presents of accidents with serious consequences, typified by multiple fatalities, major environmental impacts and big financial losses. Within the process industries, oil & gas and chemicals represent globally a very large sector with particularly high hazards and a continuing safety record that compares badly with other high hazard technology industries such as commercial aviation and rail transport.

Recent industrial disasters such as the explosions at the BP Texas City refinery and on the Macondo drilling rig are especially troubling since it is well-established that these and many others were 'repeat incidents', with numerous similarities to others that had occurred previously, sometimes within the same organizations (Hailwood, 2016; Hopkins, 2010; Kletz, 1993; Visscher, 2008). The difficulty of achieving real organizational learning indicated by such repeat incidents underlines the importance, and apparent current inadequacy, of adaptive processes within many organizations that employ high hazard technology.

Traditionally, the literature relating to the safety of high-hazard technology has typically emphasised administrative, rule-based practices (CCPS, 2011; Gowland, 2006; HSE, 2001; Khan and Abbasi, 1999) hierarchical organizational forms and leadership as 'command and control' (Grint, 2010, p19; Tyler and Blader, 2005, p1143). Increasingly though, writers suggest that safety results not only from the traditional reliance on engineering and rule-following but also from adaptive processes such as sensemaking (Weick, Sutcliffe and

Obstfeld, 2005) mindfulness (Weick and Sutcliffe, 2006) and expert improvisation (Hale and Borys, 2013; Hollnagel, 2014; Leveson, 2011; Rego and Garau, 2007).

This alternative paradigm suggests that what goes on in organizations that employ high-hazard technology safely and reliably is significantly more complex (Snowden and Boone, 2007) than that indicated by the implicit assumptions of the traditional paradigms. In this analysis, emergent adaptive processes are at work throughout the organization, including the operational 'sharp end', continually identifying and overcoming system weaknesses before they can lead to disaster (Frese and Keith, 2015; Hollnagel, 2014) and that this adaptation occurs as a result of more flexible organizing and leadership practices (Uhl-Bien and Arena, 2018). These ideas are well documented in High Reliability Organizing ('HRO') research (La Porte, 1996; Roberts, 1990; Weick, Sutcliffe and Obstfeld, 1999, 2005) and in theories of 'System Safety' (Leveson, 2011) and 'Safety II' (Hollnagel, 2014).

Despite this growing research consensus, industry practice and guidance has largely remained aligned with the traditional administrative paradigm based on engineering and procedures formalised in safety management systems (European Union, 2012; HSE, 2013; ILO, 1991, 2001; ISO, 2018; Li and Guldenmund, 2018; OSHA, n.d.) with command and control leadership focused on the characteristics and behaviours of leaders, particularly senior leaders, exercising formal authority and control of compliance within hierarchies (CCPS, 2011; HSE, 2007, 2013).

The paradox of safety is perhaps seen most clearly in the issue of improvisation, which is understood to be a very real and normal part of how people work and has been described as 'work as done' vs 'work as imagined' (Hollnagel, 2014, p40). But improvisation has also been challenged as potentially increasing risk if done by people without an accurate and complete mental model of the system in which they are working (Leveson et al., 2009). Thus on the one hand, individual local 'expert improvisations', even though they may be effective, may not be captured and reviewed for adequacy in the light of overall system aspects, and useful learning extracted; this weakness has been pointed out by Amalberti and Vincent (2019). And on the other hand, simple compliance with established rules carries the risk of following an accepted procedure that may omit some unanticipated but important local situational condition and so actually increase risk. Reason, Parker and Lawton (1998, p295) refer to this as 'mispliance'.

The important influence of leadership on resolving the adaptive/administrative paradox is well established (Lewis, Andriopoulos and Smith, 2014; Smith and Lewis, 2012; Swart et al., 2016; Yukl, 2008). However, the traditional 'administrative' leadership paradigm of 'command and control' appears inadequate to explain how such paradoxes can be successfully managed, since it assumes that engineering and operational discipline are the necessary and sufficient factors enabling proper risk management, and so does not acknowledge this paradox. Theories of ambidexterity and paradox point to other views of leadership that appear more promising. A mechanism of 'contextual ambidexterity' is suggested (Gibson and Birkinshaw, 2004, p209) that relies on an organizational context of support and trust, created by leaders (Ghoshal and Bartlett, 1994). This seems comparable to the 'holding environment' proposed by Heifetz and Laurie (1997, p134) as required for adaptation to take place and being the work of leaders to create such enabling environments. The importance of leadership skills such as communication and complex cognition is also emphasised for coping with paradox (Smith and Besharov, 2019; Smith and Lewis, 2012).

Further, a growing body of researchers depart from the traditional leader-centric model, instead seeing leadership as a phenomenon that takes form between collaborating actors in support of a common endeavour (Drath et al., 2008). In this view, leadership is seen as 'processual' (Avolio and Gardner, 2005, p333) 'relational, communicative' (Fairhurst and Uhl-Bien, 2012; Tourish, 2014) and 'adaptive' (DeRue, 2011; Heifetz, Grashow and Linsky, 2009). These ideas have evolved into a theory of 'Leadership-As-Practice' (Raelin, 2016) that sees leadership emerging as individuals interact, from practices that include dialogue, signalling, co-creation and reflection, salient as behavioural, cognitive or emotional effects within the specific context formed of the work, the organizational environment and the characteristics of the individual people involved (Denyer and Turnbull James, 2016; Fischer, Dietz and Antonakis, 2017; Osborn and Marion, 2009).

Alongside these developments in leadership theory, traditional hierarchical, directive forms of organizing have been challenged by the idea that organizations can be thought of using 'complex adaptive systems' (Holland, 2006, p1) as a useful metaphor (Lichtenstein, 2000; Osborn and Hunt, 2007; Rosenhead et al., 2019; Schneider and Somers, 2006; Tsoukas and Dooley, 2011). Complex adaptive systems are characterised as self-organizing, able to change and learn from experience, with emergent properties such that the whole is greater than the sum of the parts.

The complex systems metaphor and the 'practice' model of leadership have been integrated into a 'Complexity Leadership Theory' (Uhl-Bien, Marion and McKelvey, 2007) suggesting that administrative and adaptive processes can be effectively entangled by combinations of leadership practices: directive and managerial 'administrative' practices, 'adaptive' practices, encouraging innovation and learning, and a third kind, 'enabling' practices, supporting networks, sensemaking and using constructive tension to help the other two operate together.

Complexity Leadership Theory and Leadership-As-Practice, though both nascent theories, offer a more flexible view of leadership that may offer the possibility of more explanatory power for how the adaptive/administrative paradox may be reconciled, the interest of this research. However so far there has been little empirical research to support these theories, and both have received some challenges: Tourish (2019) has pointed out that that Complexity Leadership Theory as currently described remains leader-centric and does not explain how leadership emerges, and that it therefore does not fully embrace organizations as complex adaptive systems; Collinson (2018) has criticised Leadership-As-Practice as lacking critical engagement and neglecting power relations and structural influences. These are interesting challenges that this research has explored.

Thus a clear research gap can be seen, that both Complexity Leadership Theory and Leadership-As-Practice have little empirical evidence to support them and they both have been challenged as described above.

This gap is addressed in a qualitative empirical study of three operational oil & gas and petrochemical sites, in the Middle East, Asia-Pacific and Europe, examining the role of leadership in managing the entanglement of rule-based, administrative practices and mindfulness-based, adaptive practices (Murphy et al., 2017; Uhl-Bien, Marion and McKelvey, 2007) in avoiding, trapping and mitigating incidents.

It will be seen that the study does find evidence that supports both Complexity Leadership Theory and Leadership-As-Practice, and that also at least partially answers the challenges. Further, although leadership is found important in reconciling the paradox so that adaptive processes of organizational learning operate effectively alongside traditional administrative practices, the study also finds contextual organizational factors very influential.

The choice of the oil & gas and petrochemical industry for this study was based on four criteria. Firstly, good access was made available because of the researcher's experience in that industry, which enabled some choice of fieldwork sites. Although there is much standardisation of technology and management systems, since they were all operated by the same multinational company, the three sites were quite different in both organizational maturity and safety outcomes; recently, the two least mature sites had suffered, respectively, fatalities and high-potential near-misses, while the other, the most mature, had recently been recognised with a major award for its process safety performance. Secondly, the prevalent leadership approach in these industries is traditional leader-centric 'command and control' with highly procedural administrative processes, though different approaches are also seen. Thirdly, it is argued that researching leadership practices in such high hazard situations 'may provide particularly rich insights into organizational processes of adaptation and prioritization, resilience…' (Hallgren, Rouleau and de Rond, 2018, p112).

Fourthly, and perhaps most importantly, there is an urgent societal imperative for change in this industry. The industry has recently suffered a number of catastrophic accidents, notably the explosion at the BP Texas City Refinery in 2005, the Macondo oil well blow-out in 2010 and the huge double explosion at the Port of Tianjin in 2015 that killed 173 people. And numerous other serious accidents have continued to occur. In Europe, the eMARS database contains records of 283 'major chemical accidents' that occurred in European Union countries over the period 2010 to 2018, an average of 31 per year (European Commission JRC Major Accident Hazard Bureau, 2020). Over the same period in the US, the Chemical Safety Board, which investigates the most serious accidents, investigated 41 accidents that together resulted in 88 deaths (CSB, 2020).

As stated earlier, it is well-established that many of these were 'repeat incidents', with many similarities to others that had occurred previously, often within the same organization (Hailwood, 2016; Hopkins, 2010; Kletz, 1993; Visscher, 2008). The 'failure to learn' (Hopkins, 2010, p8) is striking. The desire for better understanding of how the adaptive processes of organizational learning may be made more effective in this industry is an important motivator of this research.

It is of great concern that as industrialisation has continued worldwide, very serious process safety accidents with catastrophic consequences have become more frequent. For example, China has suffered, as well as the infamous 2015 Tianjin explosion, a series of catastrophic accidents that includes the 2013 Qingdao pipeline explosion that killed 62 people, the 2014 Kunshan dust explosion that killed 146 people, and the explosion at a pesticide factory in Xiangshui in 2019 that killed 78 people. Alongside these acute, tragic human consequences must be placed the cumulative consequences for the global environment, especially emissions of greenhouse gases, for example methane from the frequent gas well blowouts.

Commentators on industrial disasters have repeatedly criticised leaders for tolerating or even creating the organizational conditions that led to those disasters (Flin, 2003; Hackitt, 2012; Hopkins, 2006a; Moure-Eraso, 2015; Reason, 1997). Analysis of major accidents routinely shows up system weaknesses that could have been identified and corrected but were not, and it is proposed that this failure of organizational learning can be attributed at least partly to inflexible organization and a controlling leadership that was taking inadequate account of the operational context and failing to reconcile important paradoxes of control vs adaptation. Especially in the light of the numerous recent disastrous major industrial incidents, achieving an effective balance between administrative and adaptive practices is therefore a major paradox of strategic importance for industries that employ high-hazard technology.

The traditional 'administrative processes' understanding of process safety is the model commonly used for analysis of accidents, seeking 'root causes' often as some form of human error with causation typically understood as 'linear cause and effect' (CCPS, 2019; Hopkins, 2006b; OSHA, 2016). The use of this simplistic approach to incident investigation and analysis may also be inhibiting the potential for effective organizational learning.

Viewing the socio-technical systems in which high hazard technology is operated as complex rather than complicated challenges the 'linear cause and effect' model, provoking more complex analyses of causation involving the influence of adaptive processes and configurations or conjunctions of multiple factors (Fiss, 2011; Ragin, 1987).

In summary, the purpose of this research project has been to improve understanding of how adaptive as well as administrative practices can interact effectively to improve the safety of high-hazard technology. By means of a multiple case study in the oil & gas and chemical industry, it has explored the influence of leadership and other factors on the successful combination these paradoxically different approaches in generating and embedding organizational learning in the service of avoiding major accidents.

1.2 Positioning and Structure of the Research Project and Thesis

Despite widespread acknowledgement that both administrative and adaptive practices are important to process safety and that they may be integrated, there are significant theoretical and practical problems:

First, much of the existing literature has been conceptual or positivist in approach. Few existing studies pay attention to how actors perceive administrative and adaptive practices. Positivist research typically regards administrative and adaptive practices as something more or less determined and given, which can be conceptually represented by a set of variables causally related to each other. Abbott (2001) has been particularly strident in his criticism of what he calls the variables paradigm and its acontextual treatment of human conduct: 'our normal methods parse social reality into fixed entities with variable qualities. They attribute causality to the variables rather than to actors. Variables do things, not social actors. Stories disappear. The only narrative present in such methods are the just-so stories justifying this or that relation between the variables' (Abbott, 2001, p183). Instead, it is argued that interpretative (Burrell and Morgan, 1979) and qualitative (Johnson et al., 2006) studies are required to explore the underlying meanings behind people's administrative and adaptive practices, and how various meanings interact and lead both to actions and to expected and unanticipated outcomes. The importance of this from an interpretative paradigm (Burrell and Morgan, 1979) is made clear by Sandberg and Alvesson, 2020, p12) who emphasise that meaning is 'constitutive of organizational phenomena'. That is, without understanding the meaning of administrative and adaptive practices, people cannot consciously adopt them (for example in the service of managing risk) nor can they be easily observed and recognized.

Secondly, some scholars have argued that administrative and adaptive practices are two apparently competing approaches to coping with the risks of high hazard activities, but that they can occur concurrently (Goodman et al., 2011; Hofmann and Frese, 2011; Lei, Naveh and Novikov, 2016) and indeed that their integration and balance is necessary for desirable organizational outcomes (Vogus and Sutcliffe, 2007). In their analysis of the Air France 447 disaster, Oliver, Calvard and Potočnik (2017, p740) propose that organizations adopt 'strategies that allow controls to be designed into systems while also developing and maintaining the disturbance-handling capabilities of those who operate them'.

The work on High Reliability Organizations and System Safety highlights the need for the ability to integrate, balance and shift between administrative and adaptative processes (Weick and Sutcliffe, 2006). However, as noted above, the specific ways to achieve such an integration and balance in real organizational settings remains under-explored (Goodman et al., 2011).

Third, administrative and adaptive practices and their possible integration is shaped by context. Existing theory does not fully explain why in some contexts administrative practices dominate while in others adaptive practices flourish. Further work is required to develop an understanding of how either administrative or adaptive practices are favoured by particular contexts. Activity is embedded in a constellation of multiple interconnected contextual elements; pre-existing individual, relational, organizational and institutional conditions can enable as well as constrain the actions of individuals and groups (Giddens, 1984). Context plays a constitutive or generative role (Drath et al., 2008; Uhl-Bien and Marion, 2008) and 'literally bends around the enactments of people' (Weick, 1979, p130). When people act, they 'bring events and structures into existence and set them in motion. People who act in organizations often produce structures, constraints, and opportunities that were not there before they took action' (Weick, 1988, p306).

To address these literature deficiencies, a qualitative case study approach was taken, using Repertory Grid Technique (Kelly, 1955) supplemented with semi structured interviews and an analysis of documents. The research project was carried out by conducting a systematic literature review followed by the three related empirical studies.

The project is described in four separate papers, each included in this thesis as a separate chapter, and briefly summarised below. The overall structure of the research and the thesis is portrayed in **Figure 1-1**.

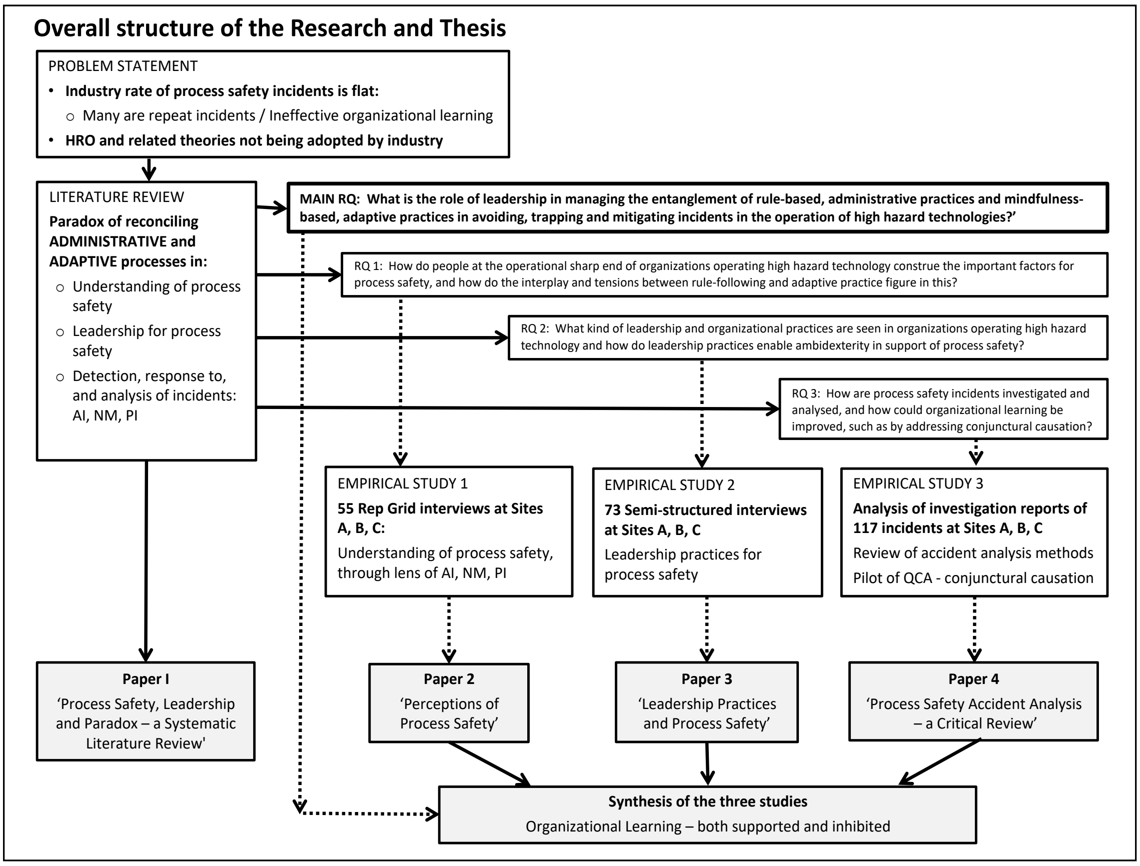

Figure 1-1 Overall structure of the research and thesis

Paper 1 – Process Safety, Leadership and Paradox - A Systematic Literature Review (Thesis Chapter 2)

Starting from a problem statement, a scoping study identified three main fields of relevant research and existing knowledge: theories of high hazard technology safety, theories of leadership and theories of paradox and ambidexterity. These three fields were then reviewed systematically and discussed, resulting in the main research question and three supporting questions that shaped the empirical studies.

The problem of interest that led to this research is the continued occurrence of process safety incidents, with many repeat incidents, indicating a general ineffectiveness of organizational learning, together with the persistence in industrial practice of the traditional 'rule-following' paradigm of process safety, despite the growing academic consensus that adaptive processes and practices are also necessary for the safety of high hazard technology.

The primary research question that emerged from the systematic literature review was:

- 'What is the role of leadership in managing the entanglement of rule-based, administrative practices and mindfulness-based, adaptive practices in avoiding, trapping and mitigating incidents in the operation of high hazard technologies?'

In support of this primary research question, three other questions were formulated, focussing on key component issues:

First: 'How do people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how do the interplay and tensions between rule-following and adaptive practice figure in this?' This is addressed in the second paper, which is **Chapter 4** of the thesis.

Second: 'What kind of leadership and organizational practices are seen in organizations operating high hazard technology and how do leadership practices enable ambidexterity in support of process safety?' This is addressed in Paper 3, which is **Chapter 5**.

Third: 'How are process safety incidents investigated and analysed, and how could organizational learning be improved, such as by addressing conjunctural causation?' This is addressed in the fourth and final paper which is **Chapter 6** of the thesis.

Thesis Chapter 3 - Research Philosophy and Design

To address these questions three studies were designed, seeking explanation of how the two paradoxically different approaches are perceived and employed in practice, including evidence to support the alternative theories of leadership and incident causation. Each study was designed with different methods of data collection: firstly interviews employing Repertory Grid Technique (Kelly, 1955) focusing on different types of incident, secondly semi-structured interviews focusing on leadership practices, and thirdly collection of investigation reports and other documents relating to incidents. With a critical realist perspective, the aim was to explore the domains of 'empirical', 'actual', and 'real' (Bhaskar, 2008, p2). Integrating the empirical results and conclusions from the two kinds of interview with the reported actual descriptions obtained from incident investigation reports and related documents, was designed to enable a 'triangulation' that provided a more complete description of the mechanisms that may operate in the 'real' domain. This approach is well-suited both to appraising the widely differing theories and also to interpreting the qualitative interview data in the light of the theoretical challenges (Kempster and Parry, 2011) and was therefore adopted as the ontological and epistemological framework for the research.

The research philosophy and design are portrayed in **Figure 1-2**

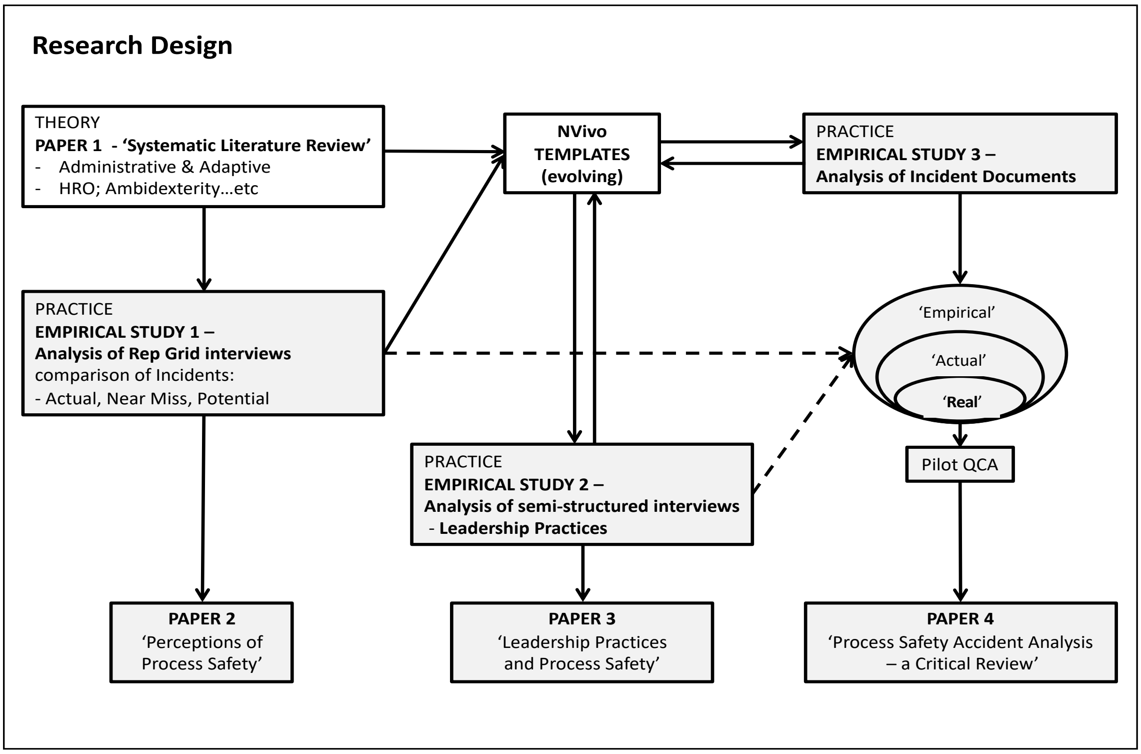

Figure 1-2 Research philosophy and design

It was assumed that an actor's perceptions of events will vary depending on their role, organizational level and between permanent staff and contractors. It was also assumed that perceptions of 'work as imagined' and 'work as done' (Hollnagel, 2014, p40) may vary, that is there may be a gap between what people think is happening and what actually happens. Therefore, the research was designed to explore qualitatively the actors' perceptions as well as the contextual conditions surrounding actual events.

Data was sought that would allow comparison between sites operating high hazard technology that had different safety outcomes and between the way that different types of incident unfolded. The rationale was that the identification of and response to 'Potential Incidents' and 'Near Misses' may indicate higher levels of effectiveness of an organization's management of safety, compared with the occurrence of 'Actual Incidents', and that sites with different safety outcomes may have different contextual conditions, working practices and leadership practices. These terms describing different process safety incident are explained using the bow tie hazard management model (ICI, 1979) following the logic widely used in high hazard operations (HSE, 2004; OSHA, 2015; Reason, 1997). This is shown in **Figure 1-3.**

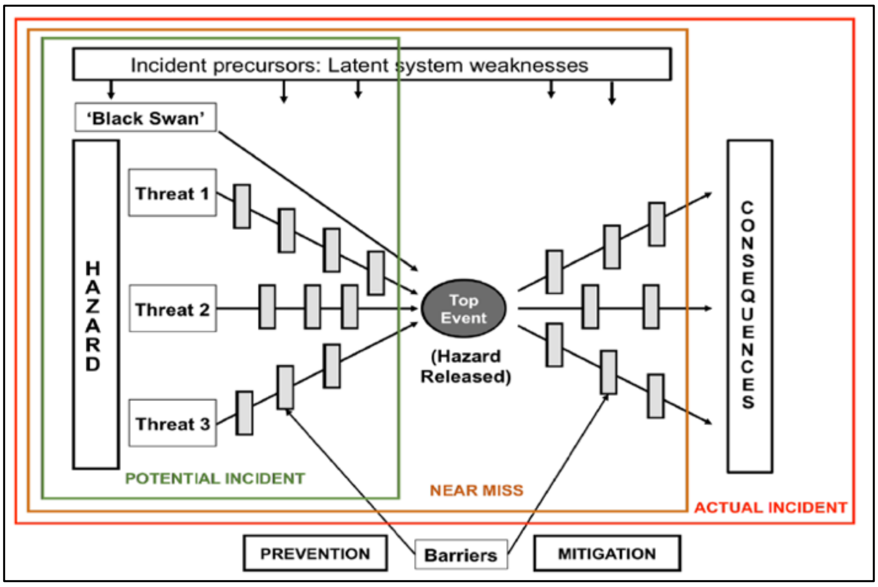

Figure 1-3 Bow Tie hazard management diagram with incident types

The left-hand side of a bow tie diagram shows the mechanisms by which a particular hazard could be released, shown as 'threat lines', along which are placed 'barriers' (defences) designed to prevent the threats from releasing the hazard. The middle of the diagram shows the release of the hazard, referred to conventionally as the 'top event', which would occur if all the prevention barriers on a threat line were to prove simultaneously ineffective. On the right-hand side of the diagram, the known possible pathways that could lead to consequences of such a hazard release are shown. Along these pathways, 'mitigation' barriers are shown that are designed to reduce potential consequences.

An 'Actual Incident', shown within the outer (red) box, is the occurrence of a 'top event' that then results in significant consequences; evidently in such a case, all of the prevention and mitigation barriers along at least one pathway proved ineffective. A 'Near Miss', shown within the middle (orange) box, is the occurrence of a 'top event' that could have resulted in significant consequences but in fact did not; even so, all of the prevention barriers on at least one threat line evidently proved ineffective. By contrast, a 'Potential Incident', shown within the inner (green) box, is the detection of a system weakness before it could incubate into a release of the hazard. Such a system weakness could be a latent 'resident pathogen' (Reason, 1990a, p32) such as an ambiguous procedure, loss of currency in a technical skill, a maintenance backlog or an unclear critical communication. In the traditionally accepted analysis, such factors can lead to degradation of barriers. In the 'Safety II' view, they can also lead to degradation of mindfulness and expert improvisation that may normally be operating to maintain safety despite imperfect equipment or system design (Hollnagel, 2014).

A Near Miss could result from the effective operation of a designed mitigation barrier or from a successful improvised intervention such as an operator opening a valve to release an unexpected build-up of pressure, or just by luck, such as a gas cloud dispersing before reaching a source of ignition. A Potential Incident could also result from luck, such as a chance observation, but more likely from an effective control room alarm or a routine inspection designed to detect such weaknesses, or from the vigilance of a human operator, technician or engineer discovering some anomaly.

These definitions of Actual Incident, Near Miss and Potential Incident are used throughout this research project. It will be argued later that the identification of and response to Potential Incidents is an indicator of an organization's effective management of safety, compared with the occurrence of Actual Incidents. The identification of and response to Near Misses, if the response involves effective mitigation, may also indicate safety, but to a lesser extent than Potential Incidents since by definition a Near Miss involves the release of a hazard, implying that all the prevention barriers proved ineffective.

Paper 2 - Perceptions of Process Safety (Thesis Chapter 4)

55 interviews using Repertory Grid Technique (Kelly, 1955) were conducted to examine how people at the sharp-end of organizations operating high hazard technology understand the important factors in process safety, including how they experience tensions between rule-following and adaptive practice, by comparing how they construe the identification of and response to the three different kinds of events relating to process safety: Actual Incidents Near Misses and Potential Incidents.

Paper 3 – Leadership Practices and Process Safety (Thesis Chapter 5)

73 semi-structured interviews drawing on Complexity Leadership Theory (Uhl-Bien, Marion and McKelvey, 2007) and 'Leadership-As-Practice' (Raelin, 2016b) were conducted to examine the leadership practices experienced by people at the sharp-end of organizations operating high hazard technology and how these practices may enable the entanglement of administrative and adaptive processes in the context of process safety.

Paper 4 – Process Safety Incident Analysis – a Critical Review (Thesis Chapter 6)

Current approaches to incident investigation and analysis were reviewed, including a review of theories organizational learning and of causation. Investigation reports and other documents relating to 117 incidents of three different types (actual incidents, near misses and potential incidents) were analysed. This analysis included a pilot demonstration of Qualitative Comparative Analysis (QCA) (Ragin, 1987) to explore the application of this method to improving organizational learning from an understanding of accident causation as the conjunction of multiple factors.

2 PROCESS SAFETY, LEADERSHIP AND PARADOX – A SYSTEMATIC LITERATURE REVIEW

2.1 Introduction and Scoping

The problem of interest that led to this research is the continued occurrence of process safety incidents in the oil & gas and chemical industry, with many repeat incidents indicating widespread ineffective organizational learning. Allied to this is the persistence in these industries of the traditional 'command and control, hierarchy and rule-following' paradigm of process safety, despite the growing body of academic literature that emphasises the importance of adaptive processes and more flexible leadership and organizing practices for the safety of high hazard technology. This latter paradigm challenges assumptions about the asymmetric power inherent in the traditional paradigms, suggesting that it may be inhibiting organizational learning.

Many forms of technology have inherent hazards with the potential for major accidents involving multiple fatalities, environmental disasters and big financial losses. Around the world, with terrible regularity, aircraft crash, ships sink, bridges collapse and chemical plants explode. In the process industries such as oil & gas and chemicals, the prevention of such major accidents is known as 'process safety' to distinguish it from 'personal safety' concerned with 'slips, trips and falls' and so on. In other industries the safety of their specific high-hazard technology is referred to as 'flight safety', 'maritime safety', 'nuclear safety' etc.

The safety of high hazard technology is of particular interest because of the intrinsic risk that using such technology presents of accidents with serious consequences, typified by multiple fatalities, major environmental impacts and big financial losses. Within the process industries, oil & gas and chemicals represent globally a very large sector with particularly high hazards and a continuing safety record that compares badly with other high hazard technology industries such as commercial aviation and rail transport.

Recent industrial disasters such as the explosions at the BP Texas City refinery and on the Macondo drilling rig are especially troubling since it is well-established that these and many others were 'repeat incidents', with numerous similarities to others that had occurred previously, sometimes within the same organizations (Hailwood, 2016; Hopkins, 2010; Kletz, 1993; Visscher, 2008). The difficulty of achieving real organizational learning indicated by such repeat incidents underlines the importance, and apparent current inadequacy, of adaptive processes within many organizations that employ high hazard technology.

The search for relevant literature began with the writing on High Reliability Organizing (HRO) and major accidents in a range of industries including aviation and nuclear as well as the process industries, since the issues underlying the safety of all these activities involving the use of high hazard technologies appeared to be similar or at least related. This idea had emerged from early reading of a number of well-established books, notably *Normal Accidents* (Perrow, 1984); *Human Error* (Reason, 1990b); *Managing the Risks of Organizational Accidents* (Reason, 1997); *Managing the Unexpected* (Weick and Sutcliffe, 2015) and *Safety, Culture and Risk* (Hopkins, 2005).

In order to obtain a broad overview of the landscape of thinking about safety, this early reading had continued with other books by established researchers in the field of safety, including: *The Human Contribution* (Reason, 2008)*; The Southwest Airlines Way* (Gittell, 2003)*; The Lessons of Longford* (Hopkins, 2000); *Failure to Learn* (Hopkins, 2010); *Learning from HROs* (Hopkins, 2009); *Disastrous Decisions* (Hopkins, 2012)*; The Challenger Launch Decision* (Vaughan, 1997a)*; Safety at the Sharp End* (Flin, O'Connor and Crichton, 2008)*; Resilience Engineering* (Hollnagel, Woods and Leveson, 2006)*; Safety I and Safety II* (Hollnagel, 2014); *Just Culture* (Dekker, 2007)*; Crew Resource Management* (Kanki, Helmreich and Anca, 2010)*; Designing for Situation Awareness* (Endsley and Jones, 2012); *Understanding and Exploring Safety Culture* (Guldenmund, 2010).

The scoping study started by reviewing academic literature referenced in these books. This revealed a wide spread of intersecting bodies of research relevant to the broader field of the safety of high hazard technology: 'Normal Accident Theory' (Perrow); 'Safety Management Systems' (HSE, ISO, Guldenmund); The '5 characteristics' HRO model (Weick & Sutcliffe); Berkeley HRO research (Roberts, La Porte, Rochlin;) 'System Safety' (Leveson); 'Resilience Engineering' (Woods, Hollnagel); 'Safety Culture' (Reason, Parker, Hudson, Flin, Guldenmund); 'Mindful Leadership' (Hopkins); 'Crew Resource Management' (Helmreich); 'Human Factors' (Flin, Reason) and 'Situation Awareness' (Endsley).

These groups of theories are portrayed in **Figure 2-1**.

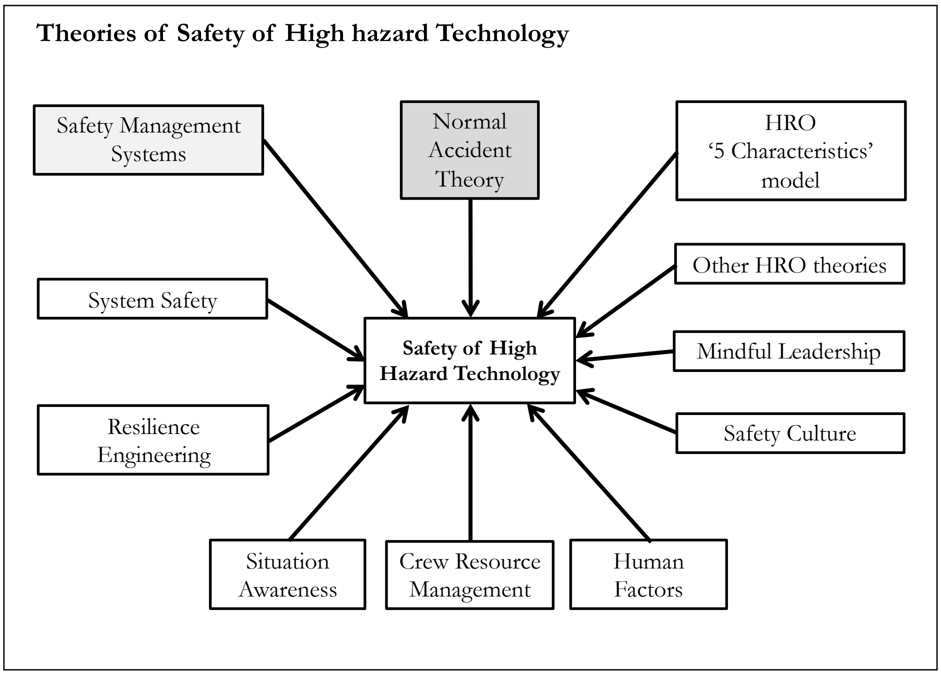

Figure 2-1 Theories of Safety of High Hazard Technology

The research interest being the influence of organization and leadership on high hazard safety, the scoping study then explored how these domains of literature intersect. The result is shown in **Fig 2-2**. The scoping continued by reviewing organization theory and leadership by familiarising with introductory texts on these topics, to seek fields within these domains that would be potentially relevant to the research area.

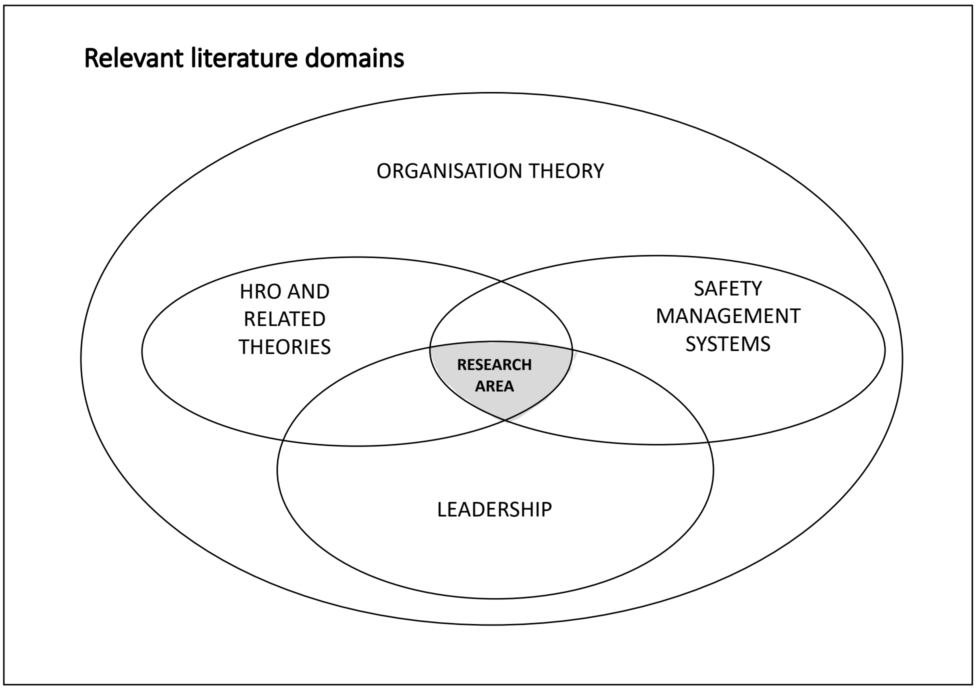

Figure 2-2 Literature Domains of Interest

Key concepts and a broad overview of the landscape of organizational theory were gained from the following textbooks: *Organizational Behaviour* (Buchanan and Huczynski, 2010); *Organization Theory* (Hatch and Cunliffe, 2006); *Understanding Organizations* (Handy, 1999); *Sociology of Organizations* (Godwyn and Gittell, 2012); *Social Psychology: A Very Short Introduction* (Crisp, 2015); *The Social Psychology of Organizing* (Weick, 1979); and *Making Sense of the Organization* (Weick, 2009).

This reading, together with reviewing academic literature referenced in these books, identified the fields of organizational ambidexterity and of paradox as particularly relevant to the research interest.

The identification of key concepts continued with the broad domain of leadership, again starting with some textbooks: *Leadership: All You Need To Know* (Pendleton and Furnham, 2011); *Leadership: A Very Short Introduction* (Grint, 2010); *A Very Short, Fairly Interesting and Reasonably Cheap Book About Studying Leadership* (Jackson and Parry, 2011); *Organizational Culture and Leadership* (Schein, 2004); and *Rethinking Leadership* (Ladkin, 2010).

This reading likewise led to identifying academic literature referenced in these books, and by an iterative process of reading, searching, discussion and reflection, the scoping study resulted in the following questions to guide the systematic literature review:

a) What are the important principles and components that make up the two main Organizational Reliability and Safety paradigms – How can they be dimensionalised?

b) How do the two paradigms conflict and how do they complement each other? Do they represent a duality or dualism?

c) How do aspects of each paradigm fit in different organizational contexts?

d) What is the role of leadership in application of both paradigms?

2.2 Method

The scoping having thus identified three main fields of interest: Theories of safety of high hazard technology, leadership and organizational paradox/ambidexterity, the systematic literature review was conducted in these areas, following established guidance (Hart, 1998) and a process based on the method of Tranfield, Denyer and Smart (2003).

Key words were chosen relating to the main fields of interest and used as search terms in a number of databases: ABI-ProQuest, EBSCO Host Business Source Complete, SCOPUS, Science Direct and Psych Info.

The following initial search strings were used:

- **String 1** – ("high reliability organi?*" OR "high reliability" OR HRO OR "safety culture" OR "situation awareness" OR "crew resource management" OR "system safety" OR "resilience Engineering" OR "normal accident theory")
- **String 2** – (leaders* OR "leadership styles" OR "distributed leaders*" OR "shared leadership" OR "adaptive leadership" OR "emerg* leadership" OR "contextual leadership" OR "follow* leadership" OR "empower* leadership" OR "sense?making leadership" OR "mindful leadership")
- **String 3** – ("system safety" OR "analytical risk management" OR "system design" OR "decision making process*" OR "safety management" OR TQM OR "total quality management" OR "organi?ational discipline")

Results from these and related searches led to more refined searches. In the fields of Leadership and Paradox, refinement included restricting search to 3- and 4-star journals and more focus on specific subjects, as knowledge of the fields developed.

As key authors were identified (such as Weick, Leveson, Hollnagel in safety, Uhl-Bien, Avolio, Lichtenstein in Leadership, and Birkinshaw, Smith, O'Reilly in paradox/ambidexterity) further searches were made using reference lists from papers by these authors. Searches were also made on Wikipedia and Google Scholar, which yielded additional key words and authors that were then used to search the databases with more success.

The literature landscape divided clearly into three areas, each with a number of key aspects:

- High Hazard Technology Safety
    - Normal Accident Theory (NAT)
    - System safety
    - High Reliability Organizing (HRO)
    - Human Factors
    - Safety Culture
    - Resilience engineering
    - Crew Resource Management / Threat and Error Management (CRM/TEM)
    - Situation Awareness
    - Mindful Leadership
- Leadership
    - Traditional leader-centric leadership theories
        - Trait and Style theories
        - Contingency theories
        - Relationship theories
        - Charismatic / Transformational / Authentic leadership
    - 'New-genre' theories of leadership
        - Distributed
        - Relational / Processual
        - Contextual
        - Adaptive / Emergence
        - Complexity / Enabling leadership
- Paradox and Ambidexterity
    - Organizational form
    - Ambidexterity theories
    - Paradox theories

The number of papers resulting from each search was reduced to around 2-300 per search by refining the search terms, the quality of journals and sometimes the date period. By this method, over 7000 papers were found in around 50 searches, of which for each search around 10-15 % of papers were filed in Mendeley for closer review. 1100 documents for review were scanned by reading the abstract and conclusions.

By reading the abstract and conclusions, these papers were assessed for their relevance to the areas of interest and their salience in terms of quality of the journal and also the academic stature of the authors. On this basis, about 300 were identified as potentially important and selected for reading in depth.

What follows is an analysis and discussion of these papers, building on the earlier reading.

2.3 Safety of High Hazard Technology

2.3.1 System Safety and Safety Management Systems

After contributing to the presidential investigation of the 1979 Three Mile Island nuclear power station accident, the sociologist Charles Perrow published his 'Normal Accident Theory' ('NAT') which suggested that organizational disasters are an inevitable result of technological or organizational 'interactive complexity' and 'tight coupling' between system components (Perrow, 1984, p4).

The 'system safety' school of thought claims that the complex socio-technological systems required for e.g. aeronautics and space (and by implication other high hazard technologies) can be engineered specifically to minimise interactive complexity and tight coupling, so that despite the obvious high hazards, risks can be well managed and accidents will be rare (Leveson et al., 2009). This supports an earlier claim made by Scott Sagan that NAT theory is pessimistic (Sagan, 1995).

The system safety view is that safety is an emergent property of the entire system in which an organization operates; risk management processes internal to an organization are strongly influenced by factors generated in the much broader system that includes regulators and other government agencies, contractors, suppliers, customers, partners and indeed all parties with which the organization has relationships. This very broad definition of the system sets the conditions and restraints on safety within the context of all the often-competing goals of the organization, thus the safety of a system can only be effectively managed when the whole system is analysed and understood. In this view, the safety of high hazard technology results from strategic decisions about engineering and not primarily from front line operators having freedom to do what they think makes sense, even though there may be cases where that could be important.

However, Leveson et al. (2009) point out if decision-makers do not have clear mental models of how their decisions will affect safety their decisions will inevitably sometimes be fallible, as was seen in both of the space shuttle disasters and also many other major accidents. Structurally, this proposition matters for organization design; responsibility for safety lies with project and operations managers and engineers, but as well, a powerful, independent, 'system safety' organizational function is needed to provide adequate challenge in management decision-making.

Leveson has proposed a modelling technique to analyse all the conditions and restraints that determine the design and manufacture of the equipment an organization uses and how it is operated and maintained, that is, all the spheres of activity from which accidents can emerge, and hence from where safety emerges, allowing decision-makers to assess the potential effects of their decisions (Leveson et al., 2009). Models such as this are the basis for 'safety management systems' commonly employed in high hazard industries, and 'safety reports' or 'safety cases' demanded by government regulators (European Union, 2012; HSE, 2013; OSHA, n.d.).

Safety management systems apply the 'management system' process of 'plan – do – check – act' (Deming, 1951; Fayol, 1916) to safety (HSE, 2013; ISO, 2018). This approach understands safety as the result of the effective management of hazards so that they do not lead to consequences.

The planning stage of this process starts with identifying hazards and assessing the level of risk they pose, followed by analysing the mechanisms by which the hazards could be released and the design of 'defences' (Reason, 1997) that inhibit such release mechanisms. The 'do' stage implements these planned defences, and the 'check' and 'act' stages close the 'management loop' with actions to assess the effectiveness of the defences compared with the design intent and make suitable corrections if necessary, forming a 'control system' (Hale et al., 1997; Rasmussen and Lind, 1982).

In this analysis, risk may be assessed by estimating the consequences, such as the number of deaths, that would ensue from the 'credible worst-case scenario' of a particular hazard being released in a particular context, and calculating a level of risk by combining this with an estimated probability of the scenario occurring. This can be done using Quantified Risk Assessment (QRA) methods, calculating values for level of risk using such measures as the 'probability of loss of life' (Det Norske Veritas/HSE, 2000) but is more often performed using simplified risk analysis methods such as 'Layers of Protection Analysis' (CCPS, 2001).

Risk can also be assessed qualitatively using experience and historical knowledge of incidents formulated into a 'risk matrix' with consequences assessed against a scale such as suggested by Summers, Vogtmann and Smolen (2011) and probability expressed in terms of historical frequency of such consequences, with risk then being assessed typically as high, medium or low in specified areas within the matrix.

Analysis of the hazards, release mechanisms and the associated risks allows defences to be designed and implemented with the aim of reducing the risk to an acceptable level, judged against criteria such as 'As Low As Reasonably Practicable' (ALARP) levels established by safety regulators or other bodies (HSE, n.d.).

Within safety management systems, the multiple release mechanisms and defences for a particular hazard are often portrayed in a 'bow tie' diagram (ICI, 1979) an example of which is shown in **Figure 2-3**.

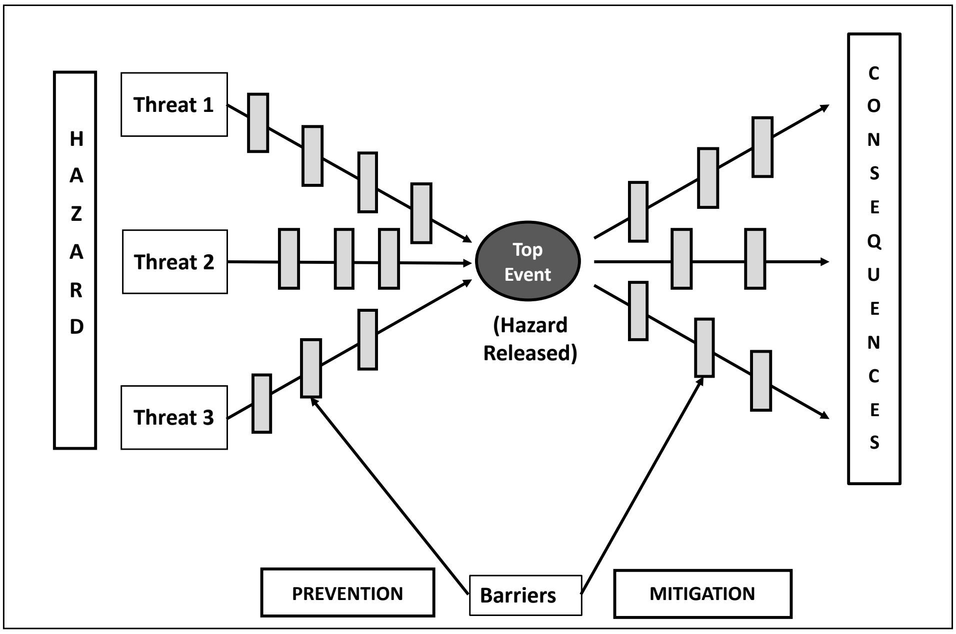

Figure 2-3 Bow Tie Hazard Management Diagram

A bow tie diagram portrays for a particular hazard such as ‘pressurised flammable gas contained in a pipe’ a number of possible incident causation pathways. It also shows the progression of an incident from left to right through several stages of incubation (Turner and Pidgeon, 1997).

The left-hand side of a bow tie diagram shows the mechanisms by which the hazard could be released, such as for an underground pipeline: corrosion, fatigue or excavator damage. These mechanisms are shown as ‘threat lines’, along which are placed ‘barriers’ (defences) designed to prevent the threats from releasing the hazard. Examples of such ‘prevention’ barriers are a steel containment envelope (e.g. piping system), a process alarm with operator response, and an automatic shut-down system (CCPS and Energy Institute, 2018).

The middle of the diagram shows the release of the hazard, referred to conventionally as the ‘top event’, which would occur if all the prevention barriers on any particular threat line were to prove simultaneously ineffective. The hazard could also be released by a previously unknown mechanism or one considered so unlikely as not to warrant preventative controls, a so-called ‘Black Swan’ (Taleb, 2007). In the process industries a typical ‘top event’ is a release of flammable gas.

On the right-hand side of the diagram, the known possible pathways that could lead to consequences of such a hazard release are shown. Along these pathways, ‘mitigation’ barriers are shown that are designed to reduce potential consequences such as injuries or damage from an incident such as explosion, fire or plume of toxic gas. Examples of mitigation barriers are an automatic firefighting system, evacuation by lifeboat and use of an escape respirator.

2.3.2 Incident Analysis

A well-known accident model in high hazard safety is the ‘Swiss Cheese model’ (Reason, 1990b, 2016, 1997) ‘undoubtedly the most popular accident causation model’ (Underwood and Waterson, 2014, p76) the classic portrayal of which is shown in **Figure 2-4**

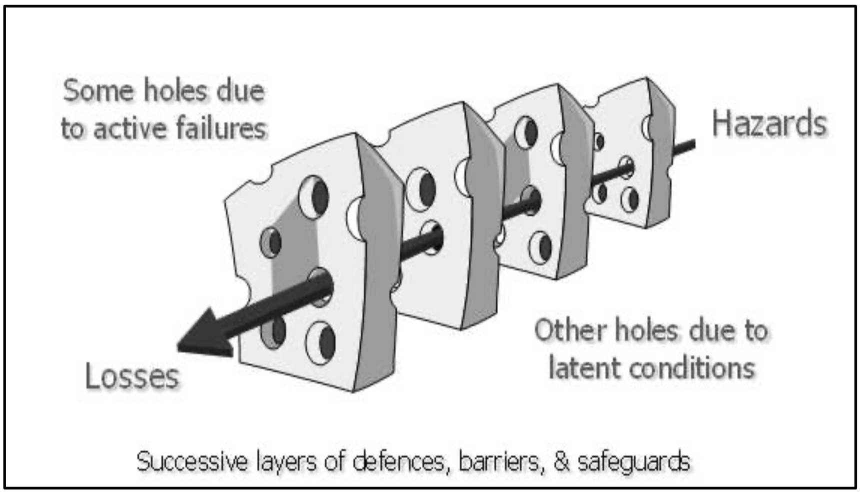

Figure 2-4 The Swiss Cheese model of accident causation (Reason, 2016, p2)

Each bow tie 'threat line' can be seen as a partial Swiss Cheese model (Hudson and Hudson, 2015). If the barriers (slices of Swiss Cheese) designed to contain the hazard from being released by a specific threat were all to fail simultaneously (the 'holes' in the slices of cheese all lining up) then a 'top event' would occur.

The bow tie and Swiss Cheese diagrams thus can be combined, providing a hazard management model that also portrays system weaknesses. This is shown in **Figure 2-5** and is useful for describing three different types of process safety event, following the logic widely used in high hazard operations (HSE, 2004; OSHA, 2015; Reason, 1997).

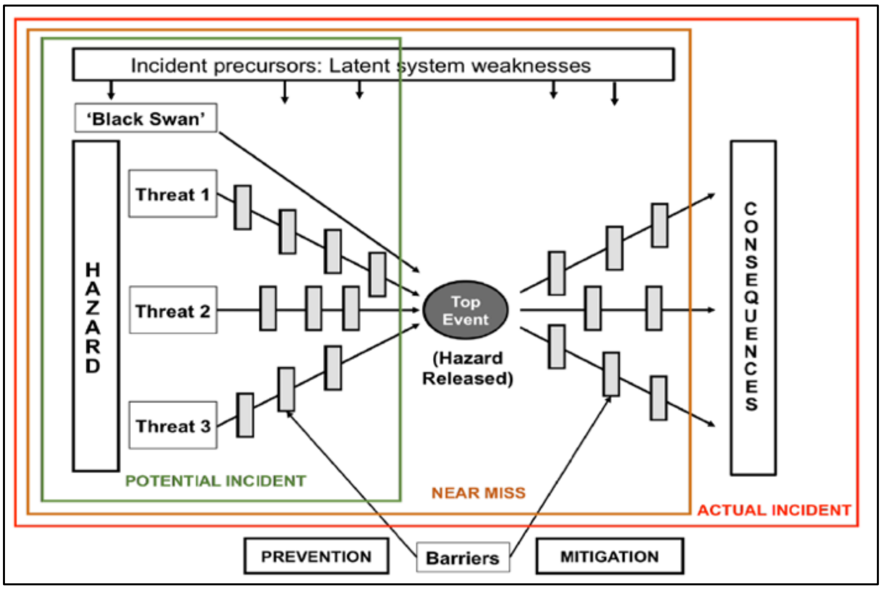

Figure 2-5 Bow Tie hazard management diagram with incident types

As described earlier, a bow tie diagram is drawn for a specific hazard (such as flammable gas under pressure in a piping system) with each 'threat line' indicating a different way in which the hazard can be released (such as corrosion, fatigue from vibration, or impact by a vehicle).

In **Figure 2-5** an 'Actual Incident' (shown within the outer (red) box) is an event in which the hazard is released (a 'top event' occurs) and the hazard goes on to result in significant consequences (such as deaths, injuries or damage to plant and equipment due to fire or explosion). A 'Near Miss' is shown as the release of the hazard (again, a 'top event' occurs) that 'could have had bad consequences, but did not' (Reason, 1997, p118); this is shown as an event within the middle (orange) box. Finally, in contrast to both an Actual Incident and a Near Miss, a system weakness that is detected before it could result in the release of the hazard (no 'top event' occurs) is known as a 'Potential Incident' and is shown within the inner (green) box.

Evidently the case of an Actual Incident, all of the prevention barriers on at least one threat line proved ineffective, allowing the hazard to be released (for example creating cloud of flammable gas) and unfortunately the mitigation barriers (for example gas detection system, remotely operated shutoff valve, water deluge system) were unable to stop the hazard from leading to significant consequences (in this example, the gas cloud being ignited with ensuing explosion and fire). Actual Incidents are thus commonly easily identified, and in most organizations operating high hazard technology in developed countries, are recorded, reported to government safety regulators and investigated to find system weaknesses that can be corrected in an attempt to avoid recurrence of such an incident. However even fatal accidents have been known to be hidden from the authorities in some circumstances, such as where misguided safety incentives exist. Although that may be exceptional, it does indicate that the identification of Actual Incidents can be problematic and prone to political or defensive interference, even in well-regulated operating environments.

A Near Miss starts in a similar way to an Actual Incident, with release of the hazard, so evidently all of the prevention barriers on at least one threat pathway proved ineffective. However, in a Near Miss, although the hazard is released, there are no significant consequences. This might be because of the effective operation of one or more designed mitigation barriers (such as the examples given above for Actual Incidents) or just by luck, such as a gas cloud dispersing before reaching a source of ignition. Another more potentially interesting mechanism that leads to a Near Miss rather than an Actual Incident is a successful improvised intervention. An example of this could be a vigilant operator correctly diagnosing an unexpected build-up of pressure and opening a valve to release the pressure, performing a non-standard but effective action. If such improvisations were frequently involved in the Near Miss incidents occurring in a particular organization that may be an indicator of the organization explicitly or tacitly supporting more adaptive practices than otherwise.

Because by definition no consequences result from a Near Miss and few regulators demand reporting of Near Miss incidents, their identification is more problematic than Actual Incidents (Phimister et al., 2003; Van Der Schaaf and Kanse, 2004). Thus although they may be observed by people working in operations or maintenance, they are more easily ignored or covered-up (Lawton and Parker, 2002) so may not be identified within an organization's incident management processes, or there may be a lack of 'organizational commitment to ensure that such lessons are remembered' (Hopkins, 2010, p62). However, many organizations operating high hazard technology in developed countries do recognise their potential value for learning about system weaknesses and therefore have internal management processes that encourage or even demand that Near Miss incidents are reported internally and investigated, although they may not be implemented as rigorously as for Actual Incidents .

It is Potential Incidents that are perhaps of most interest for this research. These are the 'latent conditions' and 'active failures' that are represented as holes in the 'Swiss Cheese' slices (Reason, 1990b, 2016, 1997). If such a system weakness is detected before it has the opportunity to incubate into a release of the hazard, it is termed a 'Potential Incident'. In the traditional view, such a system weakness could be a degraded or failed barrier, or it may be a 'resident pathogen' (Reason, 1990a, p32) such as an ambiguous procedure, loss of currency in a technical skill, a maintenance backlog or an unclear critical communication. In the 'Safety II' view, they can also manifest as a degradation of mindfulness and expert improvisation that may normally be operating to maintain safety despite imperfect equipment or system design (Hollnagel, 2014).

A system weakness representing a Potential Incident may be detected by luck, from a chance observation. Or it may be detected by the effective working of routine testing or inspection process that was designed specifically to detect such weaknesses. Or a Potential Incident may be detected by a vigilant human operator, technician or engineer discovering some anomaly, perhaps by a diligent, thorough analysis of an unusual control room alarm.

These latter two mechanisms are of most interest for this research. The identification of a Potential Incident provides the opportunity for an organization to learn about a system weakness and correct or mitigate it before it can incubate into either an Actual Incident or a Near Miss. An organization's ability to identify Potential Incidents may be a useful indicator of its safety.

These definitions of Actual Incident, Near Miss and Potential Incident are used throughout this research project. It will be argued later that the identification of and response to Potential Incidents is an indicator of an organization's effective management of safety, compared with the occurrence of Actual Incidents. The identification of and response to Near Misses, if the response involves effective mitigation, may also indicate safety, but to a lesser extent than Potential Incidents since by definition a Near Miss involves the release of a hazard, implying that all the prevention barriers on at least one threat line proved ineffective.

The Swiss Cheese and bow tie models are commonly used as a basis for modelling accident causation. However, it has been suggested that such models can limit the analysis of causation to a simple cause-and-effect approach that can suffer from 'hindsight bias' (Dekker, 2011, p122) and so limit opportunities for organizational learning. Current accident investigation practice commonly adopts 'root cause analysis' techniques (CCPS, 2019; OSHA, 2016; Pillay, 2015) based on linear cause-and-effect models, and makes recommendations that only address these apparent 'root causes', a failing that has been called 'what you look for is what you find' (Lundberg, Rollenhagen and Hollnagel, 2009, p1298).

Further, the 'causes' and recommendations resulting from such investigations are likely to be 'administrative' in nature reflecting the traditional 'rule-following' and 'command and control' paradigm prevalent in high hazard industries. This is particularly so since recommendations of this type are explicitly encouraged by current authoritative industry guidance: 'Typically, recommendations are written to prevent incident recurrence by: improving the process technology, upgrading the operating or maintenance procedures or practices, improving compliance with existing organizational systems (operational discipline); and upgrading the management systems, (often the most critical area)' (CCPS, 2019, p5).

It is therefore pertinent to review briefly the theories and methods of accident analysis. Over the past century, theory of accident causation has undergone some distinct changes, from the 'domino' accident model (Heinrich, 1936) and the 'cause-and-effect' models of 'Failure

Modes and Effects Analysis' (FMEA) (United States Department of Defense, 1949) and 'fault tree analysis' (Watson, 1961) through the 'behavioural safety' approach (Krause, 1990) criticised for its potential for blaming workers and its 'fallacy of mono-causality' (Hopkins, 2006 p585) widening to an epidemiological approach taking into account the influence of organizational processes and conditions on human error (Cullen, 1990; Perrow, 1984; Reason, 1990b, 1997) and further evolving into a 'systems' approach. Three main 'systems' accident models have emerged: 'STAMP' (Systems-Theoretic Accident Model and Processes) (Leveson, 2004) 'FRAM' (Functional Resonance Analysis Method) (Hollnagel and Goteman, 2004) and 'Accimap' (Chen, Wood and Zhao, 2019; Svedung and Rasmussen, 2002). The systems approach is now 'arguably the dominant concept within accident analysis research' (Underwood and Waterson, 2013, p154).

However, a recent review of systemic accident analysis methods concluded that despite widespread acceptance of the need for analysis of the whole system, in practice, perhaps due to difficulty obtaining data about all parts of the whole system, investigations remain focused on 'contributory factors at the sharp-end of the sociotechnical systems' (Hulme et al., 2019, p181). This echoes an earlier view of the practical difficulty of analysing accidents with systems methods: 'Organizational factors remain well described in the academic literature, but much harder to identify in real investigations' (Braithwaite, 2010, p55). Another recent review of accident analysis methods concluded that cause-and-effect methods may be appropriate to find and fix immediate problems but that to find underlying latent conditions, epidemiological methods are needed and, further, that 'Systemic methods will not add enough value to this process to justify the considerable effort' (Wienen et al., 2017, p25).

It is thus acknowledged that the 'systems' approach lacks widespread adoption in practice and it is suggested that, as well as the usability difficulty, and the research-practice gap seen in many management topics, this may also be due to a 'lack of track record within industry and the possible incentive to use non-systemic techniques to facilitate the attribution of liability' (Underwood and Waterson, 2013, p163).

2.3.3 Implications for organizational learning

Linear cause-and-effect approaches tend to suffer from 'hindsight bias' (Dekker, 2011, p122) and to limit opportunities for organizational learning to the 'single-loop learning' of finding and fixing problems 'rather than to challenge deep assumptions with rigorous and systemic thinking…', the aim of 'double loop learning' (Carroll, 2002 pp124-126). However, this limitation of learning may sometimes even be deliberate, since 'organizational learning is a political process shaped by the interpretations and interests of competing stakeholders…' who may seek to 'protect themselves from scapegoating by producing their own event narratives' (Buchanan and Denyer, 2013, p213).

Thus, for learning to be effective in improving organizational performance, three major challenges need to be overcome: first, identifying the gap(s) that may be inhibiting improvement and discovering the required knowledge, skills, frameworks or other important attributes; second, disseminating and applying these attributes in practice to generate the improvement and third, retaining the attributes in an 'organizational memory' so that the improved performance can be sustained.

The idea of organizational learning has been credited to Revans' (1982) 'creation of the "action learning" process' (Wang and Ahmed, 2003, p8). Action learning incorporates both the scientific method approach of single loop 'plan-do-check-act' learning popularised by Deming and the pragmatism of experiential learning championed by Dewey (Pedler and Burgoyne, 2011). In the light of considerable research since Revans' early ideas, organizational learning is now understood more broadly by many writers to mean 'a process of change and improvement in organizational actions brought about by better knowledge and understanding that have been acquired, shared, and combined' (Carmeli and Gittell, 2009, p709)

The idea of 'double loop learning' proposed by Argyris (1977) extended the meaning of organization learning to the more fundamental questioning of and reflecting upon basic objectives, underlying assumptions and purpose, so that 'any incongruities between what an organization openly espoused as its objectives and policies and what its policies and practices actually were could also be challenged' (Argyris, 1977, p123). This was fully articulated in Argyris and Schön's (1978) conception, 'one of the most original and pioneering works in the field of organizational learning' (Rhodes, 1998, p107) founded on a 'theory of action' (Argyris and Schon, 1974). This theory proposes that people's actual behavior within organizations is based on their 'theory-in-use', and that this is different from how they believe they behave, and indeed how they say they behave, which is their 'espoused theory'. The reflective process of double-loop learning is proposed as a means of creating the greater congruence between the two theories of action necessary for improved organizational effectiveness.

Fiol and Lyles (1985) offer a slightly different analysis, distinguishing between learning, that they see as cognitive, developing insights and knowledge that enable inference of causal links between past and future action (similar to double loop learning) and adaptation, that they see as behavioural, making incremental adjustments as a result of environmental or other changes (similar to single loop learning). They too recognise that both are important since survival and growth rely on making strategic choices as well as dealing with changes in the environment.

In their early review of organizational learning Levitt and March (1988) suggested that organizations learn by sharing interpretations of experience encoded into their operating processes and by improving these processes either by trial-and-error or by research driven by aspiring to better outcomes. However, 'lessons of experience are drawn from a relatively small number of observations in a complex, changing ecology…What has happened is not always obvious, and the causality of events is difficult to untangle' (Levitt and March, 1988, p 323) so the interpretation of experience and choice of what to retain is not straightforward.

This leads to the third challenge, perhaps the biggest, that of organizational memory. At a simple level this means that 'learning agents, discoveries, inventions, and evaluations must be embedded in organizational memory' (Argyris and Schön 1978, p19). Weick expanded on this, pointing out a number of potentially problematic aspects: 'If an organization is to learn anything then the distribution of its memory, the accuracy of its memory, and the conditions under which that memory is treated as a constraint become crucial characteristics of organizing' (Weick, 1979, p206). In their seminal review of organizational memory literature, Walsh and Ungson (1991) explore these issues, suggesting that the acquisition, retention and retrieval of organizational memory are all informed by individuals, structure, culture, the work processes that transform inputs into outputs, and the physical setting and layout of the workplace, that they term ecology; and they point out that all these features can be subject to misuse or abuse in the service of asymmetric power of individuals or groups.

A distinction has also been made between 'organizational learning' and 'the learning organization' (Garvin, 1993; Senge, 1990); the former having a focus on knowledge stored in organizational memory in the form of shared mental models consisting of routines, procedures, documents and culture, while in the latter 'knowledge exists, to a great extent, in the individuals (i.e. their bodies and brains)'… and the organization '…is more like an ideal school. The organization provides a climate that facilitates the learning of the individuals, and the managers are supposed to be coaches instead of directors' (Örtenblad, 2001, p130). But this distinction between the somewhat prescriptive and uncritical model of the learning organization, favoured more by practitioners, and the more sceptical scholarly organizational learning literature (Rhodes, 1998) is perhaps less important and maybe displaced by 'knowledge management' as a competing discipline, led by information technology, even though all of these have similar underlying concepts (Easterby-Smith, Crossan and Nicolini, 2000).

Even though their learning is likely to be incomplete and distorted by the influence of power, that organizations can and do learn is accepted. Wang and Ahmed (2003) in their critical review, identify five concepts of organizational learning, each with associated practices: individual learning: by training and development; learning as processes: of information analysis and problem solving; learning culture: of collaborative teamwork and worker involvement; knowledge management: by facilitating interaction with retained knowledge; and continuous improvement: by techniques such as 'total quality management'. Another more recent mapping of theory to practice similarly found systematic knowledge management to be an important enabler of organizational learning, particularly when integrated with people practices of job rotation and nominated roles of knowledge managers and the like and with processes such as communities of practice, action learning and post-mortems (Basten and Haamann, 2018).

Perhaps the best known technique of post-mortem continuous improvement is the US Army's debriefing process, the 'After Action Review', 'arguably one of the most successful organizational learning methods yet devised' (Senge, 2002). This semi-formal process assumes learning may be derived both from success and failure. It is led by a facilitator and involves all the people involved in a specific task, to identify specifically what went well and potential improvements (Mastaglio et al., 2011). This technique has been adopted in many non-military fields such as healthcare (Reiter-Palmon et al., 2015) international aid (Mullerbeck, 2015) and elite sports (Middlemas, Croft and Watson, 2018).

Despite the developments in understanding organizational learning, there remain difficulties. Referring to a model of organizational learning proposed by Crossan, Lane and White (1999) of four processes (so-called '4I model') of 'intuiting', developing new insights from personal experience; 'interpreting' these by explaining to others; 'integrating' in groups of individuals to generate coherent understanding; and finally 'institutionalizing' in systems, structures, procedures and strategies to guide organizational action, Schilling and Kluge (2009) identify a number of barriers to organizational learning and categorise them by the 4I model processes. These include personal biases, 'superstitious learning' (Levitt and March, 1988, p325), high level of stress, restrictive and controlling management style, and blame culture, all of which inhibit the intuiting of insights; lack of confidence or political/social skills of the innovator, and status culture, which inhibit interpretation; lack of recognition or fear of punishment, rigid and outdated beliefs or assumptions of senior managers, inhibiting the integration of new ideas and finally, cynicism towards the organization or innovation, lack of time and resources, and organizational hypocrisy, all of which inhibit the institutionalizing of learning.

So although many processes are suggested by which organizational learning may take place, there are also many barriers, not least of which are the power and politics prevalent in most organizations. Vince (2018, p 275) suggests accepting this paradox as normal: 'Our own desires to learn through collaboration are mixed up with our ambivalence towards others, our defensiveness in the face of learning, and our habits and attachments to individualised and self-serving ways of thinking and working. It is holding these tensions together that is most likely to support and sustain learning because this is a more realistic depiction of the organisational context within which learning takes place.' This builds on earlier work suggesting that organizational learning can only ever take place within the political reality of organizations. Learning requires that differences become reconciled by generating new ideas, and this may be best facilitated by open argument, mirroring civic political systems, 'based on rights and obligations within a framework of legitimate authority…However, entrenched power structures and the associated patterns of dependency tend to constrain such radical processes. Unless political action enables these structures to be challenged, higher-level learning will be inhibited' (Coopey and Burgoyne, 2000, p 879)

Baumard and Starbuck (2005, p294) are even more discouraged, suggesting that 'learning is unlikely to occur at all in a large, divisionalized firm' since such an organization is a 'political system in which senior managers compete with each other to control resources and to gain political power'. They suggest that organizational learning can be achieved, but only if the top managers are 'intellectually and financially motivated to learn'.

Cannon and Edmondson (2005, p310) reinforce the latter more positive view, pointing out that 'organizational policies such as 3M's directive that 25 percent of a division's revenues come from products developed in the last five years, and Bank of America's setting the expected level for failed experiments at 30 percent can go a long way in sending the signal that the organization values creative experimentation'. Similarly, Weinzimmer and Esken (2017, p342) stress that 'managers need to make a conscious effort to communicate to employees the value in learning from mistakes as an important part of improving and changing existing organizational practices'.

Weick (2009, p239) makes a similar point: 'Emergent change, and it close relative sensemaking, are likely to be more effective when the culture of the corporation makes it clear that people are valued when they…speak up when things aren't working'. However, to be successful such efforts need to be made within an integrated approach to learning, of supportive structures, shared beliefs and leader coaching (Edmondson, 1999) which contribute to a climate of 'psychological safety' (Argote, 2011; Baer and Frese, 2003; Edmondson, 1999) in which people feel safe to speak up about concerns, question practices or decisions and propose new ideas.

Baer and Frese (2003, p61) demonstrated the importance of a climate of initiative and psychological safety for process innovations – since they focus on 'interdependency, personal responsibility, autonomy, and flexibility'…which are 'critical in ensuring enhanced organizational performance'. And Carmeli and Gittell (2009, p724) suggest that psychological safety is enhanced by a supportive structure of 'shared goals, shared knowledge, and mutual respect', which in turn is encouraged by practices such as 'boundary spanner roles, inclusive cross-functional meetings, and cross-functional routines'.

But the effective sharing of ideas, learning and decision-making are often inhibited by common human caution (Schilling and Kluge, 2009). It is well accepted that in our interactions with others we are normally at least somewhat guarded. As Goffman (1959, p9) points out, when people are working together, 'each participant is expected to suppress his immediate heartfelt feelings, conveying a view of the situation which he feels the others will be able to find at least temporarily acceptable. The maintenance of this surface of agreement, this veneer of consensus, is facilitated by each participant concealing his own wants behind statements which assert values to which everyone present feels obliged to give lip service.' Similarly, Kahn (1990, p708) found that psychological safety depends on the specific working environment: 'situations promoting trust were predictable, consistent, clear, and nonthreatening…When situations were unclear, inconsistent, unpredictable, or threatening, personal engagement was deemed too risky or unsafe.'

The degree to which this caution is influenced by the asymmetric power within hierarchies was described by Hofstede (1980) as 'power distance', noting marked differences in different national cultures and organizations. The need to overcome unhelpful power distance on flight decks manifesting in 'unwillingness of junior crewmembers to speak up in critical situations' was an important driver for the introduction of Crew Resource Management (Kanki, Helmreich and Anca, 2010, p8).

In their major review of psychological safety research Edmondson and Lei (2014, p39) conclude that psychological safety is an essential enabler of organizational learning: 'For people to feel comfortable speaking up with ideas or questions—an essential aspect of organizational learning—without fear of ridicule or punishment, managers must work to create a climate of psychological safety'.

This importance is underlined by a major longitudinal study by Google that found psychological safety was 'more crucial to how well teams innovated than anything else' (Bergmann and Schaeppi, 2016, p4). And in another more recent review of psychological safety research, Newman, Donohue and Eva (2017) found psychological safety to be especially important in safety-critical work.

Finally, returning to the work of Chris Argyris, a critical interpretation is offered that reinforces once more the importance of power for organizational learning. Bokeno (2003, pp634-5) suggests 'that Argyris' Model I patterns of interaction, far from simply barriers to effective organizational problem solving, are linked to maintenance of power asymmetry and managerialism in organizational practice, underscoring his OL [Organizational Learning] project one of ideology critique…' and that '…double-loop learning involves "critical" reflection and illumination of the distortions and constraints on ideal communication that ensue from power asymmetry'.

Many of the barriers to learning discussed above are seen in organizations suffering major incidents. For example, those mentioned above by Schilling and Kluge (2009) such as 'restrictive and controlling management style' and 'status culture' are all too familiar features of the traditional 'rule-following' and 'command and control' paradigm prevalent in high hazard industries, along with 'high level of stress', 'lack of time and resources', 'fear of punishment' and 'blame culture' which are so often associated with the asymmetric power referred to by Baumard and Starbuck (2005), Buchanan and Denyer (2013) and indeed Argyris in the reading by Bokeno (2003).

Another observation is that none of the accident models discussed earlier adequately address causation as a conjunctural or configurational phenomenon. The idea of configuration, describing the functioning of systems in terms of how system elements interact, is accepted as the basis of important conceptual frameworks that help understand organizational behaviour (Mintzberg, 1980) and is 'arguably one of the central ideas of organization studies, stemming back to the writings of founding fathers such as Max Weber…Yet, this idea also remains one of the field's least understood aspects' (Fiss, Marx and Cambré, 2013, p2). And indeed the idea of causation being conjunctural is not new. The English philosopher John Stuart Mill proposed that 'for every event there exists some combination of objects or events…the occurrence of which is always followed by that phenomenon. We may not have found out what this concurrence of circumstances may be; but we never doubt that there is such a one' (Mill, 1843, p237).

Recent developments in philosophical thought and analytical methods offer a means of improving the understanding of causation in terms of configuration, that is, combinations of factors acting in conjunction (Baumgartner, 2008). Qualitative Comparative Analysis (QCA) (Ragin, 1987; Rihoux et al., 2009) may offer a practical method to reveal how different configurations of factors may lead to different safety outcomes such as actual incidents, near misses or potential incidents, offering the possibility of improved organizational learning.

2.3.4 Other Theories of High Hazard Technology Safety

A less problematic use of bow tie and Swiss Cheese models within safety management systems is as metaphors that help communicate the processes of hazard management and their potential weaknesses, to help managers prioritise resources to maintain barriers and to help clarify responsibilities for operations staff and maintenance technicians involved in maintaining the effectiveness of barriers. However, 'No model will ever approach the full complexity of reality' (de Ruijter and Guldenmund, 2016, p217) and Perrow takes the view that the management system / system safety approach is optimistic since 'the complexity and tight-coupling of complex, high-tech systems not only makes them opaque to the operators, but also they make it almost impossible for any one individual to understand such a system in its entirety' (Reason, 1998a, p296, quoting Perrow, 1984).

Another view of how safety of high hazard technology is managed, proposed by a group of researchers including Hollnagel, Wreathall and Woods is referred to as 'resilience engineering' (Hollnagel, Woods and Leveson, 2006; Woods, 2003). By resilience they mean an organization's ability to keep stable and recover quickly from mishaps in the face of significant operational challenges, and 'engineering' resilience means creating and maintaining that ability. They propose that this is achieved through proactive internal organizational structures and processes that actively seek and anticipate potential weaknesses in hazard controls, as well as sensing and responding to them reactively (Woods, 2006). It is argued that resilience can be developed in an organization through a number of structural changes. For Woods, the important factors for engineering such resilience are firstly having a leadership team who understand human factors and how their decisions affect system safety, and how to balance production pressure and safety risk to achieve effective risk management, and secondly creating an effective safety organization that is independent but involved in the decision making, and generates information that measures strength (or weakness) of risk controls (Woods, 2003). This analysis echoes 'system safety' but brings in the aspect of human factors.

The human factors field is primarily concerned with understanding and reducing error, including the important sub-set of rule-violation. 'Safety culture' has evolved from this field, based on the idea that an organization's culture is a source and indicator of its reliability, notably through the work of the Manchester psychologists Reason, Parker and Lawton (1998) working with Hudson at Leiden university (Hudson, 1999) and Flin at Aberdeen (Flin et al., 2000). Reason describes a strong safety culture characterised as 'just, reporting, informed, learning and flexible' (Reason, 1998b, p195). As a development of Reason's characterisations and of Westrum's 'pathological–bureaucratic–generative' cultural typology (Westrum, Adamski, 1999) Parker, Lawrie and Hudson proposed a multi-aspect five level safety culture model that describes an important process within a strong safety culture: its managers maintain 'chronic unease', staying informed about the organization's potential weaknesses and so are able to drive organizational learning. They stay informed because workers at all levels feel empowered to report problems, even their own mistakes, since they trust the managers to exercise justice and fairness in dealing with them (Parker, Lawrie and Hudson, 2006). Flin concurs but differentiates culture from climate, the latter being more appropriate for questionnaire surveys which measure transient surface features (Flin, 2007). Dekker has also emphasised the importance of justice, avoiding a blame culture (Dekker, 2011) and also introduced the idea of complexity, suggesting that errors are emergent properties of complex systems and cultures (Dekker, Cilliers and Hofmeyr, 2011).

Two further related areas of research are of interest since they have been widely adopted by commercial aviation: The first of these is 'Crew Resource Management' (CRM) which has evolved to become known now as 'Threat and Error Management' (TEM) in its latest generation (Helmreich, Merritt and Wilhelm, 1999). This is a suite of techniques developed by the Aviation Human Factors group at Texas University, and endorsed by the International Civil Aviation Organization (ICAO). CRM/TEM is now being adopted in many hospital surgical theatres (Helmreich, 2000). The second idea originating in aviation human factors research that has found wide practical and successful application in other high hazard operations is 'Situation Awareness' (Endsley, 1999). This is very akin to 'mindfulness' as described by Weick and Sutcliffe (Weick and Sutcliffe, 2006) and applies at individual, team and organizational levels. Hopkins also notes the need, for top leaders especially, to maintain the 'big picture' of the effectiveness of their organization's risk management systems with rapid and comprehensive information flows (Hopkins, 2009). Endsley's work includes design of equipment and systems to facilitate such information flows.

Safety culture, CRM/TEM and situation awareness all share some of the ideas that make up 'HRO theory'. For example, chronic unease is evidently closely related to the HRO researchers Weick and Sutcliffe's term 'mindfulness', which also Hopkins emphasises in his view of HROs (Hopkins, 2007) by particularly focussing on 'mindful leadership', which he suggests is the defining HRO characteristic (Hopkins, 2009). And the effective interpersonal communication that is a key component of CRM/TEM is also a key aspect of HRO theory (Roberts, 1990).

2.3.5 HRO Theory

Interest in HRO has grown over the past decade as a result of the continuing series of high-profile major industrial disasters. Several literature reviews of HRO have been carried out recently, which serve well as logical entry points to this field. Chief among these are the extensive British Health and Safety Executive review (Lekka, 2011), that by the psychologist Karlene Roberts who was a leading member of the original Berkeley HRO researchers (Roberts, 2009) and the 20 year retrospective by the Geneva sociologist Mathilde Bourrier (Bourrier, 2011).

The Berkeley research (Roberts, 1990) represents the first view of how HROs work: that despite the hazards, the likelihood of bad consequences is kept very low by having active organizational and interpersonal processes that reduce and contain human errors and system failures. Roberts points out the previous dearth of organizational theory concerned with organizational reliability other than accident analyses, and the difficulty of deducing any useful theory of organizational reliability based on such a trial and error approach. Additionally she noted that at that time the only social science-based accident analyses, by Perrow, Sagan and Shrivastava, are based entirely on reviews of historical documentary evidence. This led the Berkeley group to adopt the quite different ethnographic method of the in depth 'embedded researcher' case study: they wanted to watch and talk to the people inside HROs to find out what they did that was so effective in avoiding accidents.

Their research method is interesting: for intermittent periods of five to ten days over an extended period (three years) team members of different social science disciplines joined the ships full time. They rotated round all the relevant activities so that in the end all members observed all these activities, with the intent of reducing individual bias. They looked specifically for ways that the organization minimised the negative potential effects of Perrow's 'interactive complexity' and 'tight coupling'. A key coping strategy they noted was that these HROs were adept at coping with paradoxes: for example standardisation vs flexibility. The ships' exercises were developed with much standardisation and specialisation of individual roles, but also with deliberate flexibility to encourage creativity in problem-solving, and considerable redundancy both of systems (e.g. many different means of instant communication: radios, public address systems, hand signals etc) and people (crew members were given skills in many different tasks).

Another well managed paradox noted was the maintenance of a high workload for key individuals such as pilots, landing officers and nuclear plant operators to achieve the high attention levels necessary to reduce error and also to develop high competence, while avoiding the obvious potential negative effect of overstress on error-rate with the deliberate strategy of high redundancy: having many pairs of eyes watching for errors or anomalies. This vigilant cross-checking and teamwork focussed on catching errors was a key component of a strong safety culture that was frequently reinforced by the officers and petty officers by rewarding the reporting of errors and defects and avoiding individual blame; teams were also given the flexibility to decide themselves who would do what on a rapid dynamic basis.

La Porte observed how the although authority was predominantly hierarchical, as one would expect in the military, 'collegial patterns of authority based on skill and functional relationships emerge as the tempo of operations increases…As these clearly recognised patterns shift, communication patterns and role-relationships are altered to integrate the skills and experience called for by the situation.'(La Porte, 1996, p64). Roberts similarly emphasised the importance to the operation of an HRO of flexible organizational form. 'In a sense the pyramid is inverted. The organization focusses on training and on letting people use that training. Low level decision making is part of that focus' (Roberts, 1990, p171). This flexibility of authority structure offers an insight into how the control vs adaptation paradox can be managed.

Summarising, both Roberts and la Porte claim that these organizations avoid catastrophe by having effective strategies deliberately aimed at minimising the interactive complexity and tight coupling of NAT. These strategies include organizational 'slack' and multiple redundant systems, the development of high competence, the creation by the leaders of a strong safety culture: encouraging strong responses to weak signals and avoiding blame, and deliberately decentralising the normal hierarchical authority structure in conditions of high-tempo operations, enabling decision-making at the lower levels where operational expertise has been developed.

These ideas have been further developed into what has become possibly the best-known HRO model – the 'five characteristics model' established by a team of sociologists led by Karl Weick (Weick, Sutcliffe and Obstfeld, 1999) and further developed by them under the key ideas of 'sense making' (Weick et al., 2005) and mindfulness (Weick and Sutcliffe, 2006). Weick, Sutcliffe and Obstfeld have put this forward as a consolidated theory of HRO (Weick, Sutcliffe and Obstfeld, 1999). They agree with Roberts' suggested HRO characteristics of redundancy, high competence from continuous training and vigilance from strategic prioritization of safety as necessary but not sufficient, seeing high reliability more of an active process of seeking and fixing problems, than a condition. They describe an active nature of HROs, sensitive to and dynamically responsive to the environment, compared with 'normal' or 'low reliability' organizations whose operating models lean more towards exploitation than exploration, so these organizations are less adept at recognising and responding appropriately to changes to the operating situation and more easily lose the 'big picture'. This 'organizational cognitive ability' Weick Sutcliffe and Obstfeld call 'mindfulness' and propose that this is the core of what differentiates an HRO. They go on to analyse the component activities, proposed as more tactical than strategic, that they claim allow HROs to develop and maintain mindfulness, presenting the 'five characteristics' as follows:

Preoccupation with failure: which implies maintaining a culture and infrastructure that support the reporting and expert analysis of near-miss incidents and other learning opportunities, and which suppresses the complacency that often accompanies a focus on success.

Reluctance to simplify explanations: this is based on the assumption that it takes a complex system to sense a complex environment, so 'requisite variety' is cultivated, including 'diverse checks and balances embedded in a proliferation of committees and meetings, frequent adversarial reviews, selection of new employees with non-typical prior experience, frequent job rotation, and re-training' as well as sceptical but mutually respectful questioning of actual reported conditions, assumed competence and the like, all of which call for excellent interpersonal skills to deal with the implicit lack of trust. Such cross-checking represents another form of redundancy, and the value of this for reliability is acknowledged, as part of accepting human fallibility. This characteristic also expresses a willingness to accept 'false alarms' as the cost of habitually making a 'strong response to a weak signal'.

Sensitivity to operations: this idea makes reference to Endsley's description of 'situation awareness' (Endsley, 1995): Sensing the situation, i.e. gathering information from the operating environment, making sense of that information as it relates to the individual's or organization's goals and then projecting the developing situation forward to anticipate appropriate survival responses. It also contains the idea of top leaders being well-connected to the operational 'sharp end' of their organization: understanding the needs and problems of operations and maintaining personal involvement.

Commitment to resilience: more than coping well with anticipated abnormal situations arising from predictable human and system failures, resilience is seen as responding effectively to the unexpected: anomalous errors or failures that have not been observed before. Resilient organizations maintain a capacity for improvisation and ad hoc problem-solving to contain the situation, avoid escalation towards a major incident and swiftly restore normal operations. They also attach great importance to early warning systems to detect and act quickly on such anomalies.

Under-specification of structures: This is changed to 'deference to expertise' in Weick and Sutcliffe's later book (Weick and Sutcliffe, 2001). One meaning is that decision-making about safety-critical matters is not kept as the prerogative of the formal hierarchy of line management; instead, the expertise of operational and technical specialists is given due weight and will normally take precedence. Another meaning is the overt acceptance that formal procedures cannot prescribe all situations, so people are expected to challenge and sense-check to avoid mindless operation of fixed processes.

This portrayal of HROs as differentiated from other organizations by having these five attributes, the authors claim, is based on induction from a wide body of research and is intended to provide a framework of social infrastructural concepts that can be used by any organization wishing to improve its reliability. How they have done this seems to be twofold: by synthesis of observations of practices in case studies of HROs by the many writers they reference, and also by inversion from organizational weaknesses implicated in accident causation.

To summarise, a broad review of the literature reveals a wide spread of ideas relevant to understanding the key features of HROs. What seems like a confusion of ideas and theories can be rendered simpler on analysis. The common threads and apparent differences can be grouped into two main paradigms: 'Safety Management Systems' (SMS) based on a mechanistic, analytical approach, combined with 'operational discipline' of execution following established procedures and 'HRO', based on flexible, mindful sense-making and competent improvisation.

Sagan suggests that 'HRO Theory' is optimistic (Sagan, 1995). Leveson agrees and further argues that both the NAT and the HRO views of safety are incomplete and flawed (Leveson et al., 2009). She sees reliability and safety as different properties and argues that although redundancy can reduce accidents caused by component failure (lack of component reliability) most accidents in complex systems have roots in cultural and human factors where redundancy does not help and can increase complexity which then tends to reduce rather than increase overall system reliability. She also cautions against operators of high hazard technology improvising without a complete understanding of the design and potential unintended consequences of their well-intentioned actions.

This view is countered by the 'deference to expertise' attribute of HRO theory and the opposing claim that safety is an outcome of organizational reliability, so having a variety of ways of ensuring a safe activity (cross checking, many pairs of eyes etc) is a useful tactic, and that component reliability is also a good reason for having redundant sub-systems. Redundancy is also defended as necessary for organizational mindfulness: analysis of data for relevant information, in order to enact 'reluctance to simplify', needs people with time for that task (Hopkins, 2009).

HRO theory claims that the 'management system' approach reliant on 'operational discipline' fails to recognise that although standard procedures and competence and discipline in using those procedures is important, it is mindful use of them that stops things going awry: people at the operational sharp end need to be empowered and encouraged to make sense of situations and use judgement, beyond merely following standard procedures: 'What is distinctive about effective HROs is that they loosen the designation of who is the "important" decision maker in order to allow decision making to migrate along with problems' (Weick, Sutcliffe and Obstfeld, 1999, p49)

2.3.6 Summary of High Hazard Technology Safety Theory

In summary, both of these major paradigms overcome NAT, but in paradoxically different ways: traditional safety management systems by engineering; deliberately reducing interactive complexity and coupling in the overall system design and maintaining accurate models of the system to guide decision-making, HRO and related theories by flexible organizing and processes that compensate for complexity and coupling by encouraging sense-making and competent adaptation, and for example maintaining organizational 'slack' by separating critical activities from each other, providing multiple channels of communication and developing effective teamwork.

The need to reconcile the operational discipline of rule-following so essential to traditional safety management with the mindful sensemaking and competent improvisation so essential to HRO theory represents a major paradox. Such improvisation can appear as rule violation, and so of serious concern to those espousing the traditional safety management paradigm. This tension has interested researchers for some time. It is of course recognised that rules and procedures vary in their quality and usefulness. 'It is probably true to say that procedures, together with the training and checking that goes with them, are the main reason commercial aviation is safe as it is' (Green et al, 1996, p59). However, several studies indicate that in the nuclear industry the large majority of all human performance problems can be traced to unclear or otherwise bad procedures (Reason, 1990b, 1997) and the impossibility of writing a procedure to cover all situations it is widely recognised so that violating a procedure is sometimes the safest action (Dekker, 2003; Hollnagel, Woods and Leveson, 2006; Reason, 1997).

A study of anaesthetists' use of rules suggests rules could be seen alongside other principles to guide naturalistic decision-making and so could and should be violated when doing so met one of three principles: 'doing the right thing'; 'doing what works in the circumstances'; and 'using one's skills and expertise' (Phipps and Parker, 2014, p519). This concurs with the view that problems arise from slavish adherence to rules that do not work in a changed context or if rules are not used to guide adaptation (Dekker, 2003; Woods and Shattuck, 2000).

The importance of the view that procedures should normally be followed but competently adapted when necessary is reinforced by another recent study, in aviation (English and Branaghan, 2012) and a major review of the literature on management of safety rules and procedures (Hale and Borys, 2013). This point is well illustrated by the following quote: "I don't enjoy making changes to procedures. It seems like the crew only does that when they feel there's some good need for it." Mike Collins, test pilot and astronaut, Apollo 11 crew debriefing following the first manned mission to land on the Moon, July 31, 1969 (English and Branaghan, 2012, p204).

In parallel, a second paradox also exists between the current dominant leadership paradigm of leader-centric 'command and control', rooted in leader-follower and contingency theories, and the shift to a new 'enabling' paradigm of leadership as a relational process, socially constructed within context, supportive of adaptive processes and emergence of change and embracing complexity theory. This paradox is explored in the next section. Managing the tension between these two leadership paradigms and between the hierarchical system safety and flexible HRO paradigms requires a degree of organizational ambidexterity. Theories of how this can be achieved are explored later.

2.4 Leadership

2.4.1 The current dominant paradigm: leader-centric 'command and control'

Traditionally, leadership research has been preoccupied with the characteristics and behaviours of leaders, as opposed to leadership in its wider sense. The main theories that emerged in the first half of the 20th century were attempts to define the attributes, styles and behaviours of the effective leader. Taylor's scientific management (Taylor, 1911) and Fayol's management principles of 'plan, organize, command, coordinate and control' (Fayol, 1916) were founded on the military and authoritarian assumption of the leader's right to demand compliance of workers and that effective leaders were endowed with certain characteristic traits. (Antonakis, Day and Schyns, 2012). This view was stated unequivocally early in the 20th century by W. H. Cowley: 'any study of leadership to be of value should produce a list of traits which go together to make the leader.' (Cowley, 1928, p144).

Although many traits such as stamina, intelligence, self-confidence etc have been associated with leader effectiveness, research has only been able to show a weak relationship with organizational success (Kirkpatrick and Locke, 1991; Yammarino and Bass, 1991). Due to a lack of consensus and a general overlooking of context (Stogdill, 1948) trait theories fell out of favour with academia for some decades, though remained popular with practitioners, and has recently regained the interest of researchers: the introductory editorial of a Leadership Quarterly special issue on 'leader individual differences', argued that 'leadership individual difference research is at a cusp of a renaissance' (Antonakis, Day and Schyns, 2012, p643) and Daniel Goleman listed five components of 'emotional intelligence' as desirable attributes of leaders (Goleman, 1998).

As the new field of social psychology emerged in the 1930s, its pioneer Kurt Lewin observed that a leader's approach, especially to decision-making, affected group performance. He defined three styles: 'autocratic', 'democratic' and 'laissez-faire', and in a break with the 'authoritarian' tradition, proposed the democratic style as most effective (Lewin et al, 1939). Blake and Mouton's 'managerial grid' plotted more styles on the dimensions of 'concern for task' and 'concern for people' (Blake et al., 1964) and Fiedler proposed a 'contingency theory' that although assuming that a leader's style was fixed as oriented either more to task or to relations, argued that 'the performance of interacting groups is contingent upon the interaction of leadership styles and the favorability of the situation for the leader' (Mitchell et al., 1970, p253) though support for the theory remains weak. Hersey and Blanchard's 'situational leadership' model described four different levels of subordinate work group maturity and prescribed a different leader style for each. Empirical evidence supporting this theory also remains weak, though its simplicity makes it popular with practitioners (Graeff, 1983). Despite these criticisms, these approaches to leadership do suggest that organizational effectiveness is improved if the leader's behaviour is adjusted to suit the particular situation (Yukl and Lepsinger, 2006) and recently Goleman has refocused his 'emotional intelligence' idea into a leadership style that could be learned (Goleman, 2004).

Lewin's questioning of traditional authoritarianism was continued by others (Herzberg, 1959; Katz, 1960; Maslow, 1943) and was memorably crystallized by Douglas McGregor's 'theory X and Y'. He said, expanding on theory Y: 'we have not yet learned enough about organizing and managing the human resources of enterprise. Fortunately, an increasing number of managers recognize the inadequacy of present methods. In this recognition lies the hope of the future.' (McGregor, 1960, p232). With this, McGregor anticipated the 21st century 'mega-trend' in the developed world away from compliance-based authoritarianism towards forms of leadership based on engagement and building commitment (Pendleton and Furnham, 2011).

Among writers from much earlier times, Robert Owen stands out as prescient of this modern leadership trend: 'There were two ways to govern the population. 1st, by contending against the people,– to have many of them tried for theft, some imprisoned and transported, others condemned to death. This has ever been the practice of society. Or 2ndly, to consider these unfortunately placed people the creatures of ignorance and vicious circumstances, for which society alone was responsible. I had to change their evil conditions for good ones and thus, in due course, to supersede bad characters by good. This required illimitable patience, forbearance and determination.' (Owen, 1857, p7). Owen greatly improved working conditions in his mills and established Britain's first infant school, with his intent that education was to make everybody 'good, wise and happy' (Gordon, 1994, p3). This 'positive leadership' philosophy was echoed by Barnard well over a century later, who proposed an 'acceptance theory of authority' (Barnard, 1938) that said that followers would follow an instruction only if they considered it valid. 'A directive was accepted by the employee if he understood it, was able to follow it, and he believed it appropriate as it related to his understanding of organizational goals' Barnard quoted in Pindur, Rogers and Kim (1995, p63).

Attempts to understand the leader-follower relationship led to 'path-goal theory' (House, 1971) that attempted to integrate authoritarian and considerate leader behaviours using expectancy motivation theory (Vroom, 1964) in different work situations of job scope, ambiguity and autonomy, an early introduction of context to leadership theory.

Further work in the early 1970s measuring differences in individual leader-follower relationships (so-called 'vertical dyad linkages') led to the development of Leader-Member Exchange Theory (LMX) theory (Dansereau et al, 1975). This theory attempts to explain the leadership relationship from both leader and follower perspective, analysing individual relationships in terms of latitude and influence or directive supervision, and in later developments of the theory numerous other nuances of those.

Until recently though, the main focus of leadership research has remained the leader. Analysis of charismatic leaders (House, 1977) led to the distinguishing of 'transformational' from 'transactional' leader behaviours (Burns, 1978) and more recently to 'authentic' leadership theory, introducing the idea of morality, 'conscience and the scope for altruistic intention' (Bass, 1999, p211).

2.4.2 Leadership as more than just leaders

In the late 20th and early 21st centuries, the historical leader-centric view of leadership has been questioned. In 2000 Gronn claimed, building on socially distributed cognition and activity theory, that leadership invariably exists in distributed form (Gronn, 2000). He proposed that leadership is influence, frequently reciprocal, expressed in subtle ways and emerging from the flow of activities, and only makes sense in its context, which must include the temporal context of duration and timing. This affirmed and developed a much earlier view that leadership is a shared phenomenon and that 'leadership is relative always to the situation.' (Gibb, 1947, p270). The idea of distributed leadership has developed into a significant field of research and become a major influence particularly in the fields of public services and education, but how it is enacted has been criticised (Currie, Lockett and Suhomlinova, 2009).

In recent years a number of reviews of leadership research have been made, reflecting on leadership as broader than simply the leader. Firstly, in their review of LMX research, Graen and Uhl-Bien classified leadership theory in domains of leader-centric, follower-centric and relationship-centric. The simplicity of this approach could appear superficial but it underlines how much leadership theory is leader-centric, overlooking the other two domains. Their analysis examined the development of the relationship-centric LMX theory, expanding the leader-follower dyadic partnership to group and network levels that they suggest are more representative of reality. They propose that leadership is not formally designed but that its structure emerges from the network of relationships and mutual dependencies that people develop through enacting their organizational roles (Graen and Uhl-Bien, 1995).

This also concurs with Rost's proposed post-industrial model of leadership as a) non-coercive relationships with multidirectional influence between leaders, followers and others, but with power biased towards the leaders; b) leaders who take the initiative with leaderly acts, and multiple followers who are willing to participate; and c) mutual intent to work together to a common purpose to create substantial change (Rost, 1995).

Secondly, Bolden's major review of distributed, or plural, leadership and its siblings e.g. 'shared', 'dispersed' and 'collective' leadership found consensus was limited to a) leadership is an emergent property of or network of interacting individuals (agreeing with Graen and Uhl-Bien) b) leadership has open boundaries and c) leadership expertise is varied and widely distributed. He concluded that the field remains immature and descriptive and cautioned against normative or rhetorical use of this theory, pointing out the inherently political nature of leadership (Bolden, 2011).

In a major analysis of the past century of leadership research, Hernandez et al sought principles that could eventually integrate into a unified theory of leadership (Hernandez et al., 2011). They offered a similar but slightly different analysis to that of Graen and Uhl-Bien, seeing leadership as a system of leaders, followers and context, concluding that all leadership theory tries to answer two key questions: 'Where does leadership come from?' and 'How is leadership transmitted?' and so took locus and mechanism as their classification dimensions.

They chose five loci: leader, context, follower, collectives and dyads, and four mechanisms: traits, behaviours, cognition and affect. They plotted all the main leadership theories on these two dimensions, providing perspective of the nature of each main theory, how they relate and where gaps exist and showing the dearth of focus on either context or affect theory relating to followers. This is interesting in the light of the Rost claim that leadership depends on follower willingness and intent. Including cognition and affect in this classification points out their importance; these writers emphasize that without cognition there can be no sensemaking, and that affect is important since the emotional connection between leaders and followers influences mutual perceptions and shapes their relationship.

A recent review of research into followership proposed two interesting potential conceptual frameworks for understanding how the behaviour of followers contributes to leadership (Uhl-Bien et al., 2014). Firstly, inverting the normal leadership model, a framework that regards followership as an outcome of the behaviours of followers and leaders in their respective roles, and secondly leadership as a process of co-creation that produces leadership outcomes from the interaction of leading and following behaviours, exhibited irrespective of the actors' roles or hierarchical position. This constructionist model embraces leadership as depending on follower behaviours (implying even the existence of follower competences) as much as leader behaviours, implying joint responsibility of all actors, and also recognises that leadership must be context specific. These writers call for more followership research to be done across a range of paradigms and methodologies, suggesting that their 'role-based' framework is more 'entity/postpositive' and the 'leadership process' framework is more 'constructionist/interpretivist'.

2.4.3 'Relational' leadership as process

After making a deeper analysis of the social interactions between entities and reviewing research on this, Uhl-Bien proposed a 'relational leadership theory' as a framework for understanding leadership as a process of social influence that leads to the emergent changes discussed earlier (Uhl-Bien, 2006). She interpreted the term 'relational' as having the meaning of 'socially-constructed', that is, creating mutual understanding of some aspect of reality as a shared process between two or more people. A relational perspective thus sees organizations as constantly changing networks of people working together and reacting with each other and with the wider system they are part of. She made the distinction between 'entity' leadership, that focuses on interpersonal relationships in conditions of a relatively stable organization (i.e. formed of nouns) and 'relational' leadership that focuses on the processes of relating and sees leadership as a dynamic process of organizing (i.e. formed of active verbs).

Uhl-Bien also pointed out that since socially constructed leadership is embedded in context, formed of local, cultural and historical processes, this presents consequent difficulty of developing theory from observations that are themselves constructed by the observers. However, this inclusive ontology offers the advantage that it does not preclude positivist entity theories, so, she proposed relational leadership theory as a framework that can include all approaches to understanding leadership as formed of relationships, since in practice that is how leadership is enacted. This framework can provide a shared space where current such theories including LMX, distributed, relational and others can perhaps cross-fertilize.

This concept of relational leadership as a process has been developed further by DeRue, who offered a theory of 'adaptive leadership' that is a process of repeated leading-following social interactions that co-construct identities and relationships as leaders and followers. He proposed four configurations of leading-following relationships as centralized (a single leader) distributed (leadership moving around within the group over time) shared (all members contributing to leadership) or void (lack of leadership or lack of followership) and that each of these configurations results in a particular construction of leadership identity (DeRue, 2011). This may be an example of the process of theory development that Uhl-Bien had in mind for her 'relational leadership theory framework-space.'

2.4.4 Leadership in context

Although overlooked by much research until recently, the view that leadership is embedded in context, formed of local, cultural and historical processes now seems well-accepted (Gronn, 2000; Uhl-Bien, 2006). Offering a 'contextual theory of leadership' Osborn, Hunt and Jauch proposed four contexts: stability, crisis, dynamic equilibrium and 'edge of chaos'. They concluded that a different schema or mental model of leadership is needed for each context, dimensionalised in terms of position in the hierarchy, patterning of attention (how information is used) network development and organizational performance (Osborn, Hunt and Jauch, 2002). In a later study of the leadership of technical alliances between innovating firms, Osborn and Marion made similar conclusions, specifically that when faced with such complexity, interaction leading to creative emergence was positively influenced by the patterning of attention and the external network development of the alliance head (Osborn and Marion, 2009). This is not surprising since their characterisations of context are very equivalent to Snowden and Boone's 'simple, chaotic, complicated and complex' model, with the 'edge of chaos' the same as the metastable condition of complex adaptive systems described by Lichtenstein and Plowman. This concurrence of analysis and view gives some confidence in the practical utility of this context typology for interpreting and modelling leadership and also in its potential normative and predictive value.

A typology of 'extreme' contexts, associated with events or situations with severe threats including potential for loss of life, has been proposed (Hannah et al., 2009) but report conflicting theories of leadership in such contexts: the suggestion that when overwhelmed by the level of threat people feel a need for decisive leaders to bring clarity of action being countered by other were more effective, and further, that what is appropriate and effective leadership of an extreme event is likely to be different for the preparation, response and recovery phases. These writers propose that an appropriate, context-specific, combination of adaptive and administrative leadership is important not only for organizations that normally operate in extreme contexts (e.g. emergency services, military) but also for 'naïve' organizations that may face such threats only rarely.

This typology has been developed further, discriminating between 'risky', 'emergency' and 'disrupted' contexts (Hallgren, Rouleau and de Rond, 2018, p112) each with intersecting but differing organizational and leadership characterisations. The operation of high hazard technology fits the 'risky' characterisation, and these writers point out the difficulty for this kind of activity of organizational learning from extreme events such as major accidents, since their occurrence is normally infrequent, especially within a single organization, so other learning opportunities, such as minor events or errors – potential incidents and near misses that identify system weaknesses – are especially valuable. However, this learning requires 'a high degree of psychological safety, making it easier for people to identify, and own up to their involvement in making, mistakes'…and…'leadership is key to fostering psychological safety through effective coaching, communicating, and minimize power and status differences' (Hallgren, Rouleau and de Rond, 2018, p123).

Discourse analysis provides another view of how context relates to leadership (Fairhurst, 2009) Discourse analysis is focused only on understanding the specific problem under examination, and therefore is very concerned with historical, cultural and political aspects of context. She quotes Weick: 'order in organizational life comes just as much from the subtle, the small, the relational, the oral, the particular, and the momentary as it does from the conspicuous, the large, the substantive, the written, the general and the sustained' (Weick et al., 2005). And, referring to Grint's (2005, p1477) analysis of contexts relating to three different types of problem as 'Critical, Tame or Wicked', she describes how context can be socially constructed as a framing of a situation; for example, 'a crisis, real or fabricated, can justify a command posture…casting a problem as tame can justify a managerial response… complex or 'wicked' problems…require a leadership response' (Fairhurst, 2009, p1615) and points out that researchers need to be aware of this phenomenon.

Complexity and its wicked problems is put alongside volatility, uncertainty and ambiguity to make the popular acronym 'VUCA' that has been used to describe the context of the modern political and business environment. However, to make sense of this context these terms must be untangled and strategies formed to cope with each one (Bennett and Lemoine, 2014).

Finally, temporal aspects of context, timing and velocity, are also important. For example, the urgent time constraints in emergency medicine traditionally have encouraged a directive, 'command' approach to leadership in these situations but evidence from some research counters this, suggesting that enabling leadership behaviours can produce more positive outcomes from better teamwork (Yun, Faraj and Sims, 2005).

In summary, leadership cannot be usefully separated from its context, so any reconciliation of the paradoxes of organizational reliability and safety must include analysis and understanding of context.

2.4.5 Leadership-As-Practice

The foregoing established there is a growing consensus that leadership is embedded in context: of the work, the organizational environment and the relationships between the people involved. Considering further the context of work, many writers have emphasised the idea of leadership as a phenomenon that arises from what is being done. As we saw earlier, Gronn (2000) proposed that leadership is influence, frequently reciprocal, expressed in subtle ways and emerging from the flow of activities; Graen and Uhl-Bien (1995) suggested that leadership emerges from the complex network of relationships and mutual dependencies that people develop as they enact their organizational roles.

These ideas have evolved into a theory of 'Leadership-As-Practice' (Raelin, 2016) that integrates several other theories of leadership, incorporating the ideas of leadership being seen as a process (Avolio and Gardner, 2005) that is relational and communicative (Fairhurst and Uhl-Bien, 2012; Tourish, 2014) and also bound up in generating adaptive change (DeRue, 2011; Heifetz, Grashow and Linsky, 2009).

'Leadership-As-Practice' also proposes that leadership emerges, in the form of a practice of 'immanent collective action' unfolding from the discourse and actions of people working together (Raelin, 2016, p3); from practices such as dialogue, listening, signalling, co-creation and reflection, synthesizing ideas and catalysing action, as well as the more administrative leadership practices such as planning, directing and monitoring. It is suggested that the salience of such practices can be seen in behavioural, cognitive or emotional effects (Fischer, Dietz and Antonakis, 2017, p1739) within the specific context formed of the work, the organizational environment and the characteristics of the individual people involved (Osborn and Marion, 2009).

Leadership in this analysis is thus woven into shared or collective processes and interactions that 'can take on multiple directions, transcend formal hierarchies and involve multiple actors' and often involve 'skilled improvisations, dialogue and collaborative learning' (Denyer and Turnbull James, 2016, p264). Although the large and visionary are acknowledged as valid elements of leadership, it is suggested that leadership may also emerge from the small and mundane: relational practices such as listening (Alvesson and Sveningsson, 2003) or recognising emotional expressions (Walter et al., 2012) and organizing practices such as ensuring adequate resources, organizing meetings and facilitating information flow (Huettermann, Doering and Boerner, 2014).

Protagonists of Leadership-As-Practice hold that it has broad potential explanatory power. Carroll (2016, p93) has proposed 'that a practice orientation to both leadership and identity has the potential to offer unique insight into mutual construction of leadership identity by both organization and subject, and holds some promise of not over-estimating either the subject or the context in such a process'. However, it is acknowledged that as a recently proposed integrated theory, Leadership-As-Practice is in need of more supportive evidence from empirical research.

Moreover, its theoretical value has been questioned, as having a 'lack of critical engagement, particularly in relation to its neglect of asymmetrical power relations and control practices' and focussing almost entirely on agency (Collinson, 2018a, p363). Collinson recognises the importance of practices but points out that practices are inevitably influenced by structure: 'critical perspectives view practice and power, and structure and agency, as inextricably linked' (Collinson, 2018b, p386).

Much leadership theory privileges agency over structure, despite their reflexivity: 'morphogenetic and structuration approaches concur that 'action' and 'structure' presuppose one another' (Archer, 2010, p226). Structure is thus acknowledged as important to leadership, reflexively with agency. If leadership is processual and emergent then it must also, reflexively, create structure. As Tourish (2014, p86) points out, leadership is 'a communicative process whereby agents claim entitative status for emergent social structures. Moreover, without such claims being made, negotiated and formalised there would be no over-arching organizational entity within which leaders emerge from leadership processes'.

<u>Leadership-As-Practice Research Gap</u>

In summary, although Leadership-As-Practice appears to offer more promise for explaining the reconciliation of paradox than traditional leader-entity theories, these challenges represent an important research gap.

2.4.6 Complexity: enabling rather than controlling

Alongside these developments in leadership theory, the traditional hierarchical and directive paradigm of organizing has been challenged by the idea that organizations can be thought of using 'complex adaptive systems' (Holland, 2006, p1) as a useful metaphor (Lichtenstein, 2000; Osborn and Hunt, 2007; Rosenhead et al., 2019; Schneider and Somers, 2006; Tsoukas and Dooley, 2011). Complex adaptive systems are characterised as self-organizing, able to change and learn from experience, with emergent properties such that the whole is greater than the sum of the parts.

During the last two decades of the 20th century a number of thinkers made the connection between organizations and complex systems theory. Already in 1979 Weick had interpreted evolution and natural selection, adopted from the emergence of species in the natural world, as components of organizing (Weick, 1979) and by 2009 he had connected the self-organizing aspect of complexity theory with social cognition as organizational sensemaking (Weick, 2009). Meanwhile a panel discussion in 1998 between Henry Mintzberg, Larry Prusack and others sparked great interest in applying complexity theory to leadership (Petzinger et al, 1999) and in 2000 Lichtenstein described how effective self-organizing in a rapidly growing start-up company was enabled by 'combining high degrees of structuring with high levels of openness and communication' and compared this with the failure of another start-up company that was led by traditional command and control. He claimed that 'by giving a few simple rules to all components of a complex adaptive system, highly coherent collective behavior can emerge of its own accord much more effectively than if the behavior could have been planned or directed from the outside…by trusting the insights of those nearest the organization's core, a system-wide intelligence is brought to bear that ultimately produces emergent systems that are far more effective than formally controlled ones.' (Lichtenstein, 2000, p139).

A more detailed explanation of how an emergent system may be more effective than a controlled one was offered later by Lichtenstein and Plowman. They claim that leadership may emerge from interactions at all organizational levels, between individuals whether formal leaders or not. They view leadership as coming from the dynamic interactions between entities rather than the behaviours of those entities, 'aiming for the "space between" individual and context - the meso space' (Lichtenstein and Plowman, 2009, p618).

Developing the metaphor of an organization as a complex adaptive system, their 'meso' theory suggests that such 'micro-level' behaviours, enacted by anyone, aggregate to four contextual 'macro-level' conditions that can lead to constructive emergence: 1) disturbance of the system's equilibrium, so that it becomes metastable and thus 2) sensitive to small inputs, which then can create large non-linear effects that can lead to 3) recombination, that is emergence of a new (assumed to be improved) configuration and finally 4) stabilizing feedback that allows consolidation of the emergent new order. These four conditions are similar to those observed in physical complex adaptive systems such as a forest, that follows 'an adaptive cycle of growth, collapse, regeneration, and again growth' (Homer-Dixon, quoted in Boulton, Allen and Bowman, 2015, p16).

The need for leadership to enable 'adaptive work' that would generate necessary change in the face of complex problems had been emphasised earlier (Heifetz and Laurie, 1997, 2003).

These writers re-framed the role of leaders as distinguishing between 'technical' and 'adaptive' challenges and then, for the latter, instead of attempting to provide answers, suggesting leadership practices such as 'giving the work back to the people' by asking questions that encouraged everyone in the organization to contribute to finding solutions to such complex problems, challenging rather than clarifying current roles and norms, sharing the external environmental pressures internally rather than shielding the organization from them and provoking constructive conflict rather than defusing it.

These practices were later re-stated as 'adaptive leadership', which recognised that corporate adaptability comes from 'the accumulation of microadaptations originating throughout the company in response to its many microenvironments' rather than some 'sweeping new initiative dreamed up at headquarters'. These adaptive leadership practices foster such experiments by 'using leadership to generate more leadership deep in the organization' (Heifetz, Grashow and Linsky, 2009, p4) and also reflect the processual nature of leadership.

2.4.7 Complexity Leadership Theory

Marion and Uhl-Bien have also argued that complexity theory focuses leadership on enabling rather than directing organizational effectiveness. They have suggested that innovation is most effective with moderate organizational coupling; sufficiently loose to generate creativity and sufficiently tight to enable the effective communication necessary for cross-fertilization of ideas and avoidance of too much duplication, with clear implications for leaders: 'complex leaders drop seeds of innovation rather than mandating innovation plans… create opportunities to interact…tend networks… they catalyze more than they control. Complex leaders are tags, symbols…[who] can perceive those networks; they can help enable useful behaviors, including the expansion and complexification of the networks. They cannot, however, control those networks' (Marion and Uhl-Bien, 2001, p414).

Later, in the editorial introduction of a special 'Leadership and Complexity' issue of Leadership Quarterly, Marion and Uhl-Bien described complex adaptive systems as having direct and indirect influence loops providing rich but balanced interaction, with the influence of any one agent limited by its localized understanding, the system being too complex to comprehend as a whole. Also that such systems are therefore also relatively unstable, operating far from equilibrium, and because they are constantly evolving they retain memory of their history (Marion and Uhl-Bien, 2007). In their own article in the special issue, Uhl-

Bien, Marion and McKelvey describe leadership as an interactive system of dynamic, unpredictable agents that interact with each other in complex feedback networks, which can then produce adaptive outcomes such as knowledge dissemination, learning, innovation, and further adaptation to change, labelling this as 'Complexity Leadership Theory' (Uhl-Bien, Marion and McKelvey, 2007, p229)

Complexity Leadership Theory builds on earlier Uhl-Bien's earlier 'relational leadership theory' (Uhl-Bien, 2006) in which she viewed organizations as constantly changing networks of people working together and reacting with each other and with the wider system, an idea that was later developed by DeRue in the light of complexity. His four configurations of leading-following relationship (discussed earlier) replicate into group-level leadership structures that are emergent properties of this complex adaptive process model of leading and following. He suggests that distributed and shared configurations should produce a highly dynamic and variable leadership identity construction process, and further, that for high effectiveness of group-level leadership, a 'requisite variety' of leading-following relationship configurations is needed, with effectiveness highest when the variability in leader-follower configurations is the same as the variability in the group's environment (DeRue, 2011). The interesting implication is that to operate effectively in complex environments, groups should have diverse configurations of leader-follower relationships. Such diversity would follow from understanding leadership as socially constructed (i.e. self-defined) rather than as the imposed leader-follower hierarchy of entity theories. DeRue thus claims a reconciliation of entity leader-follower relationship theories with relational social construction theories, and at same time also may also offer a corollary of complexity leadership theory.

The complexity of leadership is widely recognised. It is seen as a 'social and goal-directed influence process that unfolds in space and time' that 'produces effects via multiple paths' (Fischer, Dietz and Antonakis, 2017, p1747). This draws an image of emergence and complexity. Further, 'leadership cannot be understood so long as it is envisaged as a means whereby powerful actors exercise more or less unidirectional influence on others and on organizational systems. Every aspect of leadership and the identities of those who hold leadership positions are themselves complex' (Tourish, 2019, p233).

That said, leadership as a concept must imply the existence of leaders, and notwithstanding the risk of hubris with heroic leaders and associated leader-centric theories, the enactment of leadership by leaders, however they are instituted, is acknowledged as the essence of leadership, in the context of a specific relationship with others, who as a result give their support to a specific vision, aim or goal, which may indeed be co-constructed (Drath et al., 2008). Whether individuals have formal authority or not, leaders can be seen as individuals who have 'claimed entitative status for the role of leader' (Tourish, 2019, p229) without any conflict with the idea of leadership as a phenomenon of leaderly influence that is emergent from process, relations and context (Ladkin, 2010).

An important feature of Complexity Leadership Theory is its integration of the complex adaptive systems metaphor with the Leadership-As-Practice model. Complexity Leadership Theory claims that administrative and adaptive processes can be effectively entangled by combinations of leadership practices: 'administrative' practices that are directive and managerial, 'adaptive' practices encouraging innovation and learning, and a third kind, 'enabling' practices, supporting networks, sensemaking and using constructive tension to help the other two operate together (Uhl-Bien, Marion and McKelvey, 2007).

However, in their very structured critical review of current research and leadership theory development, Avolio et al, noting the trend away from entity-based theories and towards a more holistic view of leadership as emergent from the complexity of the organization, suggest that 'the complexity leadership field clearly lacks substantive research' (Avolio, Walumbwa and Weber, 2009, p431). In a similar manner, Bolden (2011, p251) reviewing plural leadership more broadly concluded that 'descriptive and normative perspectives which dominate the literature should be supplemented by more critical accounts'.

Another criticism is that Complexity Leadership Theory as currently proposed is inconsistent in viewing organizations as complex adaptive systems yet not explaining the mechanisms by which leadership may emerge from individual interactions, instead remaining leader-centric: 'traditional leadership thinking inserted into a complex organizational context' (Tourish, 2019, p223). The theory relies on traditional agentic, even heroic, leaders viewing their organizations as complex and so encouraging experimentation, promoting learning, injecting tension and conflict to encourage creativity, creating the conditions for informal networking but still retaining control within limits set by them. Viewing organizations as truly complex adaptive systems would mean accepting that instead of formal leaders exercising command and control, 'leaders are themselves part of the complexity processes they manage' (Tourish, 2019, p229) and that who exercises leadership over whom in a given situation will depend on the context, history and dynamic interaction processes.

This is a logical challenge; a more complete complexity theory of leadership would indeed include an explanation of how leadership emerges and how asymmetrical power relations and control practices may be accommodated. But there may still be merit in a theory that helps explain how leaders, however they are instituted, can be more effective by adopting a more realist approach that takes better account of complexity.

Complexity Leadership Theory Research Gap

In summary Complexity Leadership Theory adds to Leadership-As-Practice with a more detailed and complete account of how complexity theory informs leadership, and specifically proposes that administrative and adaptive processes can be effectively entangled by combinations of leadership practices: adaptive, administrative and enabling that are appropriate to the organizational context, and so taken together the two theories do appears to offer more promise for explaining the reconciliation of paradox than traditional leader-entity theories. However, so far there are few empirical studies providing evidence to support them, and they have both received important challenges. This represents a significant gap that this research addresses.

2.5 Reconciling Paradox

March stated 'the basic problem confronting an organization is to engage in sufficient exploitation to ensure its current viability and, at the same time, devote enough energy to exploration to ensure its future viability' (March, 1991, p105). Earlier it had been shown that different organizational forms are better suited to different activities (e.g. research and production) within the same organization, and complex organizations with multiple separate activities need to balance this differentiation with integrative processes, and this takes energy and effective management (Lawrence and Lorsch, 1967). This built on the observation that a stable environment suited a 'mechanistic' hierarchical organizational form with defined roles and standardised operating procedures, while organizations operating in turbulent environments need to be more 'organic' with more informal ways of working and more lateral coordination (Burns and Stalker, 1961). A later more nuanced theory of organizational form and function based on five idealised organization types (Mintzberg, 1980) describing how effective organizations configure their structural elements to suit their activity and environment, proposed that for sophisticated innovation in complex and dynamic environments a form of 'adhocracy' is needed, organic and project-focused, relying on matrix structures and coordination by mutual adjustment between experts. Mintzberg pointed out that this typology is simply a conceptual framework; many real organizations are hybrids, and hybridity could be a means for organizations to find a good balance between exploitation and exploration.

Reviewing research on organizational ambidexterity, O'Reilly and Tushman suggest 'the difficulty in achieving this balance is a bias in favour of exploitation with its greater certainty of short-term success' (O'Reilly and Tushman, 2013, p325). Exploration, they claim, is by its nature, inefficient and 'associated with an unavoidable increase in the number of bad ideas'. This is reminiscent of the system safety theorists' criticism that HRO theory apparently encourages people at the sharp end of high hazard technology, e.g. pilots, chemical plant control room operators, to improvise when they think that established procedures seem inappropriate, with potential negative unintended consequences (Leveson et al., 2009). This notion lies at the heart of the difficulty of reconciling the two paradigms, since in contrast, as discussed earlier, without mindful sense-making the slavish following of rules can also lead to danger (Dekker, 2003). O'Reilly and Tushman's observation of bias in favour of exploitation also speaks to the bias towards the hierarchical, standardised 'mechanistic' structures prevalent in high hazard technology operations. O'Reilly and Tushman identify three ambidexterity mechanisms: 'sequential', i.e. changing structures over time, 'simultaneous or structural', i.e. separate groups within the organization for the two separate strategies and thirdly 'contextual', referencing Gibson and Birkinshaw's seminal 2004 ambidexterity study of 4,195 individuals from 41 business units in 10 multinational firms.

Gibson and Birkinshaw describe contextual ambidexterity as 'the behavioural capacity to simultaneously demonstrate alignment and adaptability across an entire business unit'. By 'alignment' they mean coherence in patterns of activities, thus similar in meaning to exploitation, and they use the term 'adaptability' in the sense of capacity for rapid reconfiguring of activities in response to changes in the environment, implying the problem-solving and learning that exploration involves. They define context as 'the systems, processes and beliefs that shape individual-level behaviours in an organization' and propose that contextual ambidexterity is achieved by 'building a set of processes or systems that enable and encourage individuals to make their own judgments about how to divide their time between conflicting demands for alignment and adaptability' (Gibson and Birkinshaw, 2004, p210).

This view of ambidexterity is the most interesting of the three in the search for complementarity between the 'System Safety' and 'HRO' paradigms since it implies that there are indeed processes that enable individuals to reconcile in 'real-time' such conflicting demands depending on how they interpret the particular situation facing them. Analysis of the sequence of events in high hazard technology disasters shows that they often develop over significant periods of time, and give out warning signs in the minutes, hours, days, weeks or even months before the event (Hopkins, 2005; Reason, 1997) so successful interventions to avert them need to be made in those time-frames. Because of this timing, intervention decisions sometimes need to be made by people at the sharp end of operations, who therefore, in the view of writers on HRO, need to be empowered to respond with a strong response to a weak signal, so that 'when they see a problem they own it either until they solve it or until someone who can solve it takes responsibility for it' (Roberts, 1990, p171).

Gibson and Birkinshaw suggest this ambidextrous capacity is enabled by the existence of an organizational context with four attributes: discipline, stretch, support, and trust as proposed by Ghoshal and Bartlett (1994, p95) and quoted in Gibson and Birkinshaw (2004, p213) which together induce individuals to act with initiative, cooperation and learning and 'to do whatever it takes to deliver results'. They characterise 'discipline' as having clear standards of performance and behaviour together with open, candid and rapid feedback, 'stretch' by collective identity in which people find personal meaning in their contribution the organization's purpose and shared goals, 'support' by having access to shared resources, freedom of initiative and senior people providing help and guidance rather than authority, and 'trust' by just and fair decision processes, involvement of individuals in decisions and activities affecting them, and the staffing of positions with competent people. Finally, Gibson and Birkinshaw emphasize the important influence of senior leaders on the creation of a supportive organization from which contextual ambidexterity can emerge.

2.5.1 Managing tensions between 'administrative' and 'adaptive' leadership

The important influence of leadership on reconciling the adaptive/administrative paradox is thus well supported (Lewis, Andriopoulos and Smith, 2014; Smith and Lewis, 2012; Swart et al., 2016; Yukl, 2008)

However, the traditional 'administrative' leadership paradigm of 'command and control' with its assumption that adherence to operating procedures is necessary and sufficient appears inadequate to explain how such paradoxes can be successfully managed. Theories of ambidexterity and paradox point to other views of leadership that appear more promising.

A mechanism of 'contextual ambidexterity' is suggested (Gibson and Birkinshaw, 2004, p209) that relies on an organizational context of support and trust, created by leaders (Ghoshal and Bartlett, 1994). This seems comparable to the 'holding environment' proposed by Heifetz and Laurie (1997, p134) as required for adaptation to take place and being the work of leaders to create such enabling environments. The importance of leadership skills such as communication and complex cognition is also emphasised for coping with paradox (Smith and Besharov, 2019; Smith and Lewis, 2012).

Snowden and Boone, presenting a framework for analysing the nature of issues facing an organization that differentiates the complex from the complicated, the simple and the chaotic, also put forward a similar list of specific leader actions that enable emergence of the adaptive behaviours needed in an organization facing complexity. They claim that attempts to over-control will stifle the emergence of informative patterns and instead leaders should encourage dissent and diversity, stimulate democratic discussion and establish simple rules, saying that 'leaders who try to impose order in a complex context will fail, but those who set the stage, step back a bit, allow patterns to emerge, and determine which ones are desirable will succeed' (Snowden and Boone, 2007, p74).

In similar vein, Osborn, Hunt and Jauch (2002) argue that simple, hierarchical structures underestimate the complexity of the context in which the organization must function and adapt, and refer to the 'law of requisite variety' (Ashby, 1958, p4) that says that it takes complexity to defeat complexity. [This same concept is applied to managing the risks of organizational accidents with 'defences in depth' and dispersed decision-making (Reason, 1997).] Uhl-Bien, Marion and McKelvey (2007) point out the need for leadership of knowledge-based activity to move away from the currently dominant leadership paradigm of formal hierarchical structures aimed at production efficiency and 'other bureaucratic notions that likewise mute uncontrolled behaviors' (Uhl-Bien, Marion and McKelvey, 2007, p301), and propose a 'complexity leadership theory' that has three aspects they see as entangled with each other: 'adaptive', (e.g. enabling creative problem-solving) 'administrative' (e.g. planning) and 'enabling', this latter minimizing the constraints of the (necessary) bureaucracy.

Entanglement of adaptive and administrative leadership manifests in the avoidance of undue constraint of creativity by micromanagement while providing the framework and conditions within which adaptive behaviours can take place. Uhl-Bien et al emphasize that it is the entanglement of 'enabling' leadership with the other forms that is critical for achieving balance and so managing the tension between them. They give examples of enabling leadership as injecting strategic direction while encouraging autonomy to implement within limits, providing resources for adaptive work, setting recruitment policies to increase diversity and acting as 'agents' by championing the implementation of new ideas and recognising when too much consensus may stifle creativity, so welcoming constructive tension, playing devil's advocate and addressing 'elephants on the table'.

The meaning of Ghoshal and Bartlett's terms of 'support' and 'trust' resonate with 'adaptive leadership' as described by Uhl-Bien, and the meaning of 'discipline' and 'stretch' with her 'administrative leadership'. Altogether, Gibson and Birkinshaw's analysis of how contextual ambidexterity is created is very reminiscent of the entanglement of leadership forms that construct enabling leadership.

Interest in complexity theory and adaptation has focussed on organizations' ability to innovate, but the same issue of organizational learning is important in in the area of high hazard technology risk management. Adaptation in this field translates as the mindful sensemaking, hazard perception, situation awareness and related notions proposed as important for resilience and safety within HRO and the related theories.

The practices of enabling leadership described by Uhl-Bien and Arena (2017, p17): 'Increasing and decreasing tension to manage levels of conflicting, creating or energizing network connections that enable information flow, creating simple guidelines for behavior that enable network & complexity dynamics (e.g., brokering, cohesion, energizing, conflicting, linking up, network closure)' producing the conditions for emergence of adaptive change seems very well aligned with the concept of contextual ambidexterity. A good example of contextual ambidexterity in action may be seen in the observation from early HRO research (La Porte, 1996; Roberts, 1990) that as operating conditions changed the authority structure changed from hierarchical, becoming flatter, integrating skills and experience and allowing decisions to migrate to lower organizational levels. These authors did not though, explain the enabling mechanisms that made that happen.

Contextual ambidexterity arising from enabling leadership, allowing the co-existence of operational discipline with expert improvisation and mindful sensemaking, may be the key to understanding how the paradoxes of organizational form and leadership are reconciled effectively to improve the reliability and safety of high hazard technology.

2.6 Conclusions from the literature review

The literature review addressed four questions that arose from the scoping study. In summary, these are answered in the following::

a) What are the important principles and components that make up the two main Organizational Reliability and Safety paradigms – How can they be dimensionalised?

The important dimensions of the traditional and dominant 'Safety Management Systems' paradigm are administrative practices of systematic hazard and risk analysis, design of defences in depth and implementation by 'plan-do-check-act' systematic management reliant on operational discipline. The 'HRO / System Safety / Safety II' paradigm includes adaptive practices of active seeking of potential system weaknesses, a norm of mindful compliance that fosters constructive challenge of existing processes and accepts expert improvisation as necessary to cope with inevitably imperfect system design and for organizational learning.

b) How do the two paradigms conflict and how do they complement each other? Do they represent a duality or dualism?

The two paradigms do appear as a dualism, where the essential elements of operational discipline of compliance and improvisation being apparently mutually exclusive. However, if the approach is adopted of mindful compliance that includes and expects challenge and modification of procedures, then it is possible to view the two paradigms as an interdependent and mutually enabling duality. The conditions under which that can operate is the main interest of the research.

c) How do aspects of each paradigm fit in different organizational contexts?

The compliance-based approach of 'Safety Management Systems' naturally fits in the traditional hierarchical organizational context. The more adaptive practices inherent within the 'HRO / System Safety / Safety II' paradigm appear to require a more flexible organizational context that is supportive of challenge. Understanding and characterising this kind of organization also represents an important area for research.

d) What is the role of leadership in application of both paradigms?

The 'command and control' leadership paradigm fits easily with the traditional 'Safety Management Systems' approach; the role of leadership in the 'HRO / System Safety / Safety II' paradigm not well understood and is an important part of the main research interest. Theories of complexity leadership and Leadership-As-Practice appear promising.

Research gaps identified

Safety

This review has identified that the traditional and still dominant paradigms of safety management systems, hierarchical organizational form and leader-centric command and control appear not to provide a complete enough description of the processes that lead to the safety of high hazard technology. These traditional forms of leadership and organizing, may be inhibiting potentially valuable adaptive processes of sensemaking and naturalistic decision-making inherent in HRO theory by failing to reconcile paradoxes of control and adaptation such as operational discipline vs sensemaking, clarity of structure vs flexible decision-making and leader vs leadership.

Leadership and reconciling paradox

Recent developments of leadership theory viewing leadership as a relational and processual phenomenon in the form of practices that emerge from the working context, may reveal ways that these paradoxes can be reconciled. Leadership practices based on theories of Complexity Leadership and Leadership-As-Practice may enable contextual ambidexterity by encouraging adaptive processes and practices of sensemaking and competent improvisation within traditional bureaucracies in which administrative processes and practices are also important. Empirical evidence supporting these theories remains weak, however, and some challenges have been made.

Accident causation analysis and organizational learning

The review has also identified ambiguities in the understanding of accident causation and hence the investigation and analysis of accidents, notably the dominance of 'root cause' analysis which largely identifies administrative causal factors at the expense of possible adaptive factors. The review also identified potential for improving organizational learning from a more reflective double-loop approach, within a climate of psychological safety to overcome inhibitions arising from asymmetric power, and from alternative methods of accident analysis such as conjunctural causation.

2.6.1 Research Questions

The following primary research question emerged from the review:

- 'What is the role of leadership in managing the entanglement of rule-based, administrative practices and mindfulness-based, adaptive practices in avoiding, trapping and mitigating incidents in the operation of high hazard technologies?'

In support of this primary research question, three other questions were formulated, focussing on key component issues:

1. How do people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how do the interplay and tensions between rule-following and adaptive practice figure in this?
2. What kind of leadership and organizational practices are seen in organizations operating high hazard technology and how do leadership practices enable ambidexterity in support of process safety?
3. How are process safety incidents investigated and analysed, and how could organizational learning be improved, such as by addressing conjunctural causation?

3 RESEARCH PHILOSOPHY AND DESIGN

3.1 Introduction

The literature review informing this research argued that long term safe operation of high hazard technologies relies on both administrative and adaptive processes, and that traditional administrative leadership is inadequate to explain how these two paradoxically different approaches are reconciled in practice. Alternative leadership theories, including adaptive leadership, complexity leadership and Leadership-As-Practice, together with theories of ambidexterity and paradox, were identified as promising theories to help explain this, but empirical evidence supporting these was weak.

The literature also identified ambiguities in the understanding of accident causation and the analysis of accidents, notably the dominance of 'root cause' analysis which largely identifies administrative causal factors at the expense of possible adaptive factors, and also the possibility of improving organizational learning from alternative methods of analysis such as conjunctural causation.

Empirical studies were therefore designed to seek explanation of how these two paradoxically different approaches are perceived and employed in practice, including evidence to support the alternative theories of leadership and incident causation. Data was sought that would allow comparisons between sites with different safety outcomes and between different types of incident: Actual Incident, Near Miss and Potential Incident (defined below). The rationale was that the identification of and response to Potential Incidents and Near Misses may indicate higher levels of effectiveness of an organization's management of safety, compared with the occurrence of Actual Incidents, and that sites with different safety outcomes may have different contextual conditions and leadership practices.

3.1.1 Research Questions

The primary research question was:

- 'What is the role of leadership in managing the entanglement of rule-based, administrative practices and mindfulness-based, adaptive practices in avoiding, trapping and mitigating incidents in the operation of high hazard technologies?'

In support of this primary research question, three other questions were formulated, focussing on key component issues:

1. How do people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how do the interplay and tensions between rule-following and adaptive practice figure in this?
(addressed in **Paper 2**)

2. What kind of leadership and organizational practices are seen in organizations operating high hazard technology and how do leadership practices enable ambidexterity in support of process safety? (addressed in **Paper 3)**

3. How are process safety incidents investigated and analysed, and how could organizational learning be improved, such as by addressing conjunctural causation?
(addressed in **Paper 4)**

3.2 Research Philosophy

This research has taken a Critical Realist perspective. Critical realism argues that the world is an open reflexive system with emergent properties, allowing both a constructionist view but also holding that objective reality formed of structures and generative mechanisms does exist, and although occluded from simple observation is at least partly discernible by processes of abduction and retroduction (Brewer, 2011) from stratified empirical experiences and actual events (Bhaskar, 2016; Outhwaite, 2019). The critical realist approach is thus well-suited both to appraising the widely differing theories and also to interpreting qualitative data in the light of the theoretical challenges (Kempster and Parry, 2011) and was therefore adopted as the ontological basis for the research. It also fits well with the epistemological framework of case studies for exploring 'the interaction of structure, events, actions, and context to identify and explicate causal mechanisms' (Wynn and Williams, 2012, p793).

A critical realist perspective aims to explore these different overlapping domains, of the 'empirical', being the domain of observable experiences, the 'actual' being the domain of actual events that are generated by mechanisms, and the domain of the 'real' where the mechanisms operate (Bhaskar, 2008). From this perspective therefore, to gain understanding of reality means interpreting empirical observations in terms of what may be the actuality and the possible underlying 'real' mechanisms.

This research has sought to understand the influence of leadership in reconciling the two paradoxically different adaptive and administrative paradigms, specifically seeking empirical evidence that may support the promising theories of Leadership-As-Practice and Complexity Leadership. The practical sources of data were interviews with people actively involved with process safety and documents relating to process safety incidents. Access was available to a number of different sites, enabling a multiple case study. This was much preferred over a single case study since it allowed cross-study comparison. Although two cases may have provided some useful comparison, the addition of a third was much preferred as it was anticipated this could add more analytical strength to the comparison. Although more cases would potentially add even more to this comparative analysis, three sites was a practical limit due to constraints of time and cost.

Consistent with the stratified reality of critical realism and in the interests of developing a more nuanced view of reality, empirical data was obtained in three different ways, providing some degree of triangulation of the data. To achieve this, three different but linked studies were designed, each study collecting data from all three case study sites.

Firstly, interviews were conducted employing Repertory Grid Technique (Kelly, 1955) focusing on the three different types of process safety event described earlier. This technique was chosen because it is considered a powerful and adaptable tool that can 'help respondents articulate their views on complex topics without interviewer bias' (Goffin, 2002, p199). The technique is based on Kelly's 'personal construct' theory, that people make our own personal sense of the world by observing and construing meaning from experiences; people develop, test and update 'constructs' as hypotheses in the light of their own experience. So constructs will therefore differ from person to person, although because we are influenced by other people, our personal constructs will often align and become socially constructed.

It was assumed that perceptions of 'work as imagined' and 'work as done' (Hollnagel, 2014, p40) may vary, that is there may be a gap between what people think is happening and what actually happens. Therefore, the research was designed to explore qualitatively the actors' perceptions as well as the contextual conditions surrounding actual events. Thus Study 1 employed Repertory Grid Technique interviews at the three sites (Sites A, B and C) to examine how people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how the interplay and tensions between rule-following and adaptive practice may figure. This was explored by comparing three types of occurrences, in the form of actual incidents, near-misses and potential incidents, and also the three sites, which have different safety outcomes. The assumption underlying this design is that contextual factors and leadership practices will vary across the three types of occurrence, and across the three sites. That is, agentic action will contribute to trapping and mitigating events and that leadership will play a critical role in enabling these processes.

Secondly, for Study 2, semi-structured interviews were conducted focusing on the practices of leadership and organizing. The interview protocol contained open questions aimed at eliciting observations and views about how leadership was enacted. Although the questions were designed with the theories of Leadership-As-Practice and Complexity Leadership in mind, they were deliberately constructed to avoid suggesting whether such practices were thought of as adaptive or administrative in nature, leaving such categorisation for the later analysis of the interviews. This commenced with a grounded theory approach, subsequently developing a template coding structure through cyclic abductive and retroductive analysis, with the proportion of interviewees mentioning the emerging coding and categories of the observed practices taken as a measure of their relative importance. In the overall analysis, this quantification of the qualitative data is discussed alongside quotations extracted from the interviews to illustrate and maintain the descriptive richness of the resulting categorisation of the practices.

Thirdly, in Study 3, investigation reports and other documents relating to incidents were collected. Being formally written by people directly involved with investigating and analysing the incidents, it was anticipated that these documents may be taken to be more representative of the 'actual' domain. A similar analytical approach was followed for this study as was used in Study 2.

In this way the three empirical studies provided three different views of the same phenomena of interest. These three data sets were then analysed and compared. The research aimed to achieve a better understanding of how organizational contextual conditions and leadership practices influence process safety and incident causation, by integrating empirical data from interviews with the reported actual descriptions obtained from incident investigation reports and related documents. The aim was that this approach may allow more confidence in interpreting the possible mechanisms that may operate in the 'real' domain.

3.3 Research Design

The approach taken to this multiple case study combined theory-driven and grounded methods. Theory derived from the systematic literature review was combined with the results of the Study 1 Repertory Grid interview analysis and used as input, along with concepts emerging from the Study 2 semi-structured interviews, to structure iteratively an evolving template used to code and analyse the Study 2 interviews; a similar process was followed in Study 3 to code and analyse the incident documents. Finally, the results from all three studies were consolidated into a list of possible causal factors in a pilot QCA to explore how learning may be improved from a model of conjunctural causation using this method.

The overall design of the three studies is portrayed in **Fig 3-1**

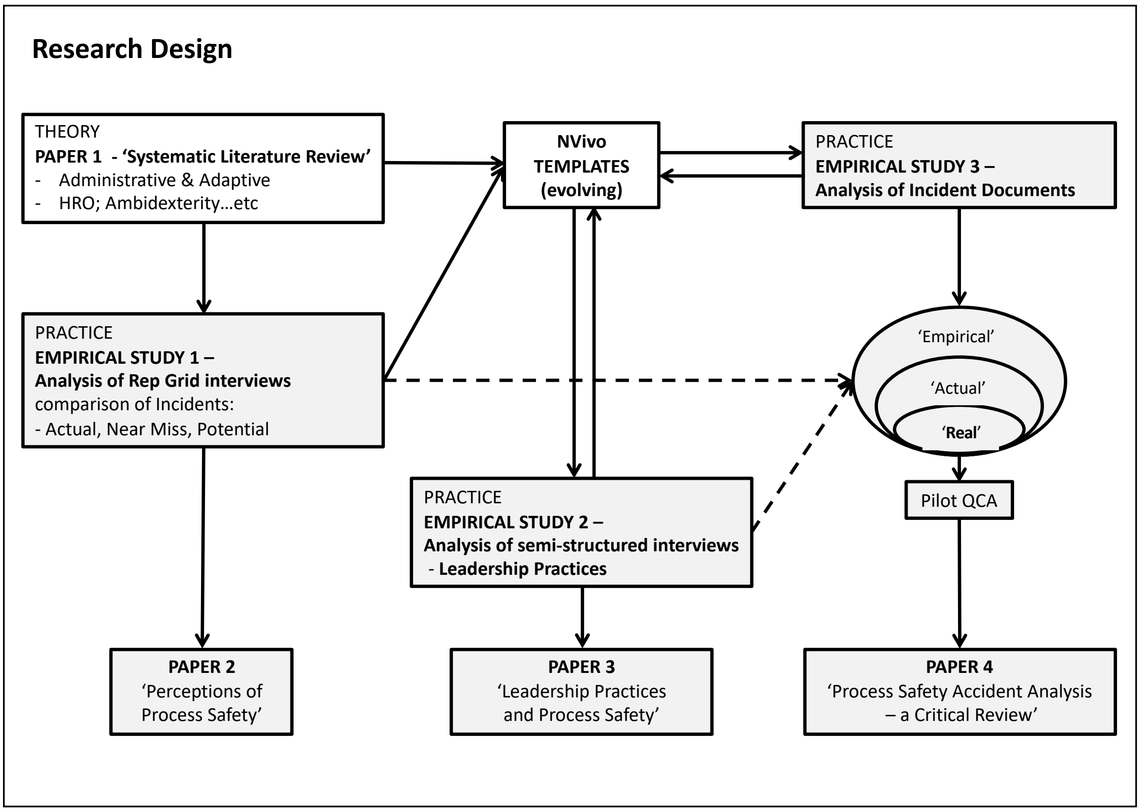

Figure 3-1 Research Design

3.3.1 Data Collection

Data was collected from interviews with operations and maintenance personnel, engineers and managers, including contractor personnel, and from incident investigation reports and other documents. The interviews were conducted in two parts, one part employing Repertory Grid Technique (Kelly, 1955) focusing on the three different types of incident, and the other part semi-structured focusing on leadership practices. The incident documents were collected during or after the interviews.

3.3.1.1 Selecting Fieldwork Sites

The rationale was to seek three different organizations that faced similar high hazards using broadly similar technology in a broadly similar organizational context, but to allow useful comparison and examination of organizational factors that may explain differences, were different in their history of process safety outcomes and in their individual organizational context, such as years of operation since construction, size, geographical location and other possible cultural characteristics.

The research sponsor was able to arrange access for the fieldwork with one multinational organization with a number of suitable operations. Discussion of the research interest with senior managers in the multinational organization led to the identification of a number of possible fieldwork locations. The three sites were selected on the basis of significant differences in size, organizational structure, organizational maturity (years since construction) geographical location and particularly their historical process safety outcomes over the previous few years: Site A had suffered several major incidents including two fatalities, Site B had suffered numerous fires, explosions and well blowouts and numerous near-misses and potential incidents including two (one near-miss and one potential incident) which could have had very serious consequences, while Site C had no major incidents and had recently received a major award for its process safety performance. The different characters of each of these three sites are summarised below.

Site A was a very large petrochemicals complex in the Middle East that had been started up only a few years earlier. The site operated continuously with a typical 24h shift pattern, supervised from a state-of-the-art central control room in radio communication with field operators monitoring the physical plant. The organization was fairly hierarchical, emphasising the importance of compliance with procedures. The operations and maintenance organizations were populated largely with ex-patriot workers of numerous different nationalities, predominantly Asian, and also many from Europe, Australasia and North America. The organization was still in transition from project-based to operations-based, with a number of modification projects in process. The site was receiving from the parent organization significant specialist support in engineering and other fields. An impressive construction safety performance had suffered in the translation into operation, the site having had a number of significant process safety incidents in the early years of operation, including some fatalities.

Site B was an oil & gas onshore production operation with a large number of geographically dispersed fields feeding a single large treatment and export plant. Many of the production units were in locations remote from support infrastructure and were only visited periodically by technical personnel. The number of production units had been growing rapidly over the previous decade, and the older units had been designed and built to lower standards than the more modern ones. The organization was a fairly flat hierarchy with a moderately open culture, steadily expanding, drawing operator/technicians from the local population and providing extensive training. The operation had been acquired only a few years earlier and was still in the process of adopting and implementing the parent organization's engineering and operating standards, for which the parent organization was providing some specialist support. The process safety record was perceived as below-average, the site having suffered a number of significant incidents including some high potential consequence near-misses and potential incidents.

Site C was an offshore oil and gas production operation, with a single large offshore platform that had been in operation for over 20 years, supported by an onshore team of engineering and operations support personnel in a local office. The mature organization had evolved to be a fairly small stable team of people with considerable experience and a markedly open culture of mutual respect; many people had worked together for some years and had rotated through a range of different roles. The local organization was largely self-sufficient with good support from the parent organization as needed. The safety performance was perceived to above average; it had recently been given a major award for its process safety performance.

A summary of the profiles of the three sites is given in **Table 3-1.**

Table 3-1 Summary profiles of the three sites

	Site A	Site B	Site C
Overview	Large single site Petrochemicals complex	Onshore Oil & Gas production, large number of remote production units dispersed geographically; single large treatment and export plant	Offshore Oil & Gas production, single platform; onshore technical and operations support
Location	Middle East	Asia Pacific	Europe
Organization form	Strong hierarchy	Hierarchy / open culture	Weak hierarchy / open culture
Personnel	Largely ex-patriot	Largely local	Largely local
No. of people	2000+	4000+	200+
Organizational maturity	In transition from very large Project to Operations	Mixed; rapidly growing number of physical assets	Stable; very mature
Years of operation	5+	10+	20+
Relation with Parent	Significant specialist support	In process of adopting new parent org technical standards	Fairly independent; supported as needed
Perceived Safety performance	Mixed	Below-average	Above average

3.3.1.2 Selection of Interviewees

The rationale was to seek the views of people with a range of perspectives. It was assumed that an actor's perceptions of events will vary depending on their role (e.g. operations and maintenance, engineering design and asset integrity) different organizational levels: sharp end or blunt end (Flin, O'Connor and Crichton, 2008) and between permanent staff and contractors. Interviewees were sought who had a few years of experience working in the same organization or plant, and who had direct knowledge of process safety incidents and potential incidents. The identification of suitable interviewees was facilitated by a manager at each site nominated by the main contact in the host company for the research.

The primary population sampled was operations and maintenance staff employed by the operating company directly involved with day-to-day running of the plant, at three organizational levels, operator/technician, shift supervisor or engineer and manager. To gain a wider perspective therefore, interviews were also sought with two other populations: firstly employees of companies contracted by the operating company, typically for work supporting maintenance such as scaffolding, welding, electrical work etc., and secondly people working in the design and construction of plant, generally in projects to modify or extend existing plant. The host company was requested to allow access to interview 3 to 4 people in each job type. Practical limitations meant the actual numbers were less evenly distributed across job types. However, the outcome was sufficient to give confidence that data saturation was achieved (see later diagrams **4-2** and **5-2**).

The interviewees were as shown in **Table 3-2**.

Table 3-2 Interviewee Population Sample

Interviewee Job Type	Repertory Grid				Semi-structured			
	Site				Site			
	A	B	C	Totals	A	B	C	Totals
Ops/Maintenance Operator/Technician	3	1	0	**4**	4	0	1	**5**
Ops/Maintenance Supervisor	3	9	0	**12**	2	11	5	**18**
Ops/Maintenance Engineer	0	5	1	**6**	0	6	1	**7**
Ops/Maintenance Manager	3	12	8	**23**	4	12	11	**27**
Project Engineer	0	1	0	**1**	0	2	0	**2**
Contractor Manager	4	0	0	**4**	5	0	1	**6**
Contractor Supervisor	3	0	0	**3**	3	0	0	**3**
Project Manager	1	1	0	**2**	3	0	2	**5**
Totals	**17**	**29**	**9**	**55**	**21**	**31**	**21**	**73**

Ahead of the interviews, the interviewees were contacted by email to thank them for agreeing to be interviewed and to explain in outline the purpose and process including the research ethics, confidentiality and anonymity, and also to request them to choose a total of six events familiar to them, two events of each type described above, to be the subject of discussion in the Repertory Grid interview. Interview protocols were prepared for both Rep Grid and semi-structured parts of the interviews. These are included in **Appendix A.**

Pilot interviews held with a colleague before starting the fieldwork had shown that 60 mins was needed for the Repertory Grid interview. This timing aligned with other researchers' experience (Jankowicz, 2004).

3.3.1.3 Selection of Incidents

Incidents were of three different types, 'Actual Incident', 'Near Miss' and 'Potential Incident' (defined below) involving process safety hazards such as flammable or toxic fluids, that had or could have had significant consequences, defined as level 3 to 5 on an industry severity scale (Summers, Vogtmann and Smolen, 2011) shown in **Table 3-3**.

Table 3-3 Consequence Severity Scale

	People	Environmental damage	Asset loss/Operation impact
5	Multiple fatalities	Catastrophic off-site damage	>$10M and substantial offsite damage
4	1 or more fatalities	Significant off-site damage	$1M - $10M and severe impact
3	Hospitalization injury	On-site or offsite release with damage	$100K - $1M and significant impact
2	Lost workday injury	On-site or offsite release without damage	$10 - $100K and some impact
1	Recordable injury	On-site release	< $10K and minor impact

The Repertory Grid interviewees were requested to come to the interview prepared to discuss six incidents that they were familiar with that met the above criteria. These incidents were therefore selected by the interviewees. Documents relating to the same incidents that were discussed in the Repertory Grid interviews (which were selected by the interviewees) were requested but were not available for all, due to confidentiality or other reasons. However, documents relating to other similar incidents were made available. The overlap of incidents discussed in Repertory Grid interviews with the incidents for which documents were obtained was 81%.

3.3.1.4 Types of Incident

The three types of incident examined in this study, Actual Incident (AI) Near Miss (NM) and Potential Incident (PI) are defined with reference to the 'bow tie' hazard management diagram (ICI, 1979) an example of which is shown in **Fig 3-2.**

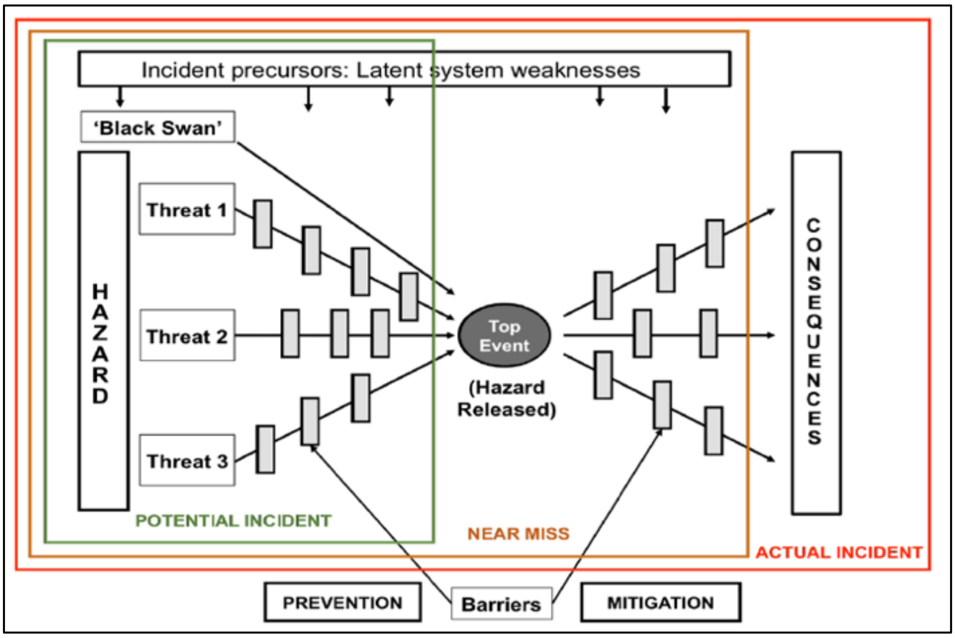

Figure 3-2 Bow Tie hazard management diagram

A bow tie diagram portrays for a particular hazard such as 'pressurised flammable gas contained in a pipe' a number of possible incident causation pathways. It also shows the progression of an incident from left to right through several stages of incubation (Turner and Pidgeon, 1997). The left-hand side shows the mechanisms by which the hazard could be released, such as for an underground pipeline: corrosion, fatigue or excavator damage. These mechanisms are shown as 'threat lines', along which are placed 'barriers' designed to prevent the threats from releasing the hazard. Examples of such 'prevention' barriers are a steel containment envelope, a process alarm with operator response, and an automatic shut-down system (CCPS and Energy Institute, 2018). Each such 'threat line' can be seen as a partial Swiss Cheese model (Reason, 1990b) (Hudson and Hudson, 2015). If the barriers (slices of Swiss Cheese) designed to contain the hazard from being released by a specific threat were all to fail simultaneously (the 'holes' in the slices of cheese all lining up) then a 'top event' would occur. In the process industries a typical 'top event' is a release of flammable gas. The hazard could also be released by a previously unknown mechanism or one considered so unlikely as not to warrant preventative controls, a so-called 'Black Swan' (Taleb, 2007).

On the right-hand side of the diagram, the known possible pathways that could lead to consequences are shown as continuations of the Swiss Cheese diagram. Along these pathways, 'mitigation' barriers are shown that are designed to reduce potential consequences such as injuries or damage from an incident such as explosion, fire or plume of toxic gas. Examples of mitigation barriers are an automatic firefighting system, evacuation by lifeboat and use of an escape respirator.

In **Figure 3-2** an 'Actual Incident' (shown within the outer (red) box) is an event in which the hazard is released (a 'top event' occurs) and the hazard goes on to result in significant consequences (such as deaths, injuries or damage to plant and equipment due to fire or explosion). A 'Near Miss' is shown as the release of the hazard (again, a 'top event' occurs) that could have resulted in significant consequences but in fact for some reason did not (Reason, 1997, p118); this is shown as an event within the middle (orange) box. Finally, in contrast to both an Actual Incident and a Near Miss, a system weakness that is detected before it could result in the release of the hazard (no 'top event' occurs) is known as a 'Potential Incident' and is shown within the inner (green) box.

Evidently the case of an Actual Incident, all of the prevention barriers on at least one threat line proved ineffective, allowing the hazard to be released (for example creating cloud of flammable gas) and unfortunately the mitigation barriers (for example gas detection system, remotely operated shutoff valve, water deluge system) were unable to stop the hazard from leading to significant consequences (in this example, the gas cloud being ignited with ensuing explosion and fire). Actual Incidents are thus commonly easily identified, and in most organizations operating high hazard technology in developed countries, are recorded, reported to government safety regulators and investigated to find system weaknesses that can be corrected in an attempt to avoid recurrence of such an incident. However even fatal accidents have been known to be hidden from the authorities in some circumstances, such as where misguided safety incentives exist. Although that may be exceptional, it does indicate that the identification of Actual Incidents can be problematic and prone to political or defensive interference, even in well-regulated operating environments.

A Near Miss starts in a similar way to an Actual Incident, with release of the hazard, so evidently all of the prevention barriers on at least one threat pathway proved ineffective. However, in a Near Miss, although the hazard is released, there are no significant consequences. This might be because of the effective operation of one or more designed mitigation barriers (such as the examples given above for Actual Incidents) or just by luck, such as a gas cloud dispersing before reaching a source of ignition. Another more potentially interesting mechanism that leads to a Near Miss rather than an Actual Incident is a successful improvised intervention. An example of this could be a vigilant operator correctly diagnosing an unexpected build-up of pressure and opening a valve to release the pressure, performing a non-standard but effective action. If such improvisations were frequently involved in the Near Miss incidents occurring in a particular organization that may be an indicator of the organization explicitly or tacitly supporting more adaptive practices than otherwise.

Because by definition no consequences result from a Near Miss and few regulators demand reporting of Near Miss incidents, their identification is more problematic than Actual Incidents (Phimister et al., 2003; Van Der Schaaf and Kanse, 2004). Thus although they may be observed by people working in operations or maintenance, they are more easily ignored or covered-up (Lawton and Parker, 2002) so may not be identified within an organization's incident management processes, or there may be a lack of 'organizational commitment to ensure that such lessons are remembered' (Hopkins, 2010, p62). However, many organizations operating high hazard technology in developed countries do recognise their potential value for learning about system weaknesses and therefore have internal management processes that encourage or even demand that Near Miss incidents are reported internally and investigated, although they may not be implemented as rigorously as for Actual Incident.

It is Potential Incidents that are perhaps of most interest for this research. These are the 'latent conditions' and 'active failures' that are represented as holes in the 'Swiss Cheese' slices (Reason, 1990b, 2016, 1997). If such a system weakness is detected before it has the opportunity to incubate into a release of the hazard, it is termed a 'Potential Incident'. In the traditional view, such a system weakness could be a degraded or failed barrier, or it may be a 'resident pathogen' (Reason, 1990a, p29) such as an ambiguous procedure, loss of currency in a technical skill, a maintenance backlog or an unclear critical communication. In the 'Safety II' view, they can also manifest as a degradation of mindfulness and expert improvisation that may normally be operating to maintain safety despite imperfect equipment or system design (Hollnagel, 2014).

A system weakness representing a Potential Incident may be detected by luck, from a chance observation. Or it may be detected by the effective working of routine testing or inspection process that was designed specifically to detect such weaknesses. Or a Potential Incident may be detected by a vigilant human operator, technician or engineer discovering some anomaly, perhaps by a diligent, thorough analysis of an unusual control room alarm.

These latter two mechanisms are of most interest for this research. The identification of a Potential Incident provides the opportunity for an organization to learn about a system weakness and correct or mitigate it before it can incubate into either an Actual Incident or a Near Miss. An organization's ability to identify Potential Incidents may be a useful indicator of its safety.

It was recognised for this research project that when an individual interviewee is describing a particular incident they may understand it either as a Near Miss or a Potential Incident, since local definitions may be vague and also individual understanding may vary. From a critical realist perspective therefore it was important to recognise that a more 'real' determination of whether an incident is a Near Miss or a Potential Incident would depend on obtaining other views or evidence. In practice this was done by a) discussing the definitions with the interviewee, b) triangulating the interviewee's categorisation with that of other interviewees and c) triangulating with the categorisation within incident documents.

These definitions of Actual Incident, Near Miss and Potential Incident are used throughout this research project. It will be argued later that the identification of and response to Potential Incidents is an indicator of an organization's effective management of safety, compared with the occurrence of Actual Incidents. The identification of and response to Near Misses, if the response involves effective mitigation, may also indicate safety, but to a lesser extent than Potential Incidents since by definition a Near Miss involves the release of a hazard, implying that all the prevention barriers on at least one threat line proved ineffective.

System weaknesses and pathogens can manifest at any stage in the life of the high-hazard technology, from the design stage, through procurement of materials and equipment, construction and start-up, operation and maintenance and de-commissioning. Unplanned human interventions to detect and prevent an incident may likewise be made by people at any stage: perhaps most often by people in the operational front line or maintenance, but also by engineers involved with design, construction or maintenance and asset integrity, by management activities such as safety audit and risk assurance, or by managers, or anyone, asking the right questions. Such interventions can also raise doubts that are later seen to be unfounded, so they are false alarms. An organization's tolerance of such false alarms may be an indicator of its safety. Interviewees and occurrences were sought covering this range of activities.

3.3.1.5 Incident Documents

The documents obtained were of five general types: 'Incident Report' downloaded from the host organization's incident management database, containing basic descriptions of the incident: date and time, location, what happened, equipment and people involved, the consequences, actions taken and the nominated person responsible for managing the incident; 'Incident Report with Update' containing updates on the investigation and actions arising; 'Incident Investigation Report' recording the findings and recommendations from the investigation; 'Learning From Incidents' documents disseminated to share the findings and recommendations; and 'Incident Review Panel' records of meetings held to review the incident, the investigation and its findings and recommendations.

The numbers of each type of incident and document are summarised in **Table 3-4.**

Table 3-4 Incidents and Related Documents

	Site			
Incidents	**A**	**B**	**C**	**Totals**
Actual Incident	19	27	13	59
Near Miss	9	24	1	34
Potential Incident	4	18	2	24
Totals	**32**	**69**	**16**	**117**
Incident-related documents				
Incident Report	3	15	1	19
Incident Report with Update	10	38	10	58
Incident Investigation Report	15	52	8	75
'Learning From Incidents' document	2	15	0	17
'Incident Review Panel' record	2	14	9	25
Totals	**32**	**134**	**28**	**194**

3.3.2 Design of Empirical Study 1 (Paper 2)

Study 1 employed Repertory Grid Technique interviews at the three sites (Sites A, B and C) to examine how people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how the interplay and tensions between rule-following and adaptive practice may figure. This was explored by comparing three types of occurrences, in the form of actual incidents, near-misses and potential incidents, and also the three sites, which have different safety outcomes. The assumption underlying this design is that contextual factors and leadership practices will vary across the three types of occurrence, and across the three sites. That is, agentic action will contribute to trapping and mitigating events and that leadership will play a critical role in enabling these processes.

Repertory Grid Technique was chosen for this research because it is considered a powerful and adaptable tool that can 'help interviewees articulate their views on complex topics without interviewer bias' (Goffin, 2002, p199). The technique is based on Kelly's 'personal construct' theory, that people make our own personal sense of the world by observing and construing meaning from experiences; people develop, test and update 'constructs' as hypotheses in the light of their own experience, so constructs will therefore differ from person to person, although because we are influenced by other people, our personal constructs will often align and become socially constructed.

Ahead of the interviews, the researcher contacted the interviewees to explain in outline the purpose and process; the interviewees were requested to choose a total of six events familiar to them, two events of each type described above, to be the subject of discussion in the interview. Pilot interviews held with a colleague before starting the fieldwork had shown that one hour was needed for the interview. This timing aligned with other researchers' experience (Jankowicz, 2004). The interviews used a standard process (Goffin, 2002; Jankowicz, 2004) in which the researcher selected three of these events (a 'triad') and asked the interviewee to compare them and to think of how any two of the events were similar and different from the third one.

Since the research interest was in the area of how process safety incidents unfold, how their unfolding may be stopped by intervention and what may differentiate these two situations, with a view to shedding light on how the interplay and tensions between rule-following and adaptive practice may influence them, the interviewees were asked the same question with each triad: "Considering these three incidents, please think about how two of these were similar, and thereby different from the third one, in regard to how people identified and responded to them". The interviewee's response formed into a specific idea, a construct, that they felt was significant and relevant to a comparison of the events. This process was repeated with different triads until the interviewer could think of no new constructs.

The interview protocol is in **Appendix A-1**, and the application of the technique is described in more detail in **Chapter 4**

3.3.3 Design of Empirical Study 2 (Paper 3)

Study 2 employed semi-structured interviews using a protocol partly derived from theory and included open questions to seek unprompted observations.

The interview protocol is given in **Appendix A-2** and the application of the technique is described in **Chapter 5**.

3.3.4 Design of Empirical Study 3 (Paper 4)

Study 3 analysed the 194 incident documents obtained, relating to 117 incidents

3.3.5 Data Analysis

The method of data analysis used was specific to each study and is described in the individual papers. The methods used are briefly summarised below:

The analysis of the Repertory Grid data (**Chapter 4**) followed the approach recommended by (Goffin, 2002).

The semi-structured interview leadership practices study (**Chapter 5**) followed the coding method recommended by Miles and Huberman (1994) using NVivo 12 (Jackson and Bazely, 2019) and used a process similar to that used by Walsh and Bartunek (2011) pursuing a cycle of abductive and retroductive reasoning, referring to the existing literature on paradox, ambidexterity, complexity leadership and HRO.

The document analysis study (**Chapter 6**) also used NVivo 12 in a similar coding method, referring to the existing literature on accident investigation, system safety, Safety II, HRO and complexity leadership [as well as **Chapters 2, 4** and **5**]. The pilot QCA was done using the approach recommended by Rihoux et al. (2009).

3.3.6 Research Ethics Policy

The Cranfield University Research Ethics Policy (**Appendix C**) was followed in full. Non-Disclosure Agreements were agreed with the host organization, confirming full confidentiality and anonymity for all data collected. This was confirmed verbally with each interviewee in each interview, with their willingness to proceed and permission to record the interview. Data was anonymised as part of analysis and confidentiality maintained.

4 PERCEPTIONS OF PROCESS SAFETY

Abstract

This paper examines empirically how safe operation of high hazard technology ('process safety') is understood by people at the operational end of organizations operating such plant in the oil & gas and chemical industry. Such organizations tend to be hierarchical, with a reliance on rule-following. It is increasingly recognised that major accident events such as explosions, fires and toxic releases are avoided not just by engineering and procedure-following but also by adaptive processes of mindfulness, sensemaking and expert improvisation. However, few studies have examined empirically the contribution and interplay of rule-following and adaptive practice in process safety and how people experience these tensions in practice. This study addresses this gap by comparing how informed actors construe different kinds of events relating to process safety: potential incidents (things identified that could have gone wrong but didn't) near misses (hazard released but contained or mitigated) and actual incidents (hazard released with significant consequences). Repertory Grid interviews were conducted with 55 people at three separate oil and gas and petrochemical sites in a single multinational company. Systematic analysis of their views revealed that organizational learning and understanding of risk were perceived as stronger influences on process safety than compliance with established procedures, and that the influence of leadership on process safety was felt through the perceived relative extent of both work pressure and deference to hierarchy, and through the importance given by the organization to incident investigation and analysis. These findings support the theories of HRO, System Safety and 'Safety II'.

4.1 Introduction

The question addressed by this study is:

- How do people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how do the interplay and tensions between rule-following and adaptive practice figure in this?

It was assumed that an actor's perceptions of events will vary depending on their role (e.g. operations and maintenance, engineering design and asset integrity) different organizational levels: sharp end or blunt end (Flin, O'Connor and Crichton, 2008) and between permanent staff and contractors. It was also assumed that perceptions of 'work as imagined' and 'work as done' (Hollnagel, 2014, p40) may vary, that is there may be a gap between what people think is happening and what actually happens. Therefore, the research was designed to explore qualitatively the actors' perceptions as well as the contextual conditions surrounding actual events.

Many writers suggest that safety of high hazard technology such as oil & gas and chemical plants, 'process safety', comes not only from the traditional reliance on engineering and rule-following but also from adaptive processes such as 'sensemaking' (Weick, Sutcliffe and Obstfeld, 2005) 'mindfulness' (Weick and Sutcliffe, 2006) and 'expert improvisation' (Hale and Borys, 2013; Hollnagel, 2014; Leveson, 2011; Rego and Garau, 2007). These ideas have been well documented in 'High Reliability Organizing' ('HRO') theory (La Porte, 1996; Roberts, 1990; Weick, Sutcliffe and Obstfeld, 1999).

Process safety has been further conceptualised as not simply the 'dynamic non-event' (Weick, 1987) of having no events such as explosions, fires or toxic releases, arising from equipment failures or errors, but more fully as the continuous process of vigilant, competent, human interaction with the equipment and its physical processes, an actively managed state in which those operating the plant are constantly anticipating and identifying threats and potential system weaknesses, interpreting and coping with them before they lead to problems. This 'Safety-II' view sees human input to the system, or 'Work-as-Done' (Clay-Williams, Hounsgaard and Hollnagel, 2015) as inevitably variable, since 'work conditions will nearly always differ from what has been specified or prescribed…' so people 'must adjust what they do to meet existing conditions' (Hollnagel, 2014, p127) in service of making 'things go right' rather than the simple 'Work-as-Imagined' of compliance with a formal procedure.

Variability of human input in the form of improvisations that are necessary to 'overcome design flaws and functional glitches' and 'interpret and apply procedures to match the conditions' (Hollnagel, 2014, p137) is thus seen in this view not in the negative sense where variability is seen as a deviation from some norm or standard, but in a positive sense that variability represents the adjustments that are the basis for safety and productivity. This is contrasted with a simpler 'Safety-I' paradigm based on assumptions of linear cause-and-effect and of safety resulting simply from reliability of equipment and minimal human error (Hollnagel, 2014).

'System safety' theorists, while basing their approach on systems engineering, sophisticated modelling techniques and organizational clarity, also accept that 'prescriptive command-and-control approach deriving rules of conduct top-down… is inadequate' for managing the safety of modern dynamic systems (Rasmussen, 1997, p185) and that therefore flexibility is also necessary: 'Humans do not always follow procedures, nor should they. We use humans to control systems because of their flexibility and adaptability to changing conditions and ability to improvise when incorrect assumptions are made by the designers' (Leveson, 2013, p273). Successful improvisation relies on competence which 'is not only a question of formal knowledge, but also includes the heuristic know-how and practical skills acquired during work and underlying the ability of an expert to act quickly and effectively in the work context' (Rasmussen, 1997, p196). This view also acknowledges that socio-technical systems controlling high hazard technology are often 'complex' (Dekker, Cilliers and Hofmeyr, 2011, p941) within which cause and effect may be non-linear (Hollnagel, 2014) so cannot be described completely and so demand a different approach to decision-making than merely complicated or simple systems (Snowden and Boone, 2007). Safety in these contexts is subject to the 'law of requisite variety' (Ashby, 1958, p206) and so for complex systems must rely on interpretation of unforeseen situations and competent improvisation.

This Safety II theory, stated above, that means that multiple adjustments are made in service of making 'things go right' may be seen in the identification and correction of 'potential incidents' that identify system weaknesses before they can develop into 'actual incidents' with significant consequences such as injuries, fatalities, impact on the environment and damage to assets or reputation. This adaptive practice of 'seeing and fixing' is an important aspect of the mindfulness of HRO theory (Weick and Sutcliffe, 2006) as well as Safety II (Hollnagel, 2014). Understanding the practices associated with potential incidents, and how they may differ from those associated with actual incidents, may provide some insights into the relationship between rule-following and adaptive practices as they relate to process safety. Other insights may be obtained by further comparing with an intermediate type of event, 'near miss' incidents, where a hazard was released but significant consequences were avoided either by chance or due to effective mitigation measures, perhaps working as designed or perhaps expertly improvised.

There are obvious tensions implicit in the proposition that process safety relies on engineering and operational discipline on the one hand, and flexibility and expert improvisation on the other. The prevalent organizational form in the oil and gas and petrochemical industries is the traditional bureaucratic hierarchy with a norm of rule-following. Analysis of major accidents routinely shows up system weaknesses and errors that could have been identified and corrected but were not, and the theory described above suggests that this can be attributed at least partly to inflexible and controlling forms of organizing that did not take adequate account of the operational context and failed to reconcile this important paradox of control versus adaptation.

The interplay between rule-following and adaptive practices in process safety and how people experience these tensions in practice is not well understood. This study addresses this gap by comparing how informed actors construe the circumstances of the three different kinds of process safety event: actual incidents, near-misses and potential incidents. The rationale is that differences in how these different kinds of event are perceived may reveal some insight into these tensions or interplay between these apparently conflicting kinds of practices.

Repertory Grid interviews (Kelly, 1955) were conducted with a total of 55 people working at three different operational oil & gas and petrochemical sites, in the Middle East, Asia-Pacific and Europe. The sites were selected on the basis of having some similarity of technology and organizational context (all were operated by a single large multinational company) but also to allow some comparison on the basis of having some differences in organizational maturity and in safety performance. Interviewees were selected to achieve a spread of different types of job, including operator/technicians, first line supervisors, engineers and managers.

Before describing the research project in detail, this paper starts with a brief review of theory relating to process safety.

4.2 Theoretical Background

The appointment of sociologist Charles Perrow to the team investigating the 1979 Three Mile Island nuclear power station accident brought a new perspective to understanding the safety of high hazard technology. His 'Normal Accident Theory' ('NAT') claims that industrial disasters are an inevitable result of 'interactive complexity' and 'tight coupling' between system components, at either a technological or organizational level (Perrow, 1984).

In response, HRO theory claims that some organizations avoid such disasters by having effective strategies to minimise and overcome the effects of interactive complexity and tight coupling. These strategies include having multiple redundant systems for detecting system weaknesses and communicating critical information, developing high competence levels in non-technical skills such as situation awareness, decision-making and teamwork, creating a safety culture that avoids blame and encourages strong responses to weak signals, and decentralising the normal hierarchical authority structure in conditions of high-tempo operations, enabling decision-making at the operational levels where specific relevant expertise has been developed (La Porte, 1996; Roberts, 1990; Weick, Sutcliffe and Obstfeld, 2005). It is recognised that there are limits to the benefit of redundancy within HRO theory, since if overdone it can lead to common-mode errors, social shirking or overcompensation (Sagan, 2004).

The 'system safety' response to NAT is that the complex socio-technological systems required for aeronautics, space and other high hazard technologies can be engineered and structured to minimise interactive complexity and tight coupling, so that despite the obvious high hazards, risks are well managed and accidents are rare (Leveson et al., 2009). Safety of high hazard technology, in this view, results not primarily from front line operators having freedom to do what they think makes sense, even though there may be cases where that could be important, but from strategic decisions about the design of the whole system (Marais, Dulac and Leveson, 2004). This theory proposes that modelling techniques can analyse all the conditions and restraints determining the design and manufacture of the equipment and all the conditions in which it is operated and maintained, that is, all the spheres of activity from which both accidents and safety emerge, and that decision-makers can use these techniques to assess the potential effects of their decisions (Hollnagel, Woods and Leveson, 2006). Safety is seen as a property of the entire system in which an organization operates; risk management processes internal to an organization are strongly influenced by factors generated in the broader system, including all the parties with which the organization has relationships: partners, regulators and other government agencies, contractors, suppliers, customers and wider society (Leveson, 2004).

An important implication of this broad view of the system is that since the conditions of and restraints on safety are set within the context of all of the (often-competing) goals of the organization, safety can only be managed effectively when the whole system is analysed and fully understood, and if that is not the case and decision-makers do not have a complete understanding of how their decisions will affect safety, their decisions will inevitably sometimes be fallible. This was of course seen in both of the space shuttle disasters (Levy, Pliskin and Ravid, 2010; Vaughan, 1997b) and numerous other major accidents. Recognising that responsibility for safety will always rest with the managers and engineers directly in charge of projects and operations, the system safety defence against this risk is to maintain a powerful, independent, 'system safety' organizational function to provide adequate challenge in management decision-making (Leveson et al., 2009).

The re-framing of safety theory under the heading of Safety II emphasises the role of mindful interpreting and adjusting practices in the light of the actual and dynamic working situation. This view contrasts with the traditional 'Safety-I' approach that focuses on compliance with formal 'Work-as-Imagined' procedures and regards deviation from them as undesirable. Safety-II conversely regards the adaptive variability of human performance in controlling systems arising from experiential learning about the idiosyncrasies of real systems, with their inevitable unintended but built-in characteristics, as essential for safe operation (Hollnagel, 2014).

The emphasis of Safety-I is on reliability engineering, probabilistic risk assessment, incident investigation and root cause analysis, learning from 'what went wrong' and measurement of incident data, while Safety-II is concerned with understanding the subtle reality of 'Work-as-Done', learning from 'what goes right' in normal operations, and acknowledges that the implications of real-world complexity are that there will always be unexpected behaviours of systems and unexpected modes of failure and interactions between system components and between systems and their operating environments (the 'NAT' view) that will demand creative improvised interventions, which at least for now means human interventions. Safety-II thus views vigilant, competent, human interaction with the equipment and its physical processes, the constant anticipation of the unexpected and readiness to respond with expert improvisation as the essential form of organizational safety (Hollnagel, 2014).

Safety-II does not preclude Safety-I but expands and complements it. This view of safety as an actively-managed condition of a system aligns with the idea of 'navigating the safety space' with both reactive and proactive measures as 'navigation aids' and driven by 'commitment, competence and cognisance' (Reason, 1997, p113) and also corresponds with the idea of avoiding 'drift to failure' by the engineering of resilient systems that enable active monitoring and adjustment of 'system properties such as buffering capacity, flexibility, margin and tolerance' (Dekker and Pruchnicki, 2013, p541).

In its view of system complexity and its implications, Safety-II thus shares an overlapping ontology of safety with 'HRO' and to a lesser degree with 'system safety', though some differences are evident. Human involvement in socio-technical systems has inevitably led to efforts to improve the human-system interface, and to the development of the science of 'human factors'. From the standpoint of system safety this has been primarily a Safety-I concern with human reliability analysis (Spurgin, 2010) and reducing human error (Reason, 1990b). The Safety-II view aligns with engineering resilient systems to cope with error (Hollnagel, Woods and Leveson, 2006; Woods, 2003) and also with the HRO view of human factors that embraces human performance to include making use of human sensemaking and problem-solving capacities (Hollnagel, 2014; Reason, 2008; Weick, Sutcliffe and Obstfeld, 1999)

The practical application of human factors has been widely and successfully adopted by commercial aviation, in the form 'Crew Resource Management' (CRM) (Kanki, Helmreich et al., 2010) a suite of human factors training techniques aimed at improving crew effectiveness, originally developed by the Aviation Human Factors group at Texas University and endorsed by the International Civil Aviation Organization (ICAO). CRM has also been adopted in many hospital surgical theatres (Helmreich, 2000) and is being encouraged in other high hazard activities including oil & gas (Flin, Wilkinson and Agnew, 2014) . A key component of CRM, that has found wide practical and successful application in other high hazard operations, is the concept of 'situation awareness' (Endsley, 1999) very akin to 'mindfulness' as described by Weick and Sutcliffe (Weick and Sutcliffe, 2006) and similarly applies at individual, team and organizational levels. Hopkins notes in particular that leaders of organizations operating with high hazards need to maintain a 'big picture' of the current effectiveness of risk management systems, requiring rapid and comprehensive information flows between control rooms and boardrooms and suggests that this 'mindful leadership' is the defining HRO characteristic (Hopkins, 2009). Endsley's work includes the design of equipment and systems to facilitate such information flows (Endsley, 1999).

Interest in human factors in the aftermath of the Three Mile Island, Bhopal, Chernobyl and Piper Alpha disasters led to the development of a theory of safety deriving from organizational culture (Bea, 1998; Hudson, 1999; Meshkati, 1991; Reason, 1990b; Shrivastava, 1985). A form of 'safety culture' has been described as 'informed, reporting, just flexible and learning' (Reason, 1997, p195) and a safety culture model based on these characteristics working together as a system has been proposed: managers continually generating organizational learning, driven by a constant state of healthy, wary, concern for safety or 'chronic unease' (Fruhen, Flin and McLeod, 2013, p2) maintained by their staying well-informed about the organization's potential weaknesses by the continual reporting, by workers at all levels, of safety issues including their own errors, which they are willing to do since they trust the managers to exercise justice and fairness in dealing with them (Parker, Lawrie and Hudson, 2006). Dekker also emphasises the importance of justice and avoiding a blame culture (Dekker, 2011). Safety culture, CRM and situation awareness all share ideas with both Safety-II in its forward-looking approach of learning how to make things go right and with HRO theory; for example all these overlap with the concept of chronic unease, and effective interpersonal communication and teamwork, a cornerstone of CRM (Flin, Wilkinson and Agnew, 2014) is also fundamental to HRO theory (Roberts, 1990).

The UCAL Berkeley research conducted in the 1980s provided the first description of how HROs work: that despite the hazards, the likelihood of bad consequences is kept very low by having active organizational and interpersonal processes that reduce and contain human errors and system failures (Roberts, 1990). Roberts points out the previous dearth of organizational safety theory other than accident analyses, and the difficulty of deducing any useful theory based on such a trial and error approach. She notes that at that time the only social-science-based accident analyses, by Perrow, Sagan and Shrivastava, were based entirely on reviews of historical documentary evidence (Roberts, 1990). This led the Berkeley group to adopt the quite different ethnographic method of the in-depth 'embedded researcher' case study: they wanted to watch and talk to the people inside HROs to find out what they did that was so effective in avoiding accidents. Their research method is interesting: for three years, team members of different social science disciplines joined US Naval ships for intermittent periods of five to ten days. To reduce individual bias they rotated round all the relevant activities on the ships so that all researchers were able to observe all the activities (Rochlin, 2011). They looked specifically for ways that the organization minimised the negative potential effects of Perrow's 'interactive complexity' and 'tight coupling'. An important organizational capacity they noted was the ability to cope with paradoxes: for example standardisation versus flexibility (Roberts, 1990). The ships' exercises were developed with much standardisation and specialisation of individual roles, but also with deliberate flexibility to encourage creativity in problem-solving (Roberts, Rousseau and La Porte, 1994). This was also noted in the considerable redundancy of systems: for example having many different means of instant communication, radios, public address systems and hand signals, and of people: crew members were deliberately encouraged to develop skills in many different tasks and teams were given the flexibility to decide themselves on a rapid dynamic basis who would do what (Roberts, 1990).

Another paradox-coping strategy noted was the deliberate maintenance of high workload for key individuals such as pilots, landing officers and nuclear plant operators, to gain high vigilance, develop high competence and reduce error, while at the same time avoiding the obvious potential negative effects from overstress and fatigue by means of a strategy of redundancy: multiple cross-checking and effective teamwork from 'many pairs of eyes' watching for errors or anomalies (Roberts, 1990, p168). These factors were seen as important contributors to a safety culture that was reinforced by leaders committed to avoiding blaming individuals, instead frequently praising the reporting of errors and system weaknesses (Weick, Sutcliffe and Obstfeld, 1999). An insight into how these paradoxes of control versus adaptation were managed is offered by the observed flexibility of authority structure. Although authority was predominantly hierarchical, as one would expected the military, this changed in busy periods: 'more collegial patterns of authority based on skill and functional relationships emerge as the tempo of operations increases…As these clearly recognised patterns shift, communication patterns and role-relationships are altered to integrate the skills and experience called for by the situation.' (La Porte, 1996, p64). 'In a sense the pyramid is inverted. The organization focusses on training and on letting people use that training. Low level decision making is part of that focus' (Roberts, 1990, p171).

These ideas have been further developed into what has become possibly the best-known HRO model, the 'five characteristics model' (Weick, Sutcliffe and Obstfeld, 1999) and further developed under the key ideas of 'sense making' (Weick et al., 2005) and mindfulness (Weick and Sutcliffe, 2006). They suggest that Roberts' HRO characteristics of redundancy, high competence and vigilance from continuous training and strategic prioritization of safety as necessary but not sufficient, seeing high reliability more as an active process of seeking and fixing problems, than as a condition (Vogus and Sutcliffe, 2012). They describe an active nature of HROs, more sensitive to and dynamically responsive to the environment compared with normal or 'low reliability' organizations whose operating models lean more towards exploitation than exploration making them less adept at recognising and responding appropriately to changes to the operating situation. This 'organizational cognitive ability' is what they call 'mindfulness', and propose that this is the core of what differentiates an HRO(Weick and Sutcliffe, 2006).

Weick's research group analyse the components that they claim allow HROs to develop and maintain this mindfulness, as five key practices (Weick, Sutcliffe and Obstfeld, 1999): 1) 'preoccupation with failure' which implies maintaining a culture and infrastructure that support the reporting, expert analysis and embedding of learning from near-miss incidents and other learning opportunities, and which suppresses the complacency that often accompanies a focus on success; 2) 'reluctance to simplify explanations' that firstly, recognising that it takes a complex system to perceive the complexity of the actual environment, cultivates a 'requisite variety' of sensing mechanisms including 'diverse checks and balances embedded in a proliferation of committees and meetings, frequent adversarial reviews, selection of new employees with non-typical prior experience, frequent job rotation and re-training' (Weick, Sutcliffe and Obstfeld, 1999, p42) as well as sceptical but mutually respectful questioning of actual reported conditions, assumed competence and the like, and secondly expresses a willingness to accept 'false alarms' as the cost of habitually making a 'strong response to a weak signal', all of which call for excellent interpersonal skills to deal with the implicit lack of trust (Weick and Sutcliffe, 2001) 3) 'sensitivity to operations' which means the organization's leaders being well-connected to the operational 'sharp end' of their organization, so they firstly, understand and actively contribute to overcoming the current problems and needs of operations, and secondly, maintain high organizational 'situation awareness' by sensing themselves what is happening in operating environment, making sense of that information as it relates to the organization's goals, and then projecting the developing situation forward to anticipate appropriate survival responses (Endsley, 1995); 4) 'commitment to resilience', which, more than simply accepting human fallibility and coping well with anticipated abnormal situations arising from predictable human and system failures, means having early warning systems to detect unexpected, anomalous errors or failures that have not been observed before, and developing the capacity to respond quickly and effectively by improvisation and ad hoc problem-solving to contain the situation, avoid escalation towards a major incident and swiftly restore normal operations (Woods, 2006); and 5) 'deference to expertise' which has one meaning that decision-making about safety-critical matters is not kept as the prerogative of the formal hierarchy of line management but instead the expertise of operational and technical specialists is given due weight and will normally take precedence (Sutcliffe, 2011) and another meaning of the overt acceptance that formal procedures cannot prescribe all situations, so people are expected to continually challenge and sense-check to avoid mindless operation of fixed processes (Weick, Sutcliffe and Obstfeld, 1999; Weick and Sutcliffe, 2001). This portrayal of HROs as differentiated from other organizations by having these five attributes, the authors claim, is based on induction from a wide body of research and is intended to provide a framework of social infrastructural concepts that can be used by any organization wishing to improve its reliability (Weick and Sutcliffe, 2001). How they have done this appears to be by a combination of synthesis of observations of practices in case studies of HROs by the many writers they reference, together with an inversion from organizational weaknesses implicated in accident causation.

System safety theorists argue that both the NAT and the HRO views of safety are incomplete and flawed, claiming that reliability and safety are different properties and that although redundancy can reduce accidents caused by component failure (lack of component reliability) most accidents in complex systems have roots in cultural and human factors where component redundancy does not help and even, by increasing system complexity, tends to reduce rather than increase overall system reliability (Leveson et al., 2009).

Perrow objects that system safety is optimistic since 'the complexity and tight-coupling of complex, high-tech systems not only makes them opaque to the operators, but they also make it almost impossible for any one individual to understand such a system in its entirety' (Reason, 1998a, p296, quoting Perrow, 1984). Sagan agrees, also maintaining that HRO Theory is optimistic (Sagan, 1995) and that notwithstanding both system safety and HRO arguments, NAT still prevails, citing among other reasons the difficulty of eliminating common-cause failures.

Despite these objections, system safety is the basis for 'safety management systems' commonly employed in high hazard industries (IPIECA and IOGP, 2014) and 'safety reports' or 'safety cases' demanded by regulators (European Commission, 2012; HSE, 2005). Such safety management systems in the oil & gas and chemical industries commonly employ a bow tie hazard management model (CCPS and Energy Institute, 2018) an example of which is shown in **Fig 4-1.**

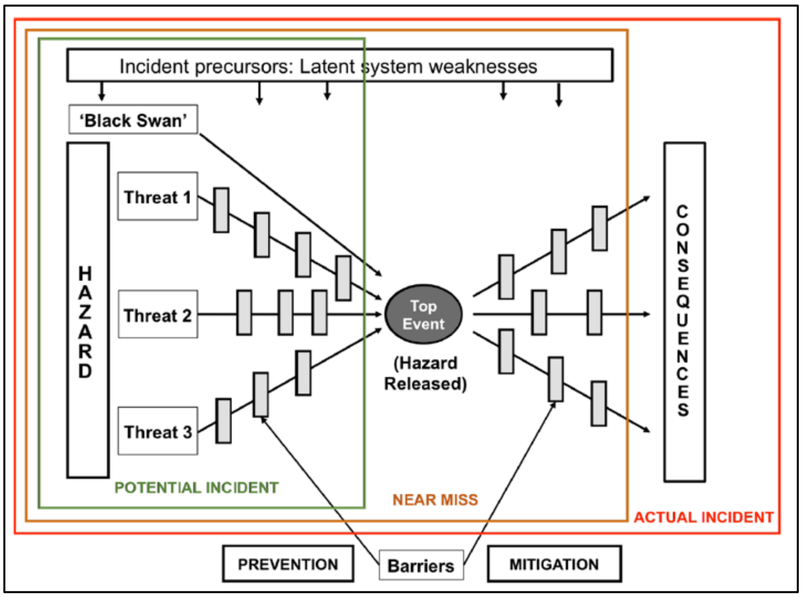

Figure 4-1 Bow Tie hazard management model

Based on the 'Swiss Cheese' accident causation model (Reason, 1990b) the left-hand side of the bow tie diagram portrays the known mechanisms by which a particular hazard could be released, shown as 'threat lines', together with the barriers designed to prevent the threats from releasing the hazard. Examples of such 'prevention' barriers are the steel containment envelope, a process control alarm with operator response, and an automatic shut-down system (CCPS and Energy Institute, 2018). If all the barriers designed to contain the hazard from being released by a specific threat were to fail, then a 'top event' would occur. In the process industries a typical 'top event' is a release of hazardous material such as flammable gas. This release of a hazard could also occur by a previously unknown mechanism or one considered so unlikely as not to warrant preventative controls, a so-called 'Black Swan' (Taleb, 2007). If a top event were to occur, then mitigation barriers are designed to minimise consequences such as injuries or damage resulting from explosions, fires or releases of toxic material. Examples of mitigation barriers are automatic water deluge firefighting systems, evacuation by lifeboat and wearing car seatbelts.

Three different types of process safety event are portrayed in **Fig 4-1**. An 'Actual Incident' is shown in the bow tie diagram as the occurrence of a 'top event' that then leads on to result in significant consequences due to the failure of the barriers on the right-hand side of the bow tie to mitigate them. Actual Incidents are shown within the (outer) red box, as events that have multiple contributory factors, failures both in prevention and in mitigation.

A 'Near Miss' is shown as occurring within the (middle) orange box, where a 'top event' occurs but without resulting in consequences because of effective mitigation barriers, which are shown on the right-hand side of the bow tie diagram. In reality, the mitigation could have been due to the effectiveness of designed mitigation barriers or due to a successful improvised mitigative intervention, such as a quick-witted operator who opened a valve to release an unexpected build-up of pressure, or just by chance, such as a gas cloud that dispersed before reaching a source of ignition.

By contrast, a Potential Incident is shown in **Fig 4-1** as an event that falls within the (inner) green box, as the detection and correction of a system weakness such as the failure or degradation of a barrier, an error or some other vulnerability, without the release of a hazard in a top event. The weakness could be detected by chance observation or by the operation of another barrier, perhaps the last prevention barrier remaining such as a pressure relief valve or an automatic shutdown system, indicating that all the other prevention barriers had failed; it could also be detected by either the successful operation of a designed system for detecting such weaknesses, such as an alarm or a routine program of inspection and testing, or by high vigilance, either of an individual or at the organizational level, perhaps including an improvised successful intervention. Potential Incidents identified by these latter mechanisms are of particular interest, since they may indicate high situation awareness, resilience and safety. Not shown in this simple diagram, but equally of interest, is another kind of Potential Incident: the detection of a weakness in a mitigation barrier on the right-hand side of the bow tie, before it was needed. As the diagram does show, weaknesses can exist anywhere in the whole prevention and mitigation system.

According to this theory, a system weakness could be the failure or degradation of one or more barriers in a particular causation trajectory (shown as threat pathways on the left hand side of the bow tie diagram and consequence pathways on the right hand side) or it could be a 'system pathogen' (Reason, 1997) such as unmanaged fatigue, an unclear procedure, loss of currency in a technical skill, incomplete communication or some other human performance influencing factor. These factors can lead, in the traditionally accepted analysis, to degradation of established barriers or omission of desirable barriers due to fallible decisions. In an alternative ('Safety II') view, they can also lead to degradation of mindfulness and expert improvisation that may normally be operating to maintain safety despite imperfect designs and understanding of risks (Hollnagel, 2014).

System weaknesses and pathogens can manifest themselves at any stage in the life of high hazard technology, from the design stage, through procurement of materials and equipment, construction and start-up, operation and maintenance and de-commissioning. Unplanned, improvised, human interventions to detect and prevent an incident may likewise be made by people at any stage: perhaps most often by people in the operational front line or maintenance, but also by engineers involved with design, construction or asset integrity, by management activities such as safety audit and risk assurance, or by managers, or anyone, asking the right questions. Such interventions can also raise doubts that are later seen to be unfounded, so they are false alarms. An organization's tolerance of such false alarms may be an indicator of its level of safety.

While HRO theory is criticised for its principle of improvisation by the people working at the operational front line, who lacking full system knowledge may adopt local work-arounds with potential unintended negative consequences (Leveson et al., 2009) 'system safety' theory also recognises the importance of flexibility: 'Allowing latitude in how tasks are accomplished will not only reduce monotony and error proneness, but can introduce flexibility to assist operators in improvising when a problem cannot be solved by only a limited set of behaviors. Many accidents have been avoided when operators jury-rigged devices or improvised procedures to cope with unexpected events.' (Leveson, 2013, p284).

'HRO' is somewhat aligned here, maintaining that although standard procedures and competent operational discipline in using those procedures are important, it is mindful use of them that stops things going awry: people at the operational sharp end need to be empowered and encouraged to make sense of situations and use their expert judgement, beyond merely following standard procedures: 'When problems and decision rights are both allowed to migrate, this increases the likelihood that new capabilities will be matched with new problems' (Weick, Sutcliffe and Obstfeld, 1999, p49).

A recent empirical case study of an offshore gas explosion found clear evidence that not all events can be anticipated; the explosion was initiated by a subtle technical failure of a gas cooler by a previously unknown failure mechanism – an example of the 'Black Swan' (Taleb, 2007) discussed earlier and shown in **Fig 4-1**. The study also showed that the potentially disastrous consequences were effectively mitigated by an operating organization that was demonstrably resilient and exhibited many aspects of the mindfulness described in HRO theory. Despite the extremity of the event ('simulation showed that the explosion and fire was caused by the release of 9.8 tons of hydrocarbon gas…released at half a ton per second'… 'the fireball expanded, engulfing the decks below and rising to 200 feet above…') (Denyer and Sibbick, 2015, p231) there were no fatalities and no criticisms from the government safety regulator, an outcome that compares very favourably with the 1988 Piper Alpha explosion.

In response to the incident, a deep investigation was done in full collaboration with the regulator, and after some intensive engineering work and extensive repairs, nine months later the asset was back in operation. Several important aspects of mindfulness, that had been deliberately developed within the operating organization over the previous four years before the incident, were identified as having contributed to the effective response to and the positive outcome of the incident. These included an emphasis, with strong encouragement from the company directors, on the need to understand and manage the risks represented by the ageing asset, through technical inspection, condition assessment and monitoring processes, and to 'worry about failure'. These practices are evidently aligned with the HRO characteristics of 'sensitivity to operations' and 'preoccupation with failure' (Weick, Sutcliffe and Obstfeld, 1999).

Likely due to these practices, the bow tie 'mitigation barriers' of emergency shutdown and deluge systems worked perfectly and everyone on board was swiftly evacuated. There was no attribution of blame, instead a major focus on welfare of the people involved. An independent investigation team was set up, with forensic technical support from the regulator; 'There wasn't a hint of anybody trying to cover anything up…' (Denyer and Sibbick, 2015, p235). (This aligns with 'reluctance to simplify explanations' and 'deference to expertise'). After the investigation, the organization actively shared the learning, drawing from the incident even more explicit focus on safety, risk and reliability through competence and adequacy of resources to deal with problems early (this aligns with 'commitment to resilience') and setting a change agenda that included both rule-based dimensions (multiple layers of protection of critical systems; systematic maintenance, inspection and monitoring) and mindfulness-based dimensions (competence, capability and authority; open reporting and situation awareness). This case 'illustrates how one organization recognised the importance of finding an appropriate balance between rule-based and mindfulness-based approaches in its attempts to become a high reliability organization' (Denyer and Sibbick, 2015, p248).

In summary, process safety depends on overcoming NAT, and the major theories claim to do that, with paradoxically different emphases: 'system safety' prioritises engineering, reducing interactive complexity and tight coupling in the overall system design, together with maintaining accurate and complete models of the system to guide risk-based decision-making (Leveson, 2004) 'HRO' by acknowledging the inherent unpredictability and complexity of real systems and developing the capacity for mindful sense-making and competent adaptation within effective teamwork processes that are enabled by flexible forms of organizing and leadership (Weick and Sutcliffe, 2001). The Safety-II view embraces both theories and emphasises the importance of understanding the reality of expert adjustment and improvisation in normal operations (Hollnagel, 2014).

Reconciling the rule-following so essential to the 'traditional bureaucracy' view, with this expert improvisation, so essential to the Safety-II and 'HRO' approaches and accepted as necessary by system safety, represents a major paradox. This tension has interested researchers for some time. It has long been recognised that rules and procedures vary in their quality and usefulness; two quotes exemplify this: 'It is probably true to say that procedures, together with the training and checking that goes with them, are the main reason commercial aviation is safe as it is' (Green et al, 1996, p59) and '70% of human errors (or 56% of all events) at nuclear plants were found to be the result of organizational, rather than individual, weakness. While these organizational deficiencies are often hidden in management processes, values or organizational structure, they can create workplace conditions that lead to a human error or degradation in the integrity of defences, such as quality of procedures or reliability of systems' (IAEA, 2013).

Dekker points out the impossibility of writing a procedure to cover all situations, so that violating a procedure is sometimes the safest action (Dekker, 2003). And a study of anaesthetists' use of rules suggests rules could be seen alongside other principles to guide naturalistic decision-making and so could and should be violated when doing so met one of three principles: 'doing the right thing', 'doing what works in the circumstances' and 'using one's skills and expertise' (Phipps and Parker, 2014, p519).

Others agree that problems will arise from slavish adherence to rules that do not work in a changed context or if rules are not used to guide adaptation (Woods and Shattuck, 2000). That procedures should normally be followed but competently adapted when necessary is supported by a recent review of the literature on management of safety rules and procedures (Hale and Borys, 2013) and is well illustrated by the following quote: "I don't enjoy making changes to procedures. It seems like the crew only does that when they feel there's some good need for it." Mike Collins, test pilot and astronaut, Apollo 11 crew debriefing following the first manned mission to land on the Moon, July 31, 1969 (English and Branaghan, 2012, p204).

This aim of this empirical study was to explore how these two paradoxically different approaches, of reliance on rule-following on one hand, and support of adaptive practices such as vigilant detection and correction of system weaknesses with expert improvisation on the other hand, may operate in practice. The approach was to examine how informed actors construe and experience the unfolding of 'potential incidents' and how this may contrast with how they construe 'actual incidents' and 'near-misses'

How people construe the unfolding of potential incidents is interesting since their identification and the subsequent action to stop them from developing into actual incidents may provide evidence of the adaptive practices inherent in the theories of HRO and Safety II. This contrasts with actual incidents since evidently the (presumably latent) organizational safety system weaknesses that led to the incident were not identified. 'Near-miss' incidents may have characteristics of both actual and potential incidents.

4.3 Method

4.3.1 Data collection

55 interviews using Repertory Grid Technique (Kelly, 1955) were conducted to examine how people at the sharp-end of organizations operating high hazard technology understand the important factors in process safety, including how they experience tensions between rule-following and adaptive practice, by comparing how they construe the identification of and response to three different kinds of events relating to process safety: actual incidents (hazard released with significant consequences) near misses (hazard released but contained or mitigated) and potential incidents (things identified that could have gone wrong but didn't).

4.3.2 Selecting fieldwork sites

The rationale was to allow for comparison between sites with similar technology and organizational context but different stages of organizational maturity and safety performance. This was achieved by selecting three geographically-separated sites operated by a single multinational company: a recently-constructed large petrochemical manufacturing operation in the Middle East with a safety performance perceived as mixed (Site A) a multiple-location rapidly-developing upstream oil & gas production operation in Asia-Pacific with a safety record perceived as below-average (Site B) and a long-established offshore upstream oil & gas production operation in Europe with a safety record perceived to be above-average (Site C). The different characters of each of these three sites are summarised below.

Site A was a very large petrochemicals complex in the Middle East that had been started up only a few years earlier. The site operated continuously with a typical 24h shift pattern, supervised from a state-of-the-art central control room in radio communication with field operators monitoring the physical plant. The organization was fairly hierarchical, emphasising the importance of compliance with procedures. The operations and maintenance organizations were populated largely with ex-patriot workers of numerous different nationalities, predominantly Asian, and also many from Europe, Australasia and North America. The organization was still in transition from project-based to operations-based, with a number of modification projects in process. The site received from the parent organization significant specialist support in engineering and other fields. An impressive construction safety performance had suffered in the translation into operation, the site having had a number of significant process safety incidents in the early years of operation, including some fatalities.

Site B was an oil & gas onshore production operation with a large number of geographically dispersed fields feeding a single large treatment and export plant. Many of the production units were in locations remote from support infrastructure and were only visited periodically by technical personnel. The number of production units had been growing rapidly over the previous decade, and the older units had been designed and built to lower standards than the more modern ones. The organization was a fairly flat hierarchy with a moderately open culture, steadily expanding, drawing operator/technicians from the local population and providing extensive training. The operation had been acquired only a few years earlier and was still in the process of adopting and implementing the parent organization's engineering and operating standards, for which the parent organization was providing some specialist support. The process safety record was perceived as below-average, the site having suffered a number of significant incidents including some high potential consequence near-misses and potential incidents.

Site C was an offshore oil and gas production operation, with a single large offshore platform that had been in operation for over 25 years, supported by an onshore team of engineering and operations support personnel in a local office. The mature organization had evolved to be a fairly small stable team of people with considerable experience and a markedly open culture of mutual respect; many people had worked together for some years and had rotated through a range of different roles. The local organization was largely self-sufficient with good support from the parent organization as needed. The safety performance was perceived as above average; it had recently been given a major award for its process safety performance.

A summary of the profiles of the three sites is given in **Table 4-1.**

Table 4-1 Summary profiles of the three sites

	Site A	Site B	Site C
Overview	Large single site Petrochemicals complex	Onshore Oil & Gas production, large number of remote production units dispersed geographically; single large treatment and export plant	Offshore Oil & Gas production, onshore technical and operations support
Location	Middle East	Asia Pacific	Europe
Organization form	Strong hierarchy	Hierarchy / open culture	Weak hierarchy / open culture
Personnel	Largely ex-patriot	Largely local	Largely local
No. of people	2000+	4000+	200+
Organizational maturity	In transition from very large Project to Operations	Mixed; rapidly growing number of physical assets	Stable; very mature
Years of operation	5+	10+	25+
Relation with Parent	Significant specialist support	In process of adopting new technical standards	Fairly independent; supported as needed
Perceived Safety performance	Mixed	Below-average	Above average

4.3.2.1 Selecting events

Events were selected of three different type as defined below, all involving process safety hazards such as flammable or toxic fluids (rather than 'personal safety': slips, trips and falls etc.) and that had, or could have had, significant consequences, defined as level 3 to 5 inclusive, on a scale of consequence severity commonly used in the industry (Summers, Vogtmann and Smolen, 2011) (see **Table 4-2**).

Table 4-2 Incident Consequence Severity Scale

	People	Environmental damage	Asset loss / Operation impact
5	Multiple fatalities	Catastrophic off-site damage	>$10M and substantial offsite damage
4	1 or more fatalities	Significant off-site damage	$1M - $10M and severe impact
3	Hospitalization injury	On-site or offsite release with damage	$100K - $1M and significant impact
2	Lost workday injury	On-site or offsite release without damage	$10 - $100K and some impact
1	Recordable injury	On-site release	< $10K and minor impact

4.3.2.2 Selecting interviewees

The rationale was to seek the views of people with a range of perspectives. The primary population sampled was the operations and maintenance staff employed by the operating company directly involved with day-to-day running of the plant, at three organizational levels, operator/technician, shift supervisor or engineer and manager. To gain a wider perspective, interviews were also sought with two other populations: firstly employees of companies contracted by the operating company, typically for work supporting maintenance such as scaffolding, welding, electrical work etc., and secondly people working in the design and construction of plant, generally in projects to modify or extend existing plant. Interviewees were sought who had a few years of experience working in the same organization or plant, and who had direct knowledge of process safety incidents and potential incidents. The sample obtained is shown in **Table 4-3.** A total of 55 repertory grid interviews were conducted.

Table 4-3 Populations sampled

Job Type	Organizational level	Interviews per site		
SITE		A	B	C
Ops/Maintenance	Contractors	7	0	0
	Operator/Technician	3	1	0
	Supervisor / Engineer	3	13	1
	Manager	3	13	8
Design/Construction	Contractors	0	0	0
	Operator/Technician	0	1	0
	Supervisor / Engineer	0	0	0
	Manager	1	1	0
	Totals	17	29	9

4.3.2.3 Repertory Grid Technique

Repertory Grid Technique was chosen for this research because it is considered a powerful and adaptable tool that can 'help interviewees articulate their views on complex topics without interviewer bias' (Goffin, 2002, p199). The technique is based on Kelly's 'personal construct' theory, that people make our own personal sense of the world by observing and construing meaning from experiences; people develop, test and update 'constructs' as hypotheses in the light of their own experience, so constructs will therefore differ from person to person, although because we are influenced by other people, our personal constructs will often align and become socially constructed. We tend to think of our personal constructs in the context of their opposite; 'A construct is a way in which some things are construed as being alike and yet different from others.' (Kelly, 1963, p105). The Repertory Grid Technique thus involves the identification of constructs and their opposites, or 'poles' in a structured manner. The interviewer follows a process that repeatedly asks the interviewee to think of ways that differentiate between changing sets of three 'elements', which are examples of or occurrences within a particular topic (Jankowicz, 2004).

In this study, the elements were events of the three different types described above. This process of comparing sets of three elements ('triads') helps elicit from people their tacit views or constructs which can otherwise remain latent and unacknowledged using simpler interviewing techniques (Goffin et al., 2012). An interview normally elicits a number of constructs. The technique results in a matrix of quantitative data, the repertory grid, with the elements forming one axis and the constructs the other axis; the cells contain the interviewee's ratings of each element on a scale from full alignment with the construct to full alignment with its opposite, or pole. The repertory grids thus created can be analysed quantitatively, to extract meaning idiographically, that is relating to an individual's understanding, and nomothetically, which seeks patterns of understanding emerging from a number of people (Tan and Hunter, 2002). The interviews can also be analysed qualitatively, using usual qualitative text coding techniques, extracting phrases that exemplify the constructs.

4.3.2.4 Interview planning

A representative sample of people to interview was sought as described above. The identification of suitable interviewees was facilitated by a manager at each site nominated by the main contact in the host company for the research. Ahead of the interviews, the researcher contacted the interviewees to explain in outline the purpose and process; the interviewees were requested to choose a total of six events familiar to them, two events of each type described above, to be the subject of discussion in the interview. Pilot interviews held with a colleague before starting the fieldwork had shown that 60 mins was needed for the interview. This timing aligned with other researchers' experience (Jankowicz, 2004).

4.3.2.5 Interview Process

The interview, following a prepared script started by asking the interviewee to describe briefly each of the six events they had chosen to discuss and to label a card for each one with a short name and its event type. The cards were pre-printed with a short definition of each of the three types of event, as a reminder to the interviewee how the types were differentiated. Any confusion about the event definitions was cleared up with a short discussion to gain a common understanding. Then, following a standard repertory grid process (Goffin, 2002; Jankowicz, 2004) the researcher selected three of these events (a 'triad') and asked the interviewee to compare them and to think of how any two of the events were similar and different from the third one. The researcher placed the cards relating to the three events in question in front of the interviewee to aid their reflection, and moved them about occasionally into different relative positions, to help the interviewee see the different possible comparisons. The process was later repeated with a series of different triads of events.

Since the research interest was in the area of how process safety incidents unfold, how their unfolding may be stopped by intervention and what may differentiate these two situations, with a view to shedding light on how the interplay and tensions between rule-following and adaptive practice may influence them, the interviewees were asked to think specifically about how the events in question did unfold, how they were identified as developing or actual incidents, and the human interventions that were involved. This was done by using the same wording with each new triad: "Considering these three incidents, please think about how two of these were similar, and thereby different from the third one, in regard to how people identified and responded to them".

The interviewee's response formed into a specific idea, a construct, that they felt was significant and relevant to a comparison of the events. Typically people found some difficulty with this at first, so the researcher prompted with open-ended questions to help the interviewee explain how they saw the contrast between the three incidents, and how the nascent construct was important to them in describing these events. Picking out one word or phrase used, the researcher then asked the interviewee to define the two extremes of that idea; e.g. if the interviewee had said 'unusual situation' they might then suggest as the two extremes 'normal procedure' and 'never been done before'. The construct and its polar opposite or 'pole' were then summarised into short phrases describing these two extremes and after the interviewee had confirmed their agreement to the wording, these phrases were written down by the researcher at each end of the first line on a prepared repertory grid sheet.

Next, the interviewee was asked to score the three events on a scale from 1 to 4, with 4 representing the extreme of the construct and 1 representing the extreme of the pole. Finally the interviewee was asked to score the remaining events on the same scale, thus creating the first line of the repertory grid. Further different combinations of three events, or triads, in a pre-determined standard sequence, were then used to elicit other constructs. With each triad, a new construct was sought; no repeat constructs were allowed, so the interviewee was encouraged to think more deeply about the events as the interview progressed. This process continued until the interviewee could think of no new constructs. Some interviewees quickly grasped the technique and were soon able to describe five or six constructs, while others found the process difficult and even with patient encouragement from the researcher were only able to express two or three ideas before they dried up. This was expected, since experience with this technique indicates that some people will have only a few genuinely different constructs concerning a particular topic (Jankowicz, 2004).

The interview protocol is given in **Appendix A-1.**

4.3.3 Data Analysis

The data collected was of two sorts, quantitative in the form of the repertory grids and qualitative in the form of the recorded interviews. The analysis was done nomothetically, i.e. seeking patterns of ideas emerging from multiple interviews. The outline process of data analysis was as follows:

1. Preparation and validation of the data
2. Analysis of overall key constructs
3. Analysis of constructs comparing between each event type
4. Analysis of constructs comparing between sites

4.3.3.1 Preparation of the data

Each of the 55 grids was made up of 6 elements i.e. the events chosen by the interviewee and between 1 and 6 constructs. The average number of constructs per interview was 2.6, resulting in over 800 quantitative data points, as well as the qualitative data of the recorded interviews. Each construct was given a three-digit reference number, the first digit indicating the site, the second digit identifying the interview and the third digit the construct within the interview.

The quantitative data from the interviews were entered into a spreadsheet, with quality checks to avoid data entry errors. An extract from this spreadsheet is in **Table 4-4** with the construct reference numbers disidentified to maintain confidentiality.

Table 4-4 Extract from Raw Repertory Grid Data spreadsheet

		Elements						
REF	CONSTRUCT	a	b	c	d	e	f	POLE
		Actual		Near-miss		Potential		
1.n.1	full understanding of hazard and required controls	1	2	4	4	3.5	3.5	unaware of hazard
1.n.2	unique incident	1	4	2	2	2	4	part of an incident cluster
1.n.3	occurrence due to response to previous circumstances	4	4	1	1	1	4	new occurrence
1.n.4	unexpectedly delayed identification of occurrence	4	4	2	2	2	1	occurrence identified as expected through routine inspection
1.p.1	required intervention	3	4	1	1	4	2	no intervention practical
1.p.2	early warning signs easy to see	2	1	4	4	3	1	early warning signs difficultto see
1.p.3	equipment integrity related	2	3	3	1	4	1	operator initiated
1.p.4	production prioritised over safety/environment	1	1	4	1	4	3	safety/environment prioritised over production
2.q.1	process safety barriers understood and good reporting of failures	4	3	1	2	3	1	poor understanding of PS barriers and poor reporting
2.q.2	reaction of isolate and make safe	4	1	1	1	1	1	reaction of immediate fix and return to service
2.q.3	proactive systematic identification of barrier weaknesses	4	4	2	1	3	3	reactive identification due to loss of primary containment
2.q.4	organisational reaction of independent deep investigation	4	1	4	1	3	2	local shallow investigation
2.q.5	engineered instrument detection	1	1	3	4	4	4	procedural human detection
2.q.6	correct risk perception and effectice emergency response	4	1	1	1	4	1	low risk perception and ineffective response

The interviews were transcribed, with quality checks for transcription errors. Explanatory quotes were extracted from the transcripts to obtain fuller descriptions of the meaning of each construct.

4.3.3.2 Data validation

Although the element scores data obtained from Repertory Grid Technique interviews is quantitative, the qualitative nature of the constructs allows interpretation of their meaning. To compensate for potential researcher bias in this interpretation, a one-day data workshop was run with two teams each with two researchers to categorise the constructs.

To minimise personal biases and limitations, each team comprised one researcher who was an experienced faculty member and one doctoral researcher who was a 'knowledgeable practitioner with conceptual interests and more than one disciplinary perspective' (Miles and Huberman, 1994, p38).

To prepare for the workshop, two identical sets of construct cards were made, each printed with the wording of the construct and its pole, the explanatory quote and the construct reference number, in the format [n1.n2.n3] n1 indicating the site, n2 the interview number at that site and n3 the construct number within the interview (see **Figure 4-2**).

ref 1.N.2

construct

reasonable system understanding

pole

lack of system understanding

explanatory quote

So feeling comfortable understanding the plant, know where equipment is, know how it relates, understand the line-up.

...I think the guy did not understand the interconnectivity between the de-min water and the caustic otherwise he wouldn't have used that point.

Figure 4-2 Example of workshop construct card

Working independently in separate rooms, each team coded the constructs, sorting them into categories that emerged from the process, each team defining their own categories. The development of categories and the allocation of constructs to the categories were informed by the wording of the construct, the pole and the explanatory quote (see **Figure 4-5**).

Table 4-5 Example of Categorisation Process

Ref	CONSTRUCT	POLE	EXPLANATORY QUOTE	CONSTRUCT CATEGORY
(NB: Reference disidentified - N is Interview number)				
1.N.1	over-familiarity combined with schedule pressure	low work pressure	this one here is repetition of job sequence, basically how they execute the job, so it's a continuation, so it's like monotonous, so to speak ...the [other] environment is not a rushed environment, so it's a more relaxed sequence So I would say no element of pressure or priorities of your line manager...	
1.N.4	no element of pressure	pressure leading to failure to implement	Element of pressure/priorities set by line or something. ...the wrong technique sir of using it.	
1.N.2	use of handtools / hazard	dehydration and time stress	He will work for 15 minutes and another guy will replace him or else he will be under the sun activities. Dehydration sir is also there. Big stress.	
1.N.1	time pressure	competence (of operator)	maybe there was a pressure on the people to finish the system as soon as possible, there was a delay in the schedule. This one basically was about competence…. Of the operatorsŸ	**WORK PRESSURE**
2.N.4	production prioritised over safety/environment	safety/environment prioritised over production	they had this massive discussion about they were below production, do we actually need to shut this down…I just waited... and then we said "that one's just burnt down...if you don't shut it down now, we will never shut one down! ever!" …and they shut it down. ...and they said we get hit morning and afternoon about production and then maybe once every 2 or 3 months someone comes out and has a chat to us about asset integrity	
2.N.2	quick fix; limited understanding… keep going	appropriate response (stop until risk understood) proper follow-up	this was in a turnaround, under operational control, and we jumped all over it.. and the guys on the tools said we're not going back in until it's safe these two we had the 'hang on we're just trying to get Train 1 running… keep charging ahead and we'll investigate - nothing really stopped we didn't shut down... rush rush...	

After the workshop, following a process similar to that used by others (Goffin and Koners, 2011) the two sets of categories were compared in a 'reliability table'. This took the form of a matrix, one axis being the categories made by one team, each category also listing the constructs allocated to it, the other axis being the categories and allocated constructs made by the other team. Where both teams agreed on a common category, the respective cell contained a list of the 'common constructs' that both teams had allocated to that common category. The 'commonality ratio' of common constructs to the total number of constructs is an indicator of data reliability (Goffin et al., 2012).

The initial comparison of the two teams' categorisation yielded a commonality ratio of 40%. Check-coding discussion between the two teams, recommended in the case of low initial data reliability (Jankowicz, 2004) to 'aid definitional clarity' and as a 'good reliability check' (Miles and Huberman, 1994) resulted in an aligned set of categories and recategorisation of a number of constructs within these categories. This improved the commonality ratio to 85% which exceeds the suggested 80% acceptable criterion (Miles and Huberman, 1994).

When the interpretation and categorisation of the individual constructs was completed, the constructs for which no agreement was reached on a common category were discarded from further analysis; this included all of the constructs from two interviews. Also discarded were the data from two interviews for quality reasons: one since it proved too difficult to transcribe due to the strong accent, the other since it contained data from sites elsewhere than those being studied. This resulted in a final total of 135 'common constructs' in 19 categories and arising from 51 repertory grids. These data were now considered as valid for further analysis.

The aligned set of these construct categories is shown **Table 4-6.** The construct category definitions were based on the explanatory quotes for the constructs, and were agreed between the two teams of researchers after some discussion.

Table 4-6 Aligned Categories of Construct

	Category Name	Definition
1	Work pressure	Tension or pressure on people created by competing priorities, time, productivity drivers and targets, leading to shortcuts instead of considered action
2	Procedures	Plans, procedures and instructions for how work is to be done
3	Communication	The processing and exchange of information relating to plant safety
4	Compliance	The action or fact of complying with prescribed rules or procedures
5	Competence	The requisite skill, knowledge and experience to do the job safely and effectively
6	Hazard Detection	The process of noticing and identifying hazards, risks or the signals of an impending incident
7	Understanding of Risk	The process of making sense and developing situation awareness of the potential consequences, events or incidents as they unfold
8	Vigilance	The action or state of keeping mindful watch for possible vulnerabilities and potential mitigations - vs an over-confidence and belief that nothing untoward is going to happen
9	Deference to Hierarchy	Submission to those in authority and hierarchy position in decision-making
10	Supervision	Guidance and instruction and management of direct reports
11	Incident Investigation and Analysis	Investigation and analysis of immediate and underlying causes, and follow-up and learning
12	Emergency Response	The immediate action of recovery from an unexpected event or dangerous situation, and the planning and preparation for that
13	Organizational Learning	The acquisition, dissemination, and implementation of knowledge or skills through experience, post-incident
14	Checking, challenge and follow-up	Intervention to challenge or review the safety of a decision, work method or situation, including follow-up checking
15	Equipment Design	System and technology that control and protect the organization against failure
16	Unique Occurrence	An unfamiliar or novel situation that has not been encountered before
17	Mistake	Actions with unintended consequences where people believed that they were doing the correct thing
18	Mitigation	Individual or collective actions to prevent or lessen the consequences of incidents and accidents
19	Risk Assessment	The process of determining the probability and consequences of a hazard or risk

Each of these construct categories includes a number of individual constructs, as indicated in the extract from the final reliability table shown in **Table 4-7**.

Table 4-7 is in the form of a matrix. Along both axes are the categories of construct, as listed in Table 4-6. The horizontal axis shows the reference numbers of the individual constructs allocated to each category by one researcher team ('Team EC') and the vertical axis shows those allocated by the other team ('Team DN'). The intersecting cells in the matrix, forming a diagonal from top left to bottom right, contain the reference numbers of the individual constructs that were allocated by both teams to the same category. In the Team EC axis row containing the allocated constructs, the reference numbers of constructs that were categorised differently from the other team are shown in red (and similarly for Team DN in the vertical axis column). Some constructs were agreed by both teams as fitting into two categories; these are shown in bold font and marked with an asterisk.

Table 4-7 Reliability Table (extract)

REF				1	2	3	4
	Team DN	Team EC		WORK PRESSURE	PROCEDURES	COMMUNICATION	COMPLIANCE
		COUNT		7	13	3	9
				1.1.1 1.10.4 1.14.2 1.20.1 2.4.4 2.5.2 2.24.2	**1.1.2*** 1.3.2 1.4.3 1.7.2 1.11.3 1.17.2 1.19.2 2.1.3 2.5.3 2.10.1 2.16.3 2.19.2 2.19.5	1.1.3 1.3.1 1.11.2	1.1.4 1.2.1 1.5.2 **2.1.1*** 2.1.2 2.4.3 2.9.5 2.24.3 2.26.1
1	WORK PRESSURE	6	1.1.1 1.10.4 1.14.2 1.20.1 2.4.4 2.24.2	1.1.1 1.10.4 1.14.2 1.20.1 2.4.4 2.24.2			
2	PROCEDURES	11	1.3.2 1.4.3 1.7.2 1.11.3 1.17.2 1.19.2 **2.1.1*** 2.5.3 2.6.2 2.10.1 2.16.3		**1.1.2 *** 1.3.2 1.4.3 1.7.2 1.11.3 1.17.2 1.19.2 **2.1.1*** 2.5.3 2.10.1 2.16.3		
3	COMMUNICATION	3	1.1.3 1.3.1 1.11.2			1.1.3 1.3.1 1.11.2	
4	COMPLIANCE	10	**1.1.2*** 1.1.4 1.2.1 1.5.2 2.1.2 2.4.3 2.9.5 2.24.3 2.26.1 2.26.2				**1.1.2*** 1.1.4 1.2.1 1.5.2 2.1.1* 2.1.2 2.4.3 2.9.5 2.24.3 2.26.1

Throughout the remaining narrative, to simplify the language, the term 'construct' also refers to 'categorised construct' and 'construct category' as further analysis is based on these 19 categories.

To confirm that enough data had been collected, a Pareto analysis (**Fig 4-3**) was conducted in a similar manner to that used by others (Goffin and Koners, 2011; Micheli et al., 2012). The x-axis is the repertory grid count and the y-axis is the increasing total of common construct categories identified as the interviews progressed. This analysis gives some confidence that theoretical saturation was achieved.

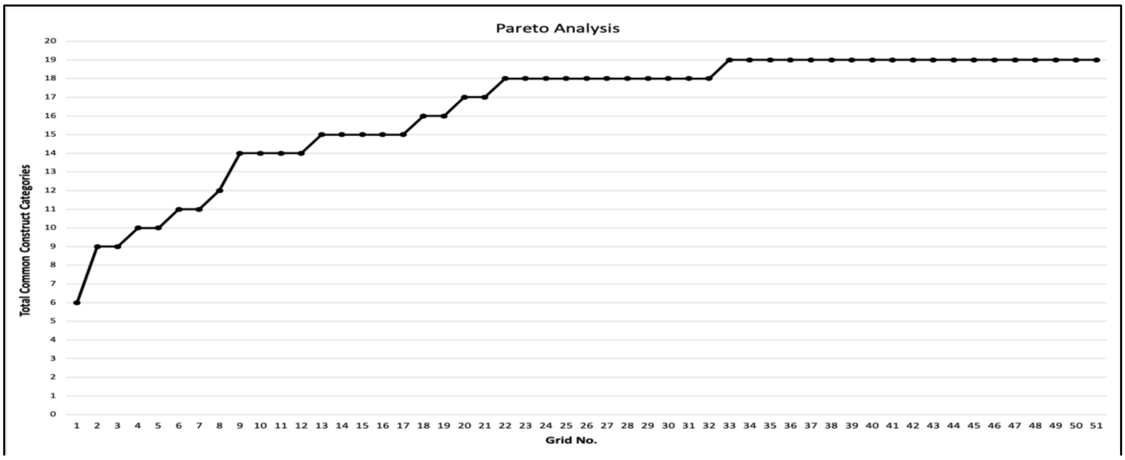

Figure 4-3 Pareto Analysis of Common Construct Categories per Repertory Grid

4.3.3.3 Analysis of overall key constructs

Having validated the data, the analysis continued with the aim of answering the research question: 'How do people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how do the interplay and tensions between rule-following and adaptive practice figure in this?'

Sorting the data into the 19 categories of construct provided a broad description of how people think about the events discussed in the interviews, but clearly some categories of construct appeared more important than others, simply because they occurred more frequently. Relying on frequency alone carries the risk of over-valuing some constructs that may occur frequently but are obvious and not so important. However, if a construct has a wide variability of element scores compared with the element scoring of other constructs within a grid, this can be taken as a measure of its importance to the person (Kelly, 1955). Using a combination of both frequency and variability thus gives a more realistic assessment of the overall relative importance of constructs; setting criteria for these measures allows 'key constructs' to be determined.

Adopting the approach taken by others (Goffin, Lemke and Szwejczewski, 2006; Lemke, Clark and Wilson, 2011) the measure of frequency used was '% Unique Frequency' (%UF) which represents the proportion of interviewees mentioning each categorised construct. This was calculated firstly by determining the UF, removing repetitive occurrences of construct categories within individual grids, and then dividing the UF by the total number of interviewees to calculate the percentage who mentioned that categorised construct.

The measure of variability used was 'Average Normalised Variability' (ANV). To calculate this, first the specialist repertory grid software *Idiogrid* (Grice, 2002) was used, to calculate the 'percentage Total Sum of Squares' (%TSS) of each construct in a category within its grid. This is 'the percentage of the total SS computed for the entire grid… reported for each construct' (Grice, 2002: 340) a measure of the variability of a particular construct within an interviewee's grid, indicating its relative importance to the interviewee. This value was normalised then for the different numbers of constructs in all the grids and finally averaged over all the occurrences of constructs in a category, yielding the ANV for that construct category.

Thus the normalisation calculation for a particular category of construct within an individual grid (Pidcock, 2016) is as follows:

Construct NV = %TSS * No. of constructs in the individual grid/Average No. of constructs per grid

Equation 4-1 Calculation of Construct Normalised Variance for an Individual Grid

As described above, the construct NVs from each grid obtained from this were then averaged over all occurrences of that construct, to obtain the construct ANV. These calculations were based on the whole data set and thus the ANV values are overall, for all of the constructs without differentiating between event types or sites, which is done later.

The criteria for determining 'key constructs' i.e. those of particular importance to the sampled population, were established following the same approach to that used by others (Goffin, Lemke and Szwejczewski, 2006; Raja et al., 2013). This approach determines that a construct is 'key' if it meets the chosen criteria for both %UF and ANV. Goffin et al note that 'The frequency count necessary for identifying important constructs is left open for interpretation in the repertory grid literature.' (Goffin, Lemke and Szwejczewski, 2006, p200) and they chose 'mentioned by at least 25% of respondents' as a criterion for relative importance of a construct compared with their total list of constructs, which represented approximately half their constructs, which aligns with their key criterion for ANV of 'above average'.

In this study, using a %UF key criterion of 25% would limit the number of such 'relatively important' constructs to just two: 'Hazard Detection' and 'Incident Investigation and Analysis', so to avoid such a limiting criterion, a lower figure of 10% was used; this then led to the inclusion of approximately half of the total list of constructs, similarly to Goffin et al.

The criterion used in this study for ANV also aligns with the Goffin et el ANV criterion set as 'above average', taken as having a value equal to or greater than the mean of all the individual construct values of ANV, which was calculated as 38.

The results of applying these criteria are shown in **Table 4-8** (see section **4.4 Results**) which ranks the 19 constructs in descending order of %UF. The constructs that meet the key criteria for both %UF and ANV are shown with a Y in the 'Key' column and are shaded grey, with the nature of the constructs indicated as administrative (Am) or adaptive (Ad); the adaptive constructs are shaded darker grey to differentiate them more clearly.

Because of the somewhat approximate nature of both the data and the criteria for determining constructs as 'key', the criteria have not been applied strictly, but instead as slightly 'soft' criteria, so that if a construct ANV for example is very close the criterion figure, and the others are more distant, then the very close one has been accepted as meeting the criterion. Thus in **Table 4-8** both 'Procedures' with an ANV of 37, and 'Understanding of Risk' with an ANV of 36 have been accepted as 'key' whereas the next nearest construct, 'Deference to Hierarchy', with an ANV of 32, has been rejected.

Two further steps of analysis were done, firstly to examine the importance attached by the interviewees to the constructs in relation to each of the three incident types, Actual Incident, Near Miss and Potential Incident (AI, NM and PI) and secondly to compare similarly across the three sites (A, B and C).

4.3.3.4 Analysis of constructs across incident types (AI, NM and PI)

To examine for differences in the importance of the constructs for each of the three different types of incident, a similar analysis was done as described above but with the data restricted to include only that for each incident type in turn. Idiogrid was used to calculate the %TSS for each construct within each 'reduced' grid i.e. separately for each event type (Actual Incident, Near Miss and Potential Incident). From these NVs were calculated and then averaged over all occurrences of that construct to obtain construct ANVs specific to each event type. Note that this analysis is based on the whole set of the grids, so the frequency of mentioning constructs and thus also the % unique frequency (%UF) remains the same for this analysis as for the earlier overall analysis. The same criteria as used for the overall key constructs were used to determine the key constructs specific to each incident type. The results of this analysis are shown in **Table 4-9**.

4.3.3.5 Analysis of constructs across the sites (A, B and C)

To examine for differences in construct importance between the three sites A, B and C, a similar analysis was done as described above but with the data restricted to include only that for each site in turn. However, since in this case the analysis only include the grids obtained from each site, the frequency of mention and thus %UF is specific to each site. The ANVs are also specific to each site. Once again similar criteria for determining 'key' constructs were used. But since the ANVs were based on the site-specific data, the mean ANVs were different for each site, and were calculated individually for sites A, B and C as 31, 35 and 19 respectively. Once again these criteria were treated as 'soft' because of their approximate nature. The results of applying these criteria are shown in **Table 4-10**.

The overall process of collecting, validating and analysing the Repertory Grid data is shown in **Figure 4-4**

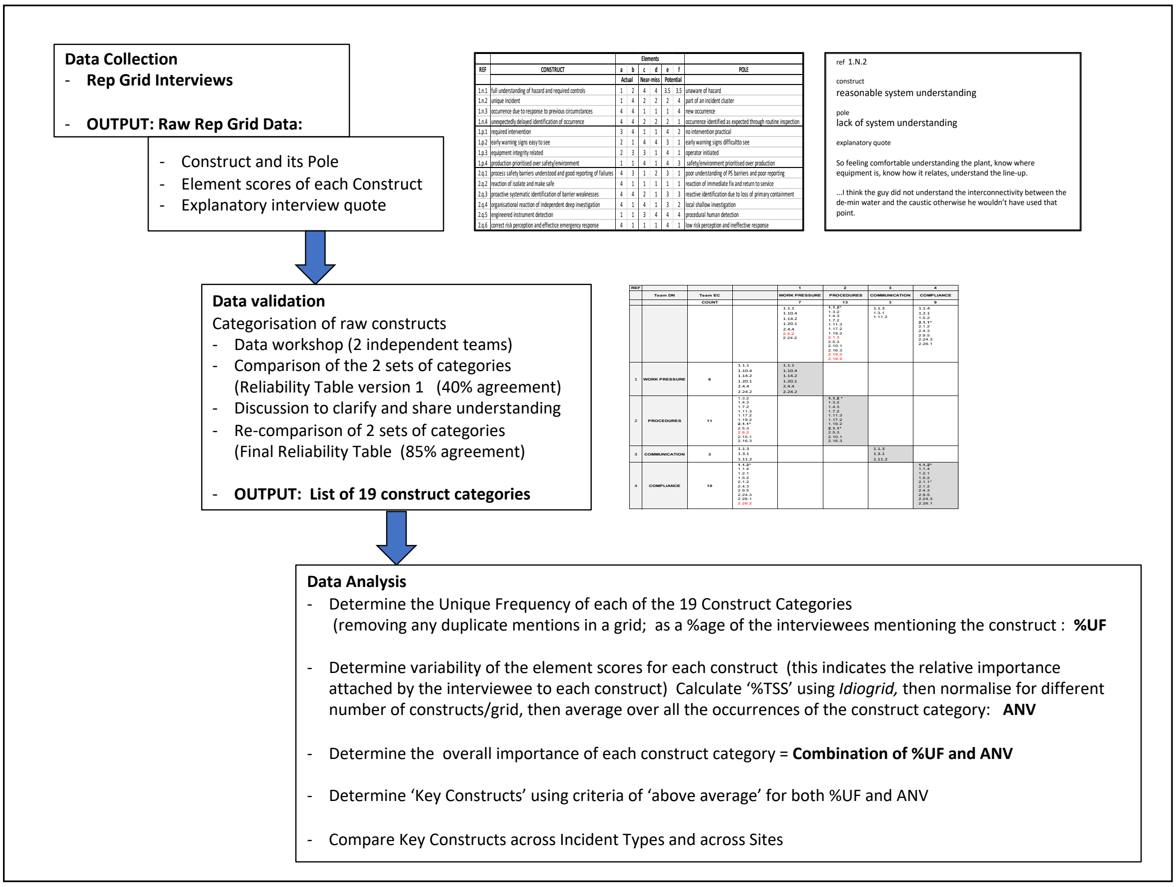

Figure 4-4 Process of Repertory Grid data collection, validation and analysis

4.4 Results

Table 4-8 shows the 9 constructs, marked as 'key', that the interviewees considered to be the most important for process safety, as elicited through the lens of identification and response to the three types of incident; it also indicates the nature of the constructs as administrative (shaded light grey) or adaptive (shaded dark grey).

The allocation of constructs to the two types of 'administrative' or 'adaptive' was done by analysing the wording of the constituent constructs within the individual grids that together make up each of the 19 construct categories, in particular the wording of the explanatory interview quotes. The meaning and nature of each of the 19 construct categories was thus analysed as relating to the paradigm of 'rule-following' 'management systems' and 'command and control' (labelled here as 'administrative') or to the paradigm of 'mindful sensemaking' 'Safety II' and 'flexible organizing and leadership practices' (labelled here as 'adaptive').

Thus the constructs of 'Hazard Detection', 'Vigilance' 'Understanding of Risk', and 'Organizational Learning' were categorised as very clearly adaptive, while 'Procedures', Compliance', 'Work Pressure', 'Risk Assessment', 'Deference to Hierarchy' 'Equipment Design' and 'Supervision' were categorised as very clearly administrative. The remaining construct categories required more detailed analysis of the constituent constructs. Incident Investigation and Analysis' was seen as the predominantly administrative formal process; 'Communication' was understood in this context as the 'non-technical skill' (Flin, Wilkinson and Agnew, 2014) of informal intra-work group communication, so seen as adaptive rather than the more administrative formal kind of communication; finally, 'Mitigation' 'Competence', and 'Checking Challenge and Follow-up' were all understood as adaptive practices required for recognising and coping with problems (Hollnagel, 2014).

Two constructs 'Unique Occurrence' and 'Mistake' were rejected since they added no meaning to the analysis and labelled as NA meaning Not Applicable. The final categorisation shown in **Table 4-8** was confirmed by the independent analysis of two other researchers.

One immediate observation is that the key constructs are a mixture of both administrative and adaptive kinds. Although the remaining constructs do not meet the 'key' criteria, they are still of interest and are discussed later.

Table 4-8 Overall Construct Ranking (all incident types and all sites)

Am or Ad	Construct	ALL			
		UF	%UF	ANV	KEY
Ad	HAZARD DETECTION	19	37	39	Y
Am	INCIDENT INVESTIG. & ANALYSIS	13	25	38	Y
Ad	VIGILANCE	11	22	41	Y
Am	PROCEDURES	10	20	37	Y
Am	COMPLIANCE	9	18	38	Y
Ad	UNDERSTANDING OF RISK	8	16	36	Y
Am	WORK PRESSURE	6	12	43	Y
Am	RISK ASSESSMENT	5	10	39	Y
Am	EMERGENCY RESPONSE	5	10	39	Y
Am	DEFERENCE TO HIERARCHY	5	10	32	
Ad	MITIGATION	4	8	42	
Am	EQUIPMENT DESIGN	4	8	32	
Ad	ORGANIZATIONAL LEARNING	4	8	30	
Ad	COMPETENCE	4	8	26	
NA	UNIQUE OCCURRENCE	3	6	50	
Ad	COMMUNICATION	3	6	32	
Am	SUPERVISION	2	4	51	
NA	MISTAKE	2	4	44	
Ad	CHECKING, CHALLENGE & FOLLOW-UP	1	2	54	

Table 4-9 shows the constructs compared across incident type. It is in the same ranking order of %UF to allow direct comparison with the overall key constructs determined in Table 4-8, with the construct ANVs for each incident type in separate columns. It also, as in Table 4-8, indicates the nature of the constructs as administrative (shaded light grey) or adaptive (shaded dark grey).

The key constructs for Actual Incidents and Near Misses are similar, all administrative in nature: 'Work Pressure' and 'Deference to Hierarchy' figuring alongside 'Compliance' and 'Incident Investigation and Analysis'. The key constructs for Potential Incidents are quite different: although 'Compliance' is common to all incident types, two adaptive constructs are included: 'Hazard Detection' and 'Understanding of Risk'.

Table 4-9 Key Constructs for each Incident Type

Am or Ad	Construct	ALL		AI		NM		PI	
		UF	%UF	ANV	KEY	ANV	KEY	ANV	KEY
Ad	HAZARD DETECTION	19	37	19		22		44	Y
Am	INCIDENT INVESTIG. & ANALYSIS	13	25	49	Y	45	Y	32	
Ad	VIGILANCE	11	22	33		33		24	
Am	PROCEDURES	10	20	12		26		31	
Am	COMPLIANCE	9	18	35	Y	43	Y	52	Y
Ad	UNDERSTANDING OF RISK	8	16	20		21		38	Y
Am	WORK PRESSURE	6	12	40	Y	46	Y	28	
Am	RISK ASSESSMENT	5	10	47	Y	16		33	
Am	EMERGENCY RESPONSE	5	10	5		35		7	
Am	DEFERENCE TO HIERARCHY	5	10	44	Y	39	Y	22	
Ad	MITIGATION	4	8	80		18		53	
Am	EQUIPMENT DESIGN	4	8	8		19		33	
Ad	ORGANIZATIONAL LEARNING	4	8	25		29		6	
Ad	COMPETENCE	4	8	26		48		4	
NA	UNIQUE OCCURRENCE	3	6	52		18		84	
Ad	COMMUNICATION	3	6	38		13		0	
Am	SUPERVISION	2	4	19		0		0	
NA	MISTAKE	2	4	55		38		43	
Ad	CHECKING, CHALLENGE & FOLLOW-UP	1	2	68		0		0	

Table 4-10 shows the constructs compared across the three sites. Again the constructs are listed in the same ranking order of overall %UF as the other tables, to facilitate comparison between them, and the key constructs for each site are indicated, as in the other tables, as well as the Y in the 'key' column, by grey shading, the darker grey indicating adaptive constructs. Some immediate observations can be made:

The only construct that is common to all three sites as key is the adaptive 'Hazard Detection'. For Site A, two key constructs are adaptive, the other five are administrative; Site B has eight key constructs, three of which are adaptive; Site C has six key constructs, five of which are adaptive: 'Hazard Detection', 'Vigilance', 'Understanding of Risk', 'Mitigation' and 'Organizational Learning'.

Table 4-10 Construct Ranking and Key Constructs for each Site

Am or Ad	Constructs	SITE A			SITE B			SITE C		
		%UF	ANV	KEY (ANV >31)	%UF	ANV	KEY (ANV >35)	%UF	ANV	KEY (ANV >19)
Ad	HAZARD DETECTION	13	33	Y	46	39	Y	56	48	Y
Am	INCIDENT INVESTIG. & ANALYSIS	0	0		42	39	Y	22	0	
Ad	VIGILANCE	38	34	Y	4	50		44	55	Y
Am	PROCEDURES	38	35	Y	15	32	Y	0	0	
Am	COMPLIANCE	19	35	Y	23	38	Y	0	0	
Ad	UNDERSTANDING OF RISK	13	29		19	37	Y	11	43	Y
Am	WORK PRESSURE	25	37	Y	8	47	Y	0	0	
Am	RISK ASSESSMENT	19	34	Y	8	41		0	0	
Am	EMERGENCY RESPONSE	0	0		15	40	Y	11	40	Y
Am	DEFERENCE TO HIERARCHY	19	25		8	36		0	0	
Ad	MITIGATION	0	0		12	40	Y	11	60	Y
Am	EQUIPMENT DESIGN	19	25		4	38		0	40	
Ad	ORGANIZATIONAL LEARNING	0	0		4	50		33	35	Y
Ad	COMPETENCE	13	22		8	30		0	0	
NA	UNIQUE OCCURRENCE	6	58		8	43		0	0	
Ad	COMMUNICATION	19	28		0	0		0	0	
Am	SUPERVISION	13	45	Y	0	0		0	0	
NA	MISTAKE	13	39		0	0		0	0	
Ad	CHECKING, CHALLENGE & FOLLOW-UP	6	48		0	0		0	0	

Some observations can be made on the results shown in Table 4-9 and Table 4-10: 'Work Pressure' is associated with Actual Incidents and Near Misses but not with Potential Incidents; 'Work Pressure' is also seen as important for Site A and B but not for Site C. Thus neither Site C nor Potential Incidents have any association with 'Work Pressure'.

Work Pressure also scores very highly at Site B on importance to individuals, as measured by ANV, even though the UF is low. This may indicate that Work Pressure is unevenly distributed at Site B, which is a multiple-location operation, but it is seen as very important where it occurs. By contrast, 'Organizational Learning' is seen as important only for Site C, and does not figure as 'key' for either Site A or Site B.

Finally, 'Hazard Detection' and 'Incident Investigation and Analysis' are both key constructs for Site B. This aligns with the content of interviews, in which numerous different incidents were discussed that involved difficulties with detection due to their remote location and unmanned operation, with a range of approaches to investigation from a simple local ‘technical fix’ to a very thorough multi-disciplinary deep causal analysis.

4.5 Discussion

The aim of this study was to gain insights about how people working directly with high hazard technology construe the important factors for process safety and experience the interplay and tensions between rule-following and adaptive practice, through the lens of three types of process safety events, actual incidents, near misses and potential incidents. 55 interviews using Repertory Grid Technique (Kelly, 1955) were conducted to examine how people at the sharp-end of organizations operating high hazard technology understand the important factors in process safety and how they construe and experience the interplay and tensions between rule-following and adaptive practice, through the lens of the three types of process safety events. 19 validated constructs were obtained from the usable 51 repertory grids interviews at three operational oil and gas and petrochemical sites with different characters but using similar technology and operated by the same multinational organization.

The sites were at different stages of organizational maturity and had different levels of safety performance. Site A, a large recently-constructed petrochemical site in the Middle East, had a safety performance perceived as mixed, Site B, a recently-acquired and rapidly-developing onshore oil and gas production operation in Asia Pacific with a large number of geographically-dispersed production units and a large central treatment and export plant, had a safety performance perceived as below-average, and Site C, a mature offshore oil and gas production operation in Europe, had a safety performance perceived as above-average, for which it had recently received a major award.

The relative importance of these constructs for the interviewees was analysed, to compare between type of process safety event and between the three sites.

Comparing the importance attached to constructs across incident types enabled a number of observations: First, out of the total of 19, the nine constructs rated most important by interviewees (the ‘key constructs’) six were administrative and three were adaptive in nature (‘Hazard Detection’, ‘Vigilance’ and ‘Understanding Risk’). This appears to support the theory that both administrative and adaptive processes and practices are important for process safety (Hollnagel, 2014; Leveson, 2011).

Second, comparing across incident types, of the three constructs the interviewees rated as important ('key') for Potential Incidents one was administrative ('Compliance') and two were adaptive (Hazard Detection' and 'Vigilance') and neither of these two adaptive constructs figure as key for Actual Incidents or Near Misses. This supports the proposition that the early detection of Potential Incidents requires adaptive processes, for example in the form of making a strong response to a weak signal (Weick, Sutcliffe and Obstfeld, 1999)

Third, all the key constructs associated with both Actual incidents and Near Misses were administrative in nature. Fourth, two administrative constructs Work Pressure and Deference to Hierarchy were associated only with Actual Incidents and Near Misses, and not with Potential Incidents. Interpreting these two observations together, these associations support the proposition that relying on administrative processes alone is insufficient for safety. (Hollnagel, 2014)

Fifth, the administrative practice of 'Compliance' was strongly associated with all three incident types. This is expected since the 'Safety 1' paradigm is accepted as an important part of safety, even if incomplete (Hollnagel, 2014; Leveson, 2011). Compliance can be regarded as a 'hygiene factor' (Herzberg, 1964) that is regarded as important but is not a differentiating factor.

Comparing across the sites, a striking observation is that Work Pressure was associated with Sites A and B, but not with Site C. Putting this alongside the association of Work pressure with Actual Incidents and Near Misses, and with the knowledge that Site C was perceived to have better safety performance reinforces the interpretation that administrative processes without adaptive is insufficient. Since as seen above, the identification and correction of Potential Incidents requires adaptive practices, this indicates an (unsurprising) negative influence on process safety of Work Pressure and Deference to Hierarchy. The negative effect of these constructs is well known (Reason, 1997; Vaughan, 1997a)

Two other observations that appear complementary are that Organizational Learning was associated with Site C, but not with Sites A and B, and that Understanding of Risk was more strongly associated with Potential Incidents than the other event types, so these two constructs can be seen as having a positive influence on process safety.

The constructs that emerged as important for Site C were Hazard Detection, Vigilance, Organizational Learning, Mitigation and Understanding of Risk. Site C had the perceived best process safety record and was seen as an exemplar in the company. The interviews at Site C also described a stable, mature organization with a marked open culture and a strong emphasis on both process safety and personal safety; there was an active practice of reviewing process safety events of all three types with a focus on learning and follow-up.

Returning to **Table 4-7**, although there are only 9 constructs that meet the 'key' criteria when analysed overall, some of the other constructs do meet the key criteria when analysed by incident type or site: As noted in **Table 4-8**, 'Deference to Hierarchy' is key for both Actual Incidents and Near Misses, and both 'Mitigation' and 'Organizational Learning' are key for Site C.

Other constructs such as 'Equipment Design', 'Competence' 'Communication' and 'Supervision', though not occurring so frequently, do show moderate to high ANVs which indicates they were quite significant to the interviewees who mentioned them.

'Of the 19 constructs, 'Unique Occurrence' and 'Mistake' appear to offer little analytical value, so are not considered further in the analysis.

In summary, taking these observations and interpreting them together allows a number of conclusions can be drawn. First, both administrative and adaptive practices were seen by the interviewees as important for process safety. Second, although both approaches contribute to process safety, adaptive practices (for example organizational learning and understanding of risk) were associated significantly more closely with the better process safety outcomes of potential incidents rather than actual incidents and near misses, while thirdly, a negative influence on process safety outcomes was construed in the form of work pressure and deference to hierarchy.

The main contribution from this study is to support the theory that the safe operation of high hazard technology relies on both engineering and rule-following and adaptive processes such as sensemaking, mindfulness and expert improvisation as described in the theories of HRO (Weick, Sutcliffe and Obstfeld, 1999) system safety (Leveson, 2004) and Safety II (Hollnagel, 2014). A second minor contribution is also made, extending this theory: that a balance of administrative and adaptive practice that slightly favours adaptive practices (such as organizational learning and understanding of risk) appears to be more supportive of process safety by the early identification of Potential Incidents.

This study provides some insight into how rule-following and adaptive practices are perceived by people working directly with high hazard technology. Although both approaches can be seen as contributing to process safety, the adaptive practices of organizational learning and understanding of risk were seen to be associated significantly more closely with the better process safety outcomes of potential incident rather than actual incidents and near misses, while a negative influence on process safety outcomes was construed in the form of work pressure and deference to hierarchy.

4.5.1 Limitations of the research

Although the access to interview people working directly with high hazard technology was much valued and appreciated by the researchers, inevitable restrictions on time and availability of people limited the scope and opportunities for data collection. It is acknowledged that limitations on the research include some missing data points in some repertory grids, some doubtful distinction between the types of event by some interviewees, a small average number of constructs that were obtained per interview, and that the number of interviews at the three sites was not well-balanced.

It is also acknowledged that although the characteristics of the three sites is described fairly, more complete data about process safety outcomes and culture at the three sites would have been useful.

4.6 Conclusions

The results of this empirical study provide some insight into how rule-following and adaptive practices are perceived by people working directly with high hazard technology. It has found evidence that people at the operational sharp-end of high-hazard technology in the oil & gas and petrochemical industry see both administrative practices such as compliance with procedures and investigation of incidents and also mindful, adaptive practices such as vigilance, hazard detection, understanding of risk and organizational learning are important for process safety. Although both approaches can be seen as contributing to process safety, the adaptive practices of organizational learning and understanding of risk were seen to be associated significantly more closely with the better process safety outcome of potential incidents rather than actual incidents and near misses, while a negative influence on process safety outcomes was construed in the form of work pressure and deference to hierarchy.

These observations support the theory that the safe operation of high hazard technology relies on both engineering and rule-following and adaptive processes such as sensemaking, mindfulness and expert improvisation as described in the theories of HRO (Weick, Sutcliffe and Obstfeld, 1999) system safety (Leveson, 2004) and Safety II (Hollnagel, 2014).

The study has not investigated the mechanisms by which these two paradoxically different approaches are entangled successfully in practice. This is an area of much research interest, embracing the fields of organizational ambidexterity, culture and leadership, which will be explored in future research.

4.6.1 Implications for process safety practitioners

This study identifies four clear implications for practice within organizations operating high hazard technology:

1. Emphasise mindful compliance with procedures
2. Encourage hazard detection, vigilance, understanding of risk and mitigation
3. Emphasise organizational learning from potential incidents, rather than actual incidents and near misses
4. Avoid negative influences on process safety from work pressure and deference to hierarchy

5 LEADERSHIP PRACTICES AND PROCESS SAFETY

Abstract

Drawing on Complexity Leadership Theory and Leadership-As-Practice, this qualitative empirical study of three operational oil & gas and petrochemical sites in the Middle East, Asia-Pacific and Europe examines the entanglement of administrative and adaptive processes in the context of process safety and the influence of leadership practices on this. The operation of high hazard technology typically employs administrative processes and a traditional leader-centric 'command and control' leadership paradigm. However, consistent with recent research, our findings reveal that safe operation also depends on adaptive practices of mindful organizing and expert improvisation. From interviews with 73 operational staff we found important differences between the three sites in their balance of administrative and adaptive practices, in their contextual conditions of culture, structure and maturity and in the extent that leadership enabled the combination and balance of rule-following with expert improvisation. Comparing these differences with the perceived different process safety outcomes of each site provides evidence that leadership practices and contextual conditions were significant influences on the successful entanglement of administrative and adaptive practices in support of avoiding major incidents. These findings support and extend both Leadership-As-Practice and Complexity Leadership Theory

5.1 Introduction

Complexity Leadership Theory views leadership as an emergent property of relations and suggests that the paradox of sustaining both adaptive practices required for change as well as the administrative processes required for efficiency may be achieved by 'enabling' leadership practices (Murphy et al., 2017; Uhl-Bien, Marion and McKelvey, 2007; Uhl-Bien and Arena, 2017; Uhl-Bien and Marion, 2009). 'Leadership-As-Practice' also proposes that leadership emerges, in the form of a practice of 'immanent collective action' unfolding from the discourse and actions of people working together (Raelin, 2016, p3). So leadership may be seen in the practices of 'ordinary work' within a frame of context, activity and outcome (Kempster and Gregory, 2017, p512). According to this perspective, leadership does imply leaders, 'those individuals who have more or less successfully claimed entitative status for the role of leader' (Tourish, 2019, p229) and the enactment of leadership by leaders is acknowledged as the essence of leadership, in the context of a specific relationship with others, who as a result give their support to a specific vision, aim or goal, which may be co-constructed (Drath et al., 2008).

Whilst the contribution of Complexity Leadership Theory has been laudable, this body of work has been criticised as being inconsistent in viewing organizations as complex adaptive systems yet not explaining the mechanisms by which leadership may emerge from individual interactions, instead remaining leader-centric: 'traditional leadership thinking inserted into a complex organizational context' (Tourish, 2019, p223). The work on Leadership-As-Practice has also been criticised as having a 'lack of critical engagement, particularly in relation to its neglect of asymmetrical power relations and control practices' and focussing almost entirely on agency (Collinson, 2018a, p363). That leadership is complex is well accepted (Fischer, Dietz and Antonakis, 2017; Tourish, 2019), likewise organizations (Snowden and Boone, 2007; Tsoukas and Dooley, 2011; Weick, 1979). Complexity also manifests in the tensions and dilemmas that people routinely face (Smith et al., 2017). This has been explored with theories of 'paradox' (Clegg, da Cunha and e Cunha, 2002; Milosevic, Bass and Combs, 2018; Smith and Lewis, 2012; Zhang et al., 2015) and 'ambidexterity' (O'Reilly and Tushman, 2013; Raisch et al., 2009; Turner and Lee-Kelley, 2013). Despite these efforts, paradox remains 'at the core of the leadership challenge' (O'Reilly and Tushman, 2013, p332).

To address this challenge, this study examines how leadership practices enable the entanglement of administrative and adaptive processes in the context of process safety.

The question addressed by this study is:

- What kind of leadership practices are seen at the operational sharp end of organizations operating high hazard technology and how do these leadership practices enable the successful entanglement of administrative and adaptive processes in support of process safety?'

The approach taken to this multiple case study combined grounded and theory-driven methods, employing a semi-structured interview protocol partly derived from theory and including open questions to seek unprompted observations. Drawing on critical realism, we argue that the world is an open reflexive system with emergent properties, allowing both a constructionist view but also hold that objective reality formed of structures and generative mechanisms does exist, and although occluded from simple observation is at least partly discernible by processes of retroduction from stratified empirical experiences and actual events (Bhaskar, 2016; Outhwaite, 2019). This approach is therefore well-suited both to appraising the widely differing theories and also to interpreting the qualitative interview data in the light of the theoretical challenges (Kempster and Parry, 2011) and was therefore adopted as the ontological and epistemological framework.

The choice of the oil & gas and petrochemical industry for this study was based on three criteria. Firstly, good access was made available because of the researcher's experience in that industry, which enabled some choice of fieldwork sites. Although there is much standardisation of technology and management systems, since they were all operated by the same multinational company, the three sites were quite different in both organizational maturity and safety outcomes; recently, the two least mature sites had suffered, respectively, fatalities and high-potential near-misses, while the other, the most mature, had recently been recognised with a major award for its process safety performance.

Secondly, the prevalent leadership approach in these industries is traditional leader-centric 'command and control' with highly procedural administrative processes, though different approaches are also seen. However, a growing consensus in the academic safety literature holds that safe operation of such technology also depends, paradoxically, on adaptive practices such as mindful sensemaking (Weick, Sutcliffe and Obstfeld, 1999; Weick and Sutcliffe, 2001) and expert improvisation (Hale and Borys, 2013; Hollnagel, 2014; Leveson, 2011; Rego and Garau, 2007) to overcome the inevitable system weaknesses. Achieving an appropriate balance of rule-following with expert improvisation is, therefore, a major paradox of strategic importance to this industry, especially in the light of the numerous recent disastrous major incidents. It represents an opportunity to challenge the dominant leadership paradigm as taking insufficient account of actual practices at the operational sharp end.

Thirdly, it is argued that researching leadership practices in such high hazard situations 'may provide particularly rich insights into organizational processes of adaptation and prioritization, resilience…' (Hallgren, Rouleau and de Rond, 2018, p112).

5.2 Theoretical Background

Recent leadership theories have challenged the traditional positivist and leader-centric assumption that leadership is something done by leaders to encourage followers in pursuit of a goal, the 'leader-follower-goal tripod' (Bennis, 2007, p3). An alternative view sees leadership as a plural socially-constructed phenomenon (Denis, Langley and Sergi, 2012) important variants of which being 'distributed' (Gronn, 2000) 'relational' (Uhl-Bien, 2006) and 'shared' (Ensley, Hmieleski and Pearce, 2006). Focusing this view on outcomes of leadership as the agreement of those involved to prioritise working together on aims and goals collectively set has suggested an alternative leadership tripod of 'direction, alignment and commitment' (Drath et al., 2008, p636). Seeing leadership in this way as a collective endeavour (Raelin, 2018) presumes a moral 'philosophy of co-development' rather than dependence (Woods, 2016, p77) and so introduces a normative aspect. This is echoed by a theory of 'relational coordination' based on 'shared goals, shared knowledge and mutual respect' (Gittell and Uhl-bien, 2016, p4).

Viewing organizations as complex adaptive systems (Lichtenstein, 2000; Weick, 1979, 2009) has led to theories of Complexity Leadership (Murphy et al., 2017; Uhl-Bien, Marion and McKelvey, 2007; Uhl-Bien and Arena, 2017; Uhl-Bien and Marion, 2009) which suggests that leadership can be analysed as three kinds of practice: administrative, adaptive and enabling, this latter being those that support the effective entanglement of the adaptive nature of complexity with the bureaucratic functioning of organizations. Other writers have recognised leadership as being necessarily contextual (Osborn and Marion, 2009) adaptive (DeRue, 2011; Heifetz, Grashow and Linsky, 2009) and 'processual, communicative' (Fairhurst and Connaughton, 2014; Tourish, 2014).

These theories see leadership as practices that are emergent from the dynamic interactions between individuals, rather than from individual acts (Lichtenstein and Plowman, 2009). This has been developed into a theory of 'Leadership-As-Practice' (Raelin, 2011) that sees leadership as woven into shared or collective processes, emerging from listening and reflecting as well as synthesizing ideas and catalysing action and that leadership 'becomes evident when agency appears as a constraint to structure' (Raelin, 2016, p5). Leadership is thus found in activities and interactions that 'can take on multiple directions, transcend formal hierarchies and involve multiple actors' and often involve 'skilled improvisations, dialogue and collaborative learning' (Denyer and Turnbull James, 2016, p264).

Collinson recognises the importance of practices but points out that practices are inevitably influenced by structure: 'critical perspectives view practice and power, and structure and agency, as inextricably linked' (Collinson, 2018b, p386) Much leadership theory privileges agency over structure, despite their reflexivity: 'morphogenetic and structuration approaches concur that 'action' and 'structure' presuppose one another' (Archer, 2010, p226). Structure is thus acknowledged as important to leadership, reflexively with agency. If leadership is processual and emergent then it must also, reflexively, create structure: 'a communicative process whereby agents claim entitative status for emergent social structures. Moreover, without such claims being made, negotiated and formalised there would be no over-arching organizational entity within which leaders emerge from leadership processes' (Tourish, 2014, p86).

Complexity leadership theory as currently proposed relies on traditional agentic, even heroic, leaders viewing their organizations as complex and so encouraging experimentation, promoting learning, injecting tension and conflict to encourage creativity, creating the conditions for informal networking but still retaining control within limits set by them. Viewing organizations as truly complex adaptive systems would mean accepting that instead of formal leaders exercising command and control, 'leaders are themselves part of the complexity processes they manage' (Tourish, 2019, p229) and that who exercises leadership over whom in a given situation will depend on the context, history and dynamic interaction processes. This is a logical challenge; a more complete complexity theory of leadership would indeed include an explanation of how leadership emerges and how asymmetrical power relations and control practices may be accommodated. But there may still be merit in a theory that helps explain how leaders, however they are instituted, can be more effective by adopting a more realist approach that takes better account of complexity.

The complexity of leadership is widely recognised. It is seen as a 'social and goal-directed influence process that unfolds in space and time' that 'produces effects via multiple paths' (Fischer, Dietz and Antonakis, 2017, p1747). This draws an image of emergence and complexity. Further, 'leadership cannot be understood so long as it is envisaged as a means whereby powerful actors exercise more or less unidirectional influence on others and on organizational systems. Every aspect of leadership and the identities of those who hold leadership positions are themselves complex' (Tourish, 2019, p233). That said, leadership as a concept must imply the existence of leaders, and notwithstanding the risk of hubris with heroic leaders and associated leader-centric theories, the enactment of leadership by leaders, however they are instituted, is acknowledged as the essence of leadership, in the context of a specific relationship with others, who as a result give their support to a specific vision, aim or goal, which may indeed be co-constructed (Drath et al., 2008). Whether individuals have formal authority or not, leaders can be seen as individuals who have 'claimed entitative status for the role of leader' (Tourish, 2019, p229) without any conflict with the idea of leadership as a phenomenon of leaderly influence that is emergent from process, relations and context (Ladkin, 2010). Although the large and visionary are acknowledged as valid elements of leadership, it is suggested that leadership may also emerge from the small and mundane: relational behaviours such as listening (Alvesson and Sveningsson, 2003) or recognising emotional expressions (Walter et al., 2012) and features of organizing such as ensuring adequate resources, organizing meetings and facilitating information flow (Huettermann, Doering and Boerner, 2014). Such leadership practices manifest in communicative processes that may operate through cognitive, affective or behavioural mechanisms (Fischer, Dietz and Antonakis, 2017).

That organizations, their activities and the environments they operate in are complex, rather than merely complicated, is also well accepted (Snowden and Boone, 2007; Tsoukas and Dooley, 2011; Weick, 1979). An important aspect of complexity manifests in the tensions and dilemmas that people routinely face in carrying out their work in organizations: 'Studies of paradox, dialectics and dualities unpack the complex and often irrational relationships between opposing poles' (Smith et al., 2017, p313). Theories of 'paradox' (Clegg, da Cunha and e Cunha, 2002; Milosevic, Bass and Combs, 2018; Smith and Lewis, 2012; Zhang et al.,

2015) and 'ambidexterity' (O'Reilly and Tushman, 2013; Raisch et al., 2009; Turner and Lee-Kelley, 2013) have explored this, but despite these efforts, paradox 'remains at the core of the leadership challenge…How can leaders manage the inevitable conflicts that arise?' (O'reilly and Tushman, 2013: 332). Birkinshaw and Gupta suggest that finding creative ways of optimising between competing priorities that may depend on many different criteria as the fundamental competence that organizations need of managers: 'why else do we need managers other than to help organizations do the things that don't come naturally to them?' (Birkinshaw and Gupta, 2013, p293).

Three ambidexterity mechanisms have been identified (O'Reilly and Tushman, 2008) 'sequential', changing structures over time, 'simultaneous or structural', having separate groups within the organization and thirdly 'contextual' in which people decide individually how to choose between conflicting demands for alignment and adaptability. This latter, 'contextual ambidexterity' of most interest to this study, relies on a 'supportive organization context' (Gibson and Birkinshaw, 2004, p210) that has four key attributes borrowed from Ghoshal and Bartlett: 'discipline' meaning clear standards of performance and behaviour with open, candid and rapid feedback; 'stretch', a collective identity and shared goals, 'trust', just and fair processes of decision-making and 'support', help and guidance from senior people, rather than just authority (Ghoshal and Bartlett, 1994). Other mechanisms have been suggested that include multitasking, knowledge-sharing and integrating within informal and formal networks and processes, building strong social relationships and establishing shared values and goals (Turner, Swart and Maylor, 2013).

O'Reilly and Tushman (2013) refer to the operation of the Toyota Production System, the highly procedural 'administrative' tasks of car assembly balanced with intentionally 'adaptive' frequent job changes aimed at improving work processes, as an exemplar model of contextual ambidexterity. Whilst car assembly is not the same as oil & gas and chemicals, the search for efficiency and process safety have a common need to balance administrative and adaptive practices at the operational level, and contextual ambidexterity may help understand how these day-to-day dilemmas are managed in both of these worlds.

One theory of paradox views competing demands as inevitable and a normal part of everyday management, and these necessarily generate relational synergy that emerges in the form of local improvised work practices (Clegg, da Cunha and e Cunha, 2002). Developing this theory further suggests that 'sustainability depends on attending to contradictory yet inter-woven demands simultaneously' (Smith and Lewis, 2011, p397) so that dealing effectively with such paradoxes calls for specific leadership practices: accepting complexity, questioning over-simplified explanations or assumptions, treating problems as opportunities for learning, using tensions to elicit creativity and sharing the rationales behind decisions with effective two-way communication (Smith and Lewis, 2012). The parallel this makes with High Reliability Organizing (HRO) practices (Weick and Sutcliffe, 2006) such as 'reluctance to simplify' and 'sense-making' is striking.

A recent longitudinal case study found that the explicit framing of separate objectives in the organization's mission as contradictory and interdependent was seen as an important leaderly act that helped internal and external stakeholders agree on strategies. This building of shared vision using these 'paradoxical frames', together with establishing structure such as goals, metrics and roles for each separate objective were seen as the critical leadership practices of 'structured flexibility' that enabled this organization to succeed (Smith and Besharov, 2019).

Operating the kinds of high hazard technology found in the oil and gas and petrochemical industries typically employs highly procedural administrative processes but the need for these to be balanced with flexibility has long been recognised: 'Prescriptive command-and-control approach deriving rules of conduct top-down… is inadequate' for managing the safety of modern dynamic systems (Rasmussen, 1997, p185). And there is a growing consensus in the academic safety literature that adaptive practices of 'sensemaking' (Weick, Sutcliffe and Obstfeld, 2005) 'mindfulness' (Weick and Sutcliffe, 2006) and 'expert improvisation' (Hale and Borys, 2013; Hollnagel, 2014; Leveson, 2011; Rego and Garau, 2007) are indeed part of the daily reality of safe operations, albeit perhaps unrecognised. Current guidance on leadership for process safety from numerous authorities remains based on the traditional paradigm (COMAH Strategic Forum, 2017; HSE, 2007; IOGP, 2013; OECD, 2012; Process Safety Leadership Group, 2008).

That this is of societal importance is underlined by the continuing history of disasters arising from high hazard technology. Although technology and cultures differ, commentators on a wide range of industrial disasters have repeatedly criticised leaders for tolerating or even creating the organizational conditions that led to them (Flin, 2003; Hackitt, 2012; Hopkins, 2006a; Reason, 1997). In their analysis of the Air France 447 disaster, Oliver et al propose that organizations operating high hazard technology need 'strategies that allow controls to be designed into systems while also developing and maintaining the disturbance-handling capabilities of those who operate them' (Oliver, Calvard and Potočnik, 2017, p740). These writers also indicate the potential value of better understanding of this topic to organizations in wider social and political spheres, for instance banking. The apparent inflexibility of design that may have contributed to the recent Boeing 737 MAX disasters (Ethiopia Aircraft Accident Investigation Bureau, 2019) may also tragically serve to underline the importance of adaptive practices of expert improvisation in the operation of high hazard technology.

5.3 Research Method

5.3.1 Data Collection

5.3.1.1 Selecting fieldwork sites

Sites were selected that had similar technology and broad organizational context but that were at different stages of organizational maturity with differences in perceived safety performance to allow comparison.

Site A was a large petrochemicals complex that had started up a few years earlier. The organization was fairly hierarchical, emphasising the importance of compliance with procedures. An impressive construction safety performance had suffered in translation into operation, the site having had a number of significant process safety incidents in the early years of operation, including some fatalities.

Site B was an onshore oil & gas production operation with a large number of geographically dispersed production units feeding a single large treatment and export plant. The organization was a fairly flat hierarchy with a moderately open culture, steadily expanding, drawing operating staff from the local population and providing extensive training. The site had suffered a number of significant process safety incidents including some high potential consequence near-misses and potential incidents.

Site C was an offshore oil and gas production operation with a fairly small team of experienced people and a markedly open culture of mutual respect. The site had recently been given a major award for its process safety performance.

A summary of the profiles of the three sites is given in **Table 5-1.**

Table 5-1 Summary profiles of the three sites

	Site A	Site B	Site C
Overview	Large single site Petrochemicals complex	Onshore Oil & Gas production, Large number of remote production units dispersed geographically; single large treatment and export plant	Offshore Oil & Gas production, onshore treatment plant and office for technical and operations support
Location	Middle East	Asia Pacific	Europe
Organizational form	Strong hierarchy	Hierarchy / open culture	Weak hierarchy / open culture
Personnel	Largely ex-patriot	Largely local	Largely local
No. of people	2000+	4000+	200+
Organizational maturity	In transition from very large Project to Operations	Mixed; rapidly growing number of physical assets	Stable; mature
Years of operation	5+	10+	25+
Relation with Parent	Significant specialist support	In the process of adopting Parent Org technical standards	Fairly independent; supported as needed
Perceived Safety performance	Mixed	Below average	Above average

5.3.1.2 Selecting interviewees

Interviewees were selected to gain a range of different perspectives. Interviewees included operator/technicians and first line supervisors directly responsible for operating and maintaining the plant as well as engineers and managers. The number of interviews conducted at each site with people of each job type is given in **Table 5-2**.

Table 5-2 Interviews conducted

	Site			
	A	**B**	**C**	Totals
Ops& Maintence Operator /Technician	4	0	1	5
Ops& Maintence Supervisor	2	11	5	18
Ops& Maintence Engineer	0	6	1	7
Ops& Maintence Manager	4	12	11	27
Project Engineer	0	2	0	2
Contractor Manager	5	0	1	6
Contractor Supervisor	3	0	0	3
Project Manager	3	0	2	5
Totals	**21**	**31**	**21**	**73**

5.3.1.3 Interview process

Interviews were conducted face-to-face at the operational plant site in the privacy of a small office. The average interview duration was around one hour. Interviewees were assured of complete confidentiality in accordance with the university's ethical policy. All interviews were one-to-one except one with two people who were working together in an extended handover.

The recorded interviews were transcribed using a confidential transcription service. The interviews were conducted based on the open questions shown in **Figure 5-1**. Not all interviews included all of the questions, and in most cases probing questions were posed to follow up on initial responses. Interviewees were encouraged to explain their ideas and give anecdotes to provide depth and context.

The detailed interview protocol is given in **Appendix A-2.**

1. How would you describe the leadership you see at your work site? What words or phrases spring to mind?
2. Who would you regard as engaging in leadership at your work site [names will not be disclosed]? What are the key actions and interactions that these people engage in (i.e. what do they do)?
3. When an urgent problem or safety issue occurs - an urgent operational or technical issue - who decides what to do? How do they get the authority to take action?
4. How effective is leadership at your workplace?
5. What are the signs of effective/ineffective leadership? How does this affect the way people work?
6. How does leadership affect safety outcomes?
7. What is the role of leadership in directing, planning and resourcing work?
8. How clear are lines of authority, roles and responsibilities?
9. How are new ideas, practices and work methods encouraged and stimulated?
10. How do people challenge established thinking and practices or adapt and bring improvements?
11. How do people manage the tension between rule-following and adapting sensibly to local conditions and problems? How does leadership influence this?
12. How do people create shared awareness of the situation regarding current operational or technical issues? How does leadership influence this?
13. How wary or uneasy are people about what could go wrong? How does leadership influence this?
14. How does the organization detect, contain and recover from unsafe acts and conditions (i.e. potential incidents) before they can develop into real incidents? How does leadership influence this?
15. How do people react when an incident occurs? How does leadership influence this?
16. How do people learn and actively change after an incident? How does leadership influence this?

Figure 5-1 Semi-structured Interview Questions

5.3.2 Data Analysis

The interview transcripts were coded following the method recommended by Miles and Huberman (1994) and using NVivo 12 (Jackson and Bazely, 2019). Starting by analysing a sample of three interview transcripts with a grounded approach, we inductively created an initial template structure of first-order codes. Coding then continued for the remainder of the 73 transcripts following a process similar to that used by Walsh and Bartunek (2011) pursuing a cycle of abductive and retroductive reasoning, referring to the existing literature on paradox, ambidexterity, complexity leadership and HRO to help explain what we found in our data, frequently modifying the template during the process.

Using this approach, we identified second-order theoretical categories of the initial codes that had emerged from our data, and finally we organized these second-order codes into aggregate theoretical dimensions. This third-order grouping follows the 'CIMO-logic' ('Context-Interventions-Mechanisms-Outcomes') structure (Denyer and Tranfield, 2006) to distinguish contextual conditions from interventions in the form of leadership practices and working practices, with outcomes understood as the perceived process safety performance of each site.

Check-coding was done by an independent researcher on a sample of interviews and the results compared. Two separate data workshop days were spent first coding the interview transcripts independently, then discussing the results to identify differences, share understanding and refine definitions. During these workshops there were numerous instances of the two independent codings being slightly different, though close in meaning when discussed. This we believe is a result of the large number of first-order codes, many of which are indeed close in meaning. When discussion led to recognition that each coder could have coded in the same way as the other, this was accepted as adequate agreement. On this basis, inter-coder reliability of 80% was achieved, which is deemed acceptable (Miles and Huberman, 1994).

We also checked systematically for data saturation by examining the cumulative number of codes identified from each interview (Figure 5-2). This procedure revealed that the last nine interviews yielded no new codes.

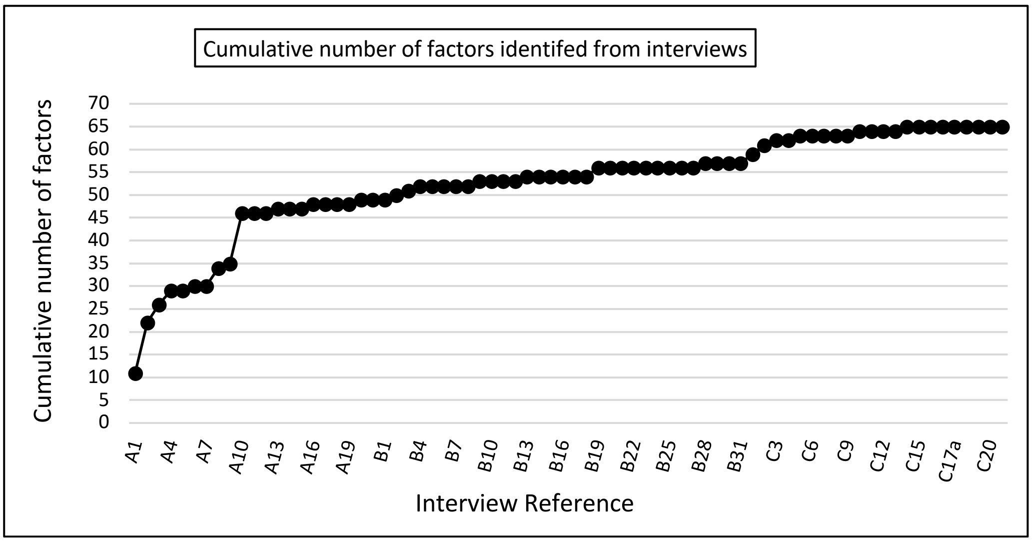

Figure 5-2 Data saturation graph

After many iterations, the final template (Table 5-3) had 63 codes, made up of 44 'Helping' factors that support process safety and 19 'Hindering' factors (coded with 'N' suffix) that impede process safety. In order to facilitate cross-site comparison of the qualitative data and the drawing of conclusions, it was decided to quantify the data by calculating the number of informants mentioning each code. It is acknowledged that in such quantification, the qualitative data loses its distinctive and valuable nature of rich description and textual meaning. To overcome this issue, evidence from the interview data for each of the second-order codes is retained in the form of illustrative quotes. Both the quantified data and the illustrative quotes are examined for differences between the three sites, and these are described and discussed below.

To facilitate comparison of the relative importance of the 17 second-order theoretical categories for each site, figures are given for the percentage of interviews per site that referred to factors in a category. Averages are used to allow for the variation in number of codes per category; they have also been normalised to allow for the variation in the number of interviews conducted at each site.

Some interviewees made several references to the same code, but only a single reference to each code per interviewee was counted, since one informant repeatedly mentioning a particular feature would over-emphasise the importance of a code whereas mentions by multiple participants would signify its importance.

Table 5-3 Coding Template

CONTEXTUAL CONDITIONS	ENABLING LEADERSHIP PRACTICES	ADMIN WORKING PRACTICES
CCu - CONTEXTUAL CONDITIONS - Culture	**LEN1 - ENABLING LEADERSHIP PRACTICES – Sensemaking and challenging**	**WAM1 – ADMIN WORKING PRACTICES - Procedures, Competence & Compliance**
CCu1 - Just culture	LEn11 - Sensemaking / sensegiving	WAm1 - Effective procedures
CCu2 - Reporting culture	LEn12 - Challenging assumptions	WAm2 - Technical competence
CCu3 - Chronic unease and 'stop' culture	LEn13N - Giving mixed messages	WAm3 - Norm of compliance
CCu4 - Open culture - trust & low threshold for challenge	**LEN2 - ENABLING LEADERSHIP PRACTICES – Supporting individuals & networks**	WAm4N - Unclear standards, procedures or work instructions
CCu5N - Blame culture	LEn21 - Engaging with and supporting workers	WAm5N - Lack of tech competence or hazard awareness
CCu6N - Ineffective processes for learning & improvement	LEn22 - Protecting people from politics	WAm6N - Ineffective implementation
CCu7N - Production pressure - short termism	LEn23 - Removing difficult people	**WAM2 – ADMIN WORKING PRACTICES - Risk Management**
CCu8N - Ineffective management of stress or fatigue	LEn24 - Supporting formal networks	WAm21 - Processes for risk management
	LEn25 - Supporting informal networking	WAm22 - Processes for shared situation awareness
CSt - CONTEXTUAL CONDITIONS - Structure & Maturity	LEn26N - Ineffective engagement with or support for workers	WAm3N - Cumbersome risk management bureaucracy
CSt1 - Accessible leaders - flat structure	**LEN3 - ENABLING LEADERSHIP PRACTICES - Enabling Ambidexterity**	
CSt2N - Inadequate resourcing	LEn31 - Enabling rule-following AND competent improvisation	ADAPTIVE WORKING PRACTICES
CSt3N - Unclear or misaligned responsibilities or authorities		**WAD1 – ADAPTIVE WORKING PRACTICES 1 - Preoccupation with Failure**
CSt4N - Ineffective transition from Project to Operations	ADMIN LEADERSHIP PRACTICES	WAd11 - Identifying & reporting Potential Incidents
CSt5N - Too much change too quickly	**LAM1 - ADMIN LEADERSHIP PRACTICES – Directing, prioritising and resourcing**	WAd12 - Reporting, reviewing & analysing Near Misses & Actual incidents
	LAm11 - Clarifying expectations, roles & responsibilities	**WAD2 – ADAPTIVE WORKING PRACTICES 2 - Reluctance to Simplify**
	LAm12 - Effective monitoring & control, including managing changes	WAd21 - Acting with mindful compliance and questioning
	LAm13 - Effective planning and resourcing	WAd22 - Making a strong response to a weak signal
	LAm14 - Encouraging proactive vs reactive work	> WAd221 - Reviewing & analysing Potential Incidents
	LAm15 - Prioritising process safety	WAd23 - Teamworking to solve problems
	LAm16N - Behaving in authoritarian manner, over-directing or over-reacting	WAd24N - Acting with complacency
	LAM2 - ADMIN LEADERSHIP PRACTICES – Embedding improvements	**WAD3 – ADAPTIVE WORKING PRACTICES 3 - Sensitivity to Operations**
	LAm21 - Embedding improvements to equipment design	WAd31 - Building and sharing situation awareness
	LAm22 - Embedding improvements to procedures	**WAD4 – ADAPTIVE WORKING PRACTICES 4 - Commitment to Resilience**
	LAm23 - Embedding improved competence	WAd41 - Building capacity for delegated decisions & competent improvisation
	LAm24N - Ineffective support for embedding improvements	WAd42 - Supporting risk awareness
		WAd43N - Improvising with good intent but without full risk awareness
	ADAPTIVE LEADERSHIP PRACTICES	**WAD5 – ADAPTIVE WORKING PRACTICES 5 - Deference to Expertise**
	LAD1 - ADAPTIVE LEADERSHIP PRACTICES – Encouraging improvement	WAd51 - Countering deference to hierarchy
	LAd11 - Demonstrating passion for improving process safety	WAd52 - Deferring to expertise
	LAd12 - Encouraging new ideas for improvement	WAd53 - Delegating decision-making to those best placed
	LAD2 - ADAPTIVE LEADERSHIP PRACTICES – Encouraging teamwork	
	LAd21 - Encouraging diverse skills & views	
	LAd22 - Encouraging effective teamwork	
	LAd23N - Ineffective support for diverse skills & views	
	LAD3 – ADAPTIVE LEADERSHIP PRACTICES – Emergent leadership	
	LAd31 - Encouraging leadership at all levels	
	LAd32 - Influencing within peer group	

5.4 Results

The results of the coding are summarised in **Table 5-4**. This lists on the left-hand side the 44 'Helping' and 19 'Hindering' codes, or first order factors, identified in the interviews, showing for each factor the number of interviews in which at least one reference to it was coded, analysed by site. These are then grouped into the 17 second-order Theoretical Categories, with the relative importance of these categories for each site shown by the percentage of interviews that mentioned the first-order codes within each category, averaged over the codes in the category and normalised for the different number of interviews per site.

In the right-hand column of the table, the 17 categories are grouped into the six Aggregate Theoretical Dimensions, which divide logically between structurally embedded contextual conditions descriptive of the organizational working environment and agentic interventions in the form of leadership practices (enabling, administrative and adaptive) and working practices (administrative and adaptive). Outcomes are taken as the perceived process safety performance of each site, which is as described above in **Table 5-1**.

Illustrative quotes from the interviewees are presented in **Tables 5-5, 5-6** and **5-7**, which were selected on the basis of being representative of the most frequently occurring codes at each site.

Table 5-4 Results Summary

First order factors - Evidence from interviewees No of interviewees mentioning the factor at least once								Theoretical Categories % interviewees mentioning per site (average for Category)							Aggregate Theoretical Dimensions
									% HELP			% HINDER			
HELPING	SITE			HINDERING	SITE				SITE			SITE			
	A	B	C		A	B	C		A	B	C	A	B	C	
Just culture	1	2	1	Blame culture	5	3	1	**Culture**	**7**	**4**	**17**	**12**	**10**	**7**	**CONTEXTUAL CONDITIONS**
Reporting culture	3		2	Ineffective learning processes	1	1	1								
'Stop' culture		2	3	Production pressure	3	8	4								
Open culture - trust & low threshold	2	1	8	Ineffective mgt of stress or fatigue	1										
Accessible leaders - flat structure			6	Inadequate resourcing	3	5	1	**Structure & Maturity**			**29**	**12**	**19**	**4**	
				Unclear responsibilities	3	5	1								
				Ineff. transition Proj to Ops	4	5	1								
				Too much change too quickly		8									
								Dim. Averages	4	2	23	12	14	5	
Sensemaking / sensegiving	9	19	8	Giving mixed messages	1		3	**Sensemaking & challenging**	**33**	**37**	**21**	**5**		**14**	**ENABLING LEADERSHIP PRACTICES**
Challenging assumptions	5	4	1												
Engaging & supporting workers	5	10	5	Ineff. engagement or support	2		1	**Supporting individuals & networks**	**19**	**12**	**16**	**10**		**5**	
Protecting people from politics	1	4	3												
Removing difficult people	4		1												
Supporting formal networks	6	2	4												
Supporting informal networking	4	2	4												
Enabling rule-following AND competent improvisation	1	8	10					**Enabling Ambidexterity**	**5**	**26**	**48**				
								Dim. Averages	19	25	28	5	0	6	
Clarifying expectations & resps	6	7	8	Authoritarian over-directing	7		1	**Directing, prioritising and resourcing**	**18**	**17**	**33**	**33**		**5**	**ADMIN. LEADERSHIP PRACTICES**
Effective monitoring & control	5	4	4												
Effective planning and resourcing	2	6	8												
Encouraging proactive work	1	1	4												
Prioritising process safety	5	8	11												
Embedding improved designs	2		2	Ineff. embedding of improvements	4	3	3	**Embedding improvements**	**8**	**8**	**14**	**19**	**6**	**14**	
Embedding improved procedures	2	6	7												
Embedding improved competence	1	1													
								Dim. Averages	13	12	24	26	3	10	
Demonstrating passion for safety	1	3	7					**Encouraging improvement**	**17**	**19**	**40**				**ADAPTIVE LEADERSHIP PRACTICES**
Encouraging new ideas	6	9	10												
Encouraging diverse skills & views	5	2	2	Ineffective support of diversity	3			**Encouraging teamwork**	**19**	**8**	**26**	**14**			
Encouraging effective teamwork	3	3	9												
Encouraging leadership at all levels		2	4					**Emergent leadership**	**5**	**3**	**24**				
Influencing within peer group	2		7												
								Dim. Averages	13	10	30	5	0	0	
Effective procedures		2	4	Unclear procedures	5	6		**Procedures, Competence & Compliance**		**3**	**30**	**14**	**9**		**ADMIN. WORKING PRACTICES**
Technical Competence			6	Lack of tech competence	1	2									
Norm of compliance		1	9	Ineffective implementation	3										
Processes for risk management	1		5	Cumbersome risk bureaucracy	2	2	1	**Risk Management**	**5**	**3**	**19**	**10**	**6**	**5**	
Processes for situation awareness	1	2	3												
								Dim. Averages	2	3	25	12	8	2	
Identifying & reporting PIs	5	6	5					**Preoccupation with Failure**	**12**	**11**	**14**				**ADAPTIVE WORKING PRACTICES**
Reporting & analysing NMs & AIs		1	1												
Mindful compliance & questioning	1	1	6	Acting with complacency	3			**Reluctance to Simplify**	**5**	**4**	**25**	**14**			
Strong response to a weak signal	3	2	4												
>Reviewing & analysing PIs		2	4												
Teamworking to solve problems			7												
Building situation awareness	1	1	5					**Sensitivity to Operations**	**5**	**3**	**24**				
Building capacity for delegated decisions	1	3		Improvising without risk awareness	2	2	1	**Commitment to Resilience**	**2**	**5**	**19**	**10**	**6**	**5**	
Supporting risk awareness			8												
Countering deference to hierarchy			2					**Deference to Expertise**	**2**	**9**	**11**				
Deferring to expertise		2	3												
Delegating decision-making	1	6	2												
								Dim. Averages	5	6	19	5	1	1	

Table 5-5 Illustrative Quotations - Site A

CONTEXTUAL CONDITIONS	
Culture	The best way is to just whatever happens, you just come out and tell exactly what happened, just be frank so that people can learn okay this happened so we should just avoid. But suppose if I say like this, then there will be a lot of finger pointing, then we end up missing actually what caused this one.
Structure & Maturity	We went into operating mode without considering what the right organization needs to be. So now we're at a point where we are in an operating phase and mature enough where we can start to say what activities do we have? How are we going to execute those activities? And then how much resources ...?
ENABLING LEADERSHIP PRACTICES	
Sensemaking / sensegiving & challenging	If you will enquire all of the permit officer there, they will tell you R is too much ask. Because sir really if I have doubt, I really ask them. If you then ask all of them there, they will tell you this, this guy always ask the question because I told him sir. I need to ask you because something when wrong and I did not ask you maybe I will do something foolish there, so I need come up to you ask you again.
Supporting individuals & networks	I've seen that at A just by giving the right steer, the right expectations to guys. Don't distract them with all kind of other shit, just let the guys focus on what they need to deliver and need to do and give them the few of the right tools and steers to them, makes a hell of a difference.
Enabling Ambidexterity	…in my previous refinery also, if your control is getting saturated you are allowed to open the bypass. With that mindset we came here. So when we used to get a saturation, we used to crack open the bypass and then things are getting managed. But then it was challenged by the technologists; how do your operators bypass this? But this should have not come after bypass opening, this should have come before bypass opening. If you cannot open the bypass, we should have not designed the bypass.
ADMINISTRATIVE LEADERSHIP PRACTICES	
Directing, prioritising and resourcing	the operators at the front line I see that they are not empowered to make decisions and then they make decisions out of fear, out of rule rather than a pragmatic thinking approach. That I see is extreme in certain areas.
Embedding improvements	So very interactive session, about two hours, we do it every quarter on a couple of processes. And that gives two ways. That gives them the way of our assurance on how healthy we are in execution, but it also gives the opportunity to feedback what we think can be better in the procedures.
ADAPTIVE LEADERSHIP PRACTICES	
Encouraging improvement	we are reasonably well engaged in the two-way, then ideas, suggestions do get raised from the ground floor and find a way, not every idea gets through but at least people feel that they can raise ideas…
Encouraging teamwork	We have a multi-cultural environment. We have people working from different countries. From India, Indonesia, Egypt and others. It's advantageous because people have worked in different environments and they have a different mindset to work.
Emergent leadership	Give the work back to the people and be very clear, all leaders, about what you expect of people. I say that to my Board, it's such a danger so I've been focussing on process safety for the past year. We didn't have any process safety incidents, hardly any weak signals. We really stepped up tremendously. I've shown it now for a year, how do I make sure that next year I will show that same rigour on this subject?
ADMINISTRATIVE WORKING PRACTICES	
Procedures, Competence & Compliance	We create a lot of paperwork; we do create a lot of paperwork versus other sites where I've worked where there's a lot less paperwork. I think this is an interesting one in that if you create a new organization, and you're bringing people in from all over the place …you tend to therefore document things very rigidly…

Risk Management	you go in the morning; the permit applicant goes in the morning and applies for a permit. Then he is taking about half an hour or 45 minutes, then he will go to the field to meet the field operator…Then he will give a toolbox talk…then there's a last-minute risk assessment. So I think people arriving to the site, for example, at six o'clock in the morning start work at eight o'clock. These two hours… demotivates the people, making mistakes to happen.
ADAPTIVE WORKING PRACTICES	
Preoccupation with Failure	One of our guys who put test packs together, he noticed on our relief valve that an impulse tube was disconnected…luckily this lad knew what he was looking at, realised the consequences and stepped in immediately. He was recognised for the P award from the group.
Reluctance to Simplify	I think we're learning how to use incidents as weak signals and I think when you do that, if you jump on everything you create also a lot of unrest in the organization.
Sensitivity to Operations	Ownership in shifts is always difficult because people…don't take the work home. So there is someone in day shift, in the operations management space, who we've put in the driving seat to make the calls on the higher risk activities. So he sees all the activities, but specifically on the high-risk activities
Commitment to Resilience	This guy looked at a process line which has had de-min water and connected the hose... That in itself was not that big of a problem but it was interconnected with the caustic line…
Deference to Expertise	If it was a safety threat, myself, my panel operators and my field operators are all empowered to take a decision of shut down or isolating or making the plant safe if it feels to be unsafe.

Table 5-6 Illustrative Quotations - Site B

CONTEXTUAL CONDITIONS	
Culture	I would say the reporting culture in itself is excellent within the company. I do believe it's certainly one of the best I've seen. However, in terms of investigation and action on low level near misses I would say we are poor.
Structure & Maturity	1) I've been in B now for six years. It's only really been the last 18 months or so that I would say it feels like an operating company. Before that, it felt like a projects company but that will be in operation. Then suddenly we had all this stuff built and handed over. 2) …we've been in a whole world of flux for the five years I've been here.
ENABLING LEADERSHIP PRACTICES	
Sensemaking / sensegiving & challenging	It's no good bringing something out and saying you're doing this. First, they've got to convince me that whilst I'm no expert on any one subject, if I can see it, if I feel it's okay, then I've got half a chance of convincing the team as okay, and not just following the direction because it's a piece of paper.
Supporting individuals & networks	I think we've got potentially some strengthening of network and networks. Again the safety leadership program should assist with that because we're making a conscious effort to jumble up the participants. Yes, that's where I'd like to see this get to but where we're at the moment is probably reliant on …communications and networks at the field manager superintendent level.
Enabling Ambidexterity	If you need to follow the rules in its entirety, the micro-manager doesn't really have a job because you just follow the rules. You're going to leave it a little bit loose, the micro-manager will want to check everyone's activity, which means no one actually has the ability to do anything. You have that. You also have a person who completely trusts his people, which does the opposite extreme and can result in people pushing themselves outside where they're actually-- their confidence level goes above where their actual competency is. It's finding that balancing point between the competency and the confidence to allow people to use that…

ADMINISTRATIVE LEADERSHIP PRACTICES	
Directing, prioritising and resourcing	There's definitely a genuine interest in some of those key things such as asset integrity, process safety review meeting, the incident review panel, and the MOC meeting. That's key. The safety guys often run those things. Now, the new leadership is, "no, I will chair that"
Embedding improvements	I think the way that I do it is I engage the technicians in doing all of the red lining and reviewing of procedures… typically use night shift. To walk and red line the procedures. Is this currently what we do? Is this best practice?
ADAPTIVE LEADERSHIP PRACTICES	
Encouraging improvement	We have some KPIs in people's goals around identifying a better way of work or coming up with a business improvement…things like that. I don't think we're as focused on to this as we could be.
Encouraging teamwork	…if this role says in our daily meeting, "I need a hand," it's now actually my job to go and find the engineer and go and chase... You need something, you're going to work it all out.
Emergent leadership	Whereas managers will come in from externally, bringing new ideas, but also get trained in what the safety culture is of the business by the people at the lower level now. I'm actually seeing that leadership transitioning from the managers that brought them in in the first place, down to people on the ground actively leading in on the safety culture.
ADMINISTRATIVE WORKING PRACTICES	
Procedures, Competence & Compliance	…we're a long way from where we need to be. The procedures that we've got in the business are one task fits all. If I pull out the procedures now it will say this is what the plant operator does, this is what the control room contributes into it, this is what the next person will do. It jumps all over the place…It becomes very disjointed.
Risk Management	Everybody wants now, tomorrow, day after, very short-term and medium-term focused. That is actually impeding the right organizational behaviors to evolve… It's a 20, 25-year operation we're looking at. I still haven't seen the maturity in the leadership.
ADAPTIVE WORKING PRACTICES	
Preoccupation with Failure	There's very active asset integrity inspection programs, testing programs, maintenance programs. There's all systemized methods of doing that. There's also encouragement of hazard reporting across most of the business units.
Reluctance to Simplify	It's definitely changed now, though commissioning was definitely production based: Let's get it finished and get it online. But now it's a lot more… stop and think a lot more
Sensitivity to Operations	If a couple descriptions weren't right on a work order, if we don't know 100%, we just revert it all back and make sure we get exactly the information that we require.
Commitment to Resilience	so I try to get them thinking about barriers. The Swiss Cheese Model and the outcomes if you don't.
Deference to Expertise	…if something's urgent, at my technician level, they can deal with certain things. Then they can escalate to my level and at a certain level…it's obviously got escalation through the line

Table 5-7 Illustrative Quotations – Site C

CONTEXTUAL CONDITIONS	
Culture	I also think that you are allowed to speak up. Also the management actually expects you to speak up. By having this open dialogue and also that extra dare to speak up and also have that ownership.
Structure & Maturity	tomorrow we're doing this monthly, it's an integrity, safety and reliability meeting. Then we go through all the safety critical elements and issues... The whole management team knows what's going on. Most of them, they have been manager at C-- they know the equipment, they understand what's going on
ENABLING LEADERSHIP PRACTICES	
Sensemaking / sensegiving & challenging	We have worked a lot to connect individuals with the strategy, so you see how you contribute because not see that link, I think is not a good position to be in. What's my purpose in this organization? Everyone here should be able to answer that question
Supporting individuals & networks	If you've got a problem, you know who to contact to talk about that problem. It's not that you go outside and shout to the moon. [laughter] You know who to contact …you know who they are, most of them.
Enabling Ambidexterity	1) I think this is a very nice balance because I don't expect people to follow procedure if they certainly see that the procedure is wrong. I will not challenge them a lot on the way they, in fact, will do the task but I will challenge them to document the difference. 2) You're complying but then you are professional enough to know when you have to deviate and then it's smarter to deviate than actually just following the rule. I think that's part of the organization knows that and knows that a procedure will have five errors in it anyway. You won't be 100% safe if all you intend to do or all you aspire to do is follow the procedure when you go to work, and we all know that
ADMINISTRATIVE LEADERSHIP PRACTICES	
Directing, prioritising and resourcing	We do regular surveillance, the team do surveillance before the morning meeting, and also after. It's not only a red and green. It's a bit richer than that, Yes. Because you need to both understand, is it trending upwards or downwards? Is it stable? Can we do better?
Embedding improvements	They have found several errors between the control room master P&ID and on the site. They have then now suggested to actually elevate this as a bigger project…I know that when they raise that to their leadership, they will get support of doing that.
ADAPTIVE LEADERSHIP PRACTICES	
Encouraging improvement	Then we give feedback to the person that's raised the question and it's open for everyone to go in and see. We also have to put good feedback if we decide not to do it, but actually we do. I think we try to do about 70, 75% of it. Since we started this, I would think we have 50 60 the last year.
Encouraging teamwork	More systematic. Better instruction and procedure. The people, our leaders, make this procedure and instruction. They are not: "our leadership is making the procedure and instruction, and here we are"... but the team are doing it together.
Emergent leadership	it could be almost everyone because if you are putting three or four people together in a working group, it's normal that one of them taking the lead in the group because he might have some more experience on the working and mostly what they're going to do. Also, the foreman tried to put people together, so we always have one that's very experienced.
ADMINISTRATIVE WORKING PRACTICES	
Procedures, Competence & Compliance	I think it's very experienced personnel in the control room. The operators, I think they know the hazards very good.
Risk Management	Okay we have risk matrices, risk meetings…My team has meetings with C and D to discuss safety issues and I attend an Ops team meeting where we discuss the issues…

	They have morning meetings offshore, onshore every day at nine o'clock. There's a structure in place so that the entire organization is on the same page
ADAPTIVE WORKING PRACTICES	
Preoccupation with Failure	I think we're fairly good, we have very few actual incidents. We have quite a lot of potential incidents, and I think that's a good thing, because potential incidents tells me as a leader that we actually notice it.
Reluctance to Simplify	Yes, you trust your good experience and your competence that even though it's in a procedure, well maybe this that or maybe you can't follow it like that. It's not that difficult to get something changing the procedure.
Sensitivity to Operations	We introduced big screens and stuff like that in the control room, and we also have introduction of situation-based information on those big screens.
Commitment to Resilience	We don't know everything and so- we have to be aware and do a lot of campaigns. So now when we have these findings, we do a lot of more inspections in same systems
Deference to Expertise	That respect for what level of organization is doing what and accept that you can't know everything at any time. That means a lot to me, that my boss appreciate that I tell him, "I don't know… The only thing I know, I have good people on it, and I will tell you when we have more information."

5.5 Findings

Examination of **Table 5-4** shows some striking differences between the three sites. In all 6 aggregate theoretical dimensions a greater proportion of respondents at Site C reported 'Helping' factors than those at either Site A or Site B, and in most dimensions a smaller proportion reported 'Hindering' factors. This difference between Site C and the other two sites was in the order of double the proportion of respondents for both administrative and adaptive leadership practices, and even greater for working practices and contextual conditions, in the order of four times or more. When set beside the perceived relative process safety outcomes of the three sites (see **Table 5-1**) these differences fit broadly with expectations: simply put, more 'Helping' factors and fewer 'Hindering' factors would be expected to deliver better process safety, and Site C had the best perceived safety performance. Differences in the findings for each site are now examined for each of the aggregate theoretical dimensions.

To seek explanation at a more detailed level and to identify possible mechanisms, the quantified data in **Table 5-4** are interrogated further and compared with the qualitative data contained in **Tables 5-5, 5-6** and **5-7** in the form of illustrative interview quotes, selected as representative of the most frequently occurring codes at each site. Before comparing in detail the different findings for each site, a short summary is given of the main findings at each site.

5.5.1 Summary of findings for each site

5.5.1.1 Site A

Respondents at Site A described a context of a hierarchical organization in transition from a major project to an operational plant, experiencing some *inadequate resourcing*, some *unclear responsibilities* and there were a number of reports of a *blame culture*. Although many interviewees mentioned enabling leadership practices of *sensemaking/sensegiving*, and 'helping' administrative leadership practices: *clarifying expectations* and *effective monitoring and control*, these were counterbalanced by other reports of 'hindering' practices: *authoritarian over-directing* and *ineffective embedding of improvements*.

Administrative working practices discussed were mainly *unclear procedures*, *ineffective implementation* and *cumbersome risk bureaucracy*. A number of respondents mentioned *reporting potential incidents* and *strong response to a weak signal*, but there were few other mentions of adaptive working practices except 'hindering' practices of *acting with complacency* and *improvising without risk awareness*.

5.5.1.2 Site B

At Site B there were many mentions of *production pressure*, as well as *too much change too quickly*. Respondents described an organization with an *ineffective transition from project to operations*, suffering from *inadequate resourcing*, some *unclear responsibilities* and a *blame culture*.

Enabling leadership practices of *sensemaking/sensegiving* were mentioned by almost two thirds of the respondents, along with many reports of *engaging & supporting workers* and *protecting people from politics*. Around a quarter of interviewees discussed *enabling rule-following AND competent improvisation*. 'Helping' administrative leadership practices of *clarifying expectations* and *effective monitoring and control* were mentioned often, but a mixed picture emerges from a balance of 'helping' *embedding improved procedures*, and 'hindering' *ineffective embedding of improvements*. There were a number of references to adaptive leadership practices, notably *encouraging new ideas* which were mentioned by almost a third of respondents.

Reports of administrative working practices mainly related to *unclear procedures*, *lack of technical competence* and *cumbersome risk bureaucracy*. The most numerous references to 'helping' adaptive working practices were *identifying and reporting potential incidents* and *delegated decision-making,* though there also some mentions of the 'hindering' practice of *improvising without risk awareness*.

5.5.1.3 Site C

Over a third of respondents described Site C as having an *open culture - trust and low threshold* and many people mentioned *accessible leaders - flat structure*, though *production pressure* also figured in the narratives. A third of respondents mentioned the 'helping' enabling leadership practice of *sensemaking/sensegiving*, though there were also a few reports of the 'hindering' practice of *giving mixed messages*. Almost half of the respondents described *enabling rule-following AND competent improvisation*. A third of interviewees mentioned administrative leadership practices, with over half making reference to *clarifying expectations, effective planning and resourcing* and *prioritising process safety,* and although there were many reports of *embedding improved procedures*, there were also some mentions of *ineffective embedding of improvements*. Adaptive leadership practices were very much in evidence, with almost half the respondents mentioning *encouraging new ideas* and *encouraging effective teamwork*, and a third of respondents making reference to *demonstrating passion for improving process safety* and *influencing within peer group*.

The administrative working practices *effective procedures, technical competence* and *norm of compliance* were mentioned by around a third of respondents, and there were many references to *processes for risk management* and *processes for situation awareness*.

Although there were two mentions of 'hindering' adaptive working practices, *cumbersome risk bureaucracy* and *improvising without risk awareness*, these were very much in the minority; there were many more references to 'helping' adaptive working practices, the most frequent being *identifying and reporting potential incidents, mindful compliance and questioning*, *teamworking to solve problems* and *supporting risk awareness*, and a quarter of the respondents mentioned factors within the 'reluctance to simply' category.

5.5.2 Differences in the findings between each site

The differences in the findings for each site are now examined, under the headings of each aggregate theoretical dimension that emerged from the data analysis.

5.5.3 Contextual conditions

Differences in the organizational context of each site can be seen in four main aspects. Firstly, a third of the interviewees at Site C, many more than at Sites A or B, made mention of its *open culture – trust & low threshold* for expressing views and reporting issues ('…the management actually expects you to speak up. By having this open dialogue and also that extra dare to speak up and also have that ownership' – Site C manager). Secondly, in stark contrast, about a quarter of Site A interviewees spoke of *blame culture,* exemplified by a quote from a Site A supervisor: 'Suppose if I say like this, then there will be a lot of finger pointing, then we end up missing actually what caused this one.' Thirdly, a quarter of Site B interviewees reported *production pressure*. 'Everybody wants now, tomorrow, day after, very short-term and medium-term focused. That is actually impeding the right organizational behaviors to evolve...' (Site B engineer). Fourthly, narratives from interviewees at both Sites A and B indicated more often described *inadequate resourcing, unclear responsibilities* and *ineffective transition from project to operations* ('We went into operating mode without considering what the right organization needs to be' – Site A manager) and ('I've been in B now for six years. It's only really been the last 18 months or so that I would say it feels like an operating company…

suddenly we had all this stuff built and handed over' - Site B manager). Nearly a quarter of respondents at Site B spoke of *too much change too quickly* ('…we've been in a whole world of flux for the five years I've been here.' – Site B shift supervisor).

Putting these contextual aspects together, a picture emerges of organizations at both Site A and Site B that appear to be putting significant constraints on the people operating and maintaining the plant, and while people at Site C did mention some 'hindering' aspects, they made much more mention of 'helping' aspects, so the overall message given here was one of a more mature organization with a culture more supportive of process safety than the other two sites.

5.5.3.1 Enabling leadership practices

The data in this theoretical dimension tells a mixed story. *Sensemaking /sensegiving* was mentioned by many respondents at all three sites, most at Site B where it was mentioned by almost two thirds of the respondents. This may be at least partly explained by Site B's relatively inexperienced workers: ('They had never experienced anything any different and they've never been educated around process safety risks…' - Site B Manager) perhaps indicating that more sensemaking / sensegiving was needed to help people understand the process safety hazards in their work. This contrasts with a quote from a site C manager: 'What's my purpose in this organization? Everyone here should be able to answer that question' which appears to indicate that in that more mature organization there was less need for an active leadership practice of sensemaking /sensegiving since most people were very experienced and familiar with their tasks and work environment.

In the 'Supporting individuals and networks' category, although about a fifth of the interviewees at Site A made 'helping' references, around 10 % made 'hindering' references. At Site B there were many reports of *engaging & supporting workers* and *protecting people from politics*, together with a recognition of a wish to improve: 'I think we've got potentially some strengthening of network and networks. Again the safety leadership program should assist with that…' (Site B manager). At Site C, support for both formal and informal networking was exemplified by this quote from a Site C supervisor: 'If you've got a problem, you know who to contact to talk about that problem. It's not that you go outside and shout to the moon [laughter] You know who to contact …you know who they are, most of them.'

The picture is much clearer in the 'enabling ambidexterity' category, where almost half the informants at Site C mentioned *enabling rule-following AND competent improvisation*, compared with a quarter at Site B and only 5% at Site A. Two quotes, from different managers, illustrate the apparent importance of this aspect at Site C. First: 'I don't expect people to follow procedure if they certainly see that the procedure is wrong. I will not challenge them a lot on the way they, in fact, will do the task but I will challenge them to document the difference.' A similar point is made in this second Site C quote: 'You're complying but then you are professional enough to know when you have to deviate and then it's smarter to deviate than actually just following the rule. I think that's part of the organization knows that and knows that a procedure will have five errors in it anyway. You won't be 100% safe if all you intend to do or all you aspire to do is follow the procedure when you go to work, and we all know that.'

Other Site C managers gave more detailed explanations of how they handled this issue: 'very often they communicate with a colleague. We do this? Yes. Okay. Yes, it is happening.... But hopefully, it's not happening in a way that we not - that we're bending the rules too much. I want to hear their reason, the rationality what we do it, and then discuss it as well and then try to change the procedure or instruction a little bit. I very often ask them, "Could you please write in what you want changed in the instruction with track changes and stuff." We used that quite a lot.' And at the working level, the practical reality of this approach was echoed by a Site C shift supervisor: 'Yes, I think the most important thing is if you're going to do something that's not in the procedure, you have to tell someone. Don't just follow on your own. I feel that's being done. Of course it depends that you know the people you're having... It's quite important to have people that you rely on.'

Although this topic was not mentioned so frequently at Site B, a similar practice was described by a Site B shift supervisor: 'I talk to my front line this way: "80% is what your procedure can give, the remaining 20% is your competency, your thinking and your adaptation, but that doesn't mean you are to deviate from the procedure."... Raise it up to us. When we review the procedure and change it for the next person, it becomes at least 90% right, so it's a journey to keep going on.' However alongside this, a Site B manager described a difficulty of this approach: '…can result in people pushing themselves outside where they're actually-- their confidence level goes above where their actual competency is. It's finding that balancing point between the competency and the confidence to allow people to use that…'

5.5.3.2 Administrative leadership practices

Over a third of respondents at Site C mentioned 'helping' factors in the 'Directing, prioritising and resourcing' category, most frequently mentioning *prioritising process safety, clarifying expectations and responsibilities* and *effective planning and resourcing*. In stark contrast however, a third of respondents at Site A reported *authoritarian over-directing*, a 'hindering' reference in this category. This is exemplified by a quote from a supervisor at Site A: 'the operators at the front line I see that they are not empowered to make decisions and then they make decisions out of fear, out of rule rather than a pragmatic thinking approach. That I see is extreme in certain areas'.

Although all three sites reported difficulty with 'embedding improvements', there were also positive accounts of this at each site; for example, a Site A manager described a process improvement workshop: 'So, very interactive session, about two hours, we do it every quarter on a couple of processes. And that gives two ways. That gives them the way of our assurance on how healthy we are in execution, but it also gives the opportunity to feedback what we think can be better in the procedures'. In the same vein, a Site B supervisor described a practice he employed: 'I think the way that I do it is I engage the technicians in doing all of the red lining and reviewing of procedures… typically use night shift. To walk and red line the procedures. Is this currently what we do? Is this best practice?'. At Site C, where a third of respondents spoke about *embedding improved procedures*, the proportion of respondents mentioning 'helping' factors in this category was almost twice that of the other sites. One Site C manager told of how operations people were supported in their improvement activities: 'They have found several errors between the control room master P&ID [Piping and Instrumentation Diagram – a key process design document] and on the site. They have then now suggested to actually elevate this as a bigger project…I know that when they raise that to their leadership, they will get support of doing that'.

5.5.3.3 Adaptive leadership practices

It is striking that references to adaptive leadership practices were made by over twice as many respondents at Site C than at Site A and three times as many than at Site B. Almost half the Site C respondents made mention of *encouraging new ideas*. A manager at site C described their process for evaluating suggestions for improvement: 'Then we give feedback to the person that's raised the question and it's open for everyone to go in and see. We also have to put good feedback if we decide not to do it, but actually we do. I think we try to do about 70, 75% of it. Since we started this, I would think we have 50-60 the last year.'

Also at Site C, well over a third of respondents told of leaders *encouraging effective teamwork*, three times as many as either of the other sites. As a Site C supervisor described this: 'Better instruction and procedure. The people, our leaders, make this procedure and instruction. They are not: "our leadership is making the procedure and instruction, and here we are" ... but the team are doing it together'. A third of Site C respondents also reported *demonstrating passion for improving process safety*, twice as many as Site B, and barely mentioned at Site A.

The concept of 'emergent leadership' was clearly described by a site B manager: 'I'm actually seeing that leadership transitioning from the managers that brought them in in the first place, down to people on the ground actively leading in on the safety culture.' It was at site C though where this form of leadership was most markedly evident. A third of the Site C respondents described *influencing within peer group*, which was mentioned by only 10% of respondents at Site A and not mentioned at all at Site B.

Emergent leadership was reported by people at all organizational levels of Site C: one supervisor described how he experienced it: '…it could be almost everyone because if you are putting three or four people together in a working group, it's normal that one of them taking the lead in the group because he might have some more experience on the working and mostly what they're going to do. Also, the foreman tried to put people together, so we always have one that's very experienced.' And a technician described how he saw it at the working level: 'the organization is quite open, and I think we are quite balanced. I think the responsibility, that practical responsibility is down at our level…' Finally, a Site C manager referred to *encouraging leadership at all levels* as follows: 'We have a very experienced people. We ask them to think for themselves and come to us with ideas and of course, that's what we want to do and it's - we think that's creating a better safety overall.'

5.5.3.4 Administrative working practices

Around a third of respondents at Site C reported *effective procedures*, *technical competence* and a *norm of compliance* and a quarter described *processes of risk management*, 'Okay we have risk matrices, risk meetings… They have morning meetings offshore, onshore every day at nine o'clock. There's a structure in place so that the entire organization is on the same page' (Site C manager). In contrast, this was not mentioned at all at Site B and was barely mentioned at

Site A, where instead interviewees described a number of 'hindering' references in this category, especially *unclear procedures* and *ineffective implementation*. One manager at Site A commented: 'we do create a lot of paperwork versus other sites where I've worked' and another Site A manager had similar views: 'if I look at the incidents, it's not that we didn't spot the hazard and we didn't put a whole bunch of controls on it but we may have actually overloaded the work crew'. Respondents at Site B told some similar stories, one supervisor saying: '…we're a long way from where we need to be. The procedures that we've got in the business are one task fits all…'.

In the 'risk management' category, all three sites made some mention of the 'hindering' practice of *Cumbersome risk bureaucracy*. The quote from Site A (see Table 5) illustrates this, describing a time-consuming and de-motivating process of obtaining a 'permit to work' with its associated documentation of work instructions and risk assessment. However, at Site C this was counterbalanced by a quarter of informants describing the 'helping' practice of *processes of risk management*, whereas at Site A this was barely mentioned (5% of respondents) and at Site B not mentioned at all. One such practice was described by a Site C manager: 'Okay we have risk matrices, risk meetings…My team has meetings with C and D to discuss safety issues and I attend an Ops team meeting where we discuss the issues… They have morning meetings offshore, onshore every day at nine o'clock. There's a structure in place so that the entire organization is on the same page'. Another quote describes effective *processes for situation awareness*: 'The whole management team knows what's going on. Most of them, they have been the manager at C - they know the equipment, they understand what's going on' (Site C supervisor).

5.5.3.5 Adaptive working practices

Higher percentages of interviewees at Site C mentioned 'helping' adaptive working practices than at either Site A or Site B. Particularly striking is the quarter of informants at Site C who mentioned practices in the 'reluctance to simplify' category, especially *teamworking to solve problem*s and *mindful compliance and questioning*. One Site C supervisor described this: 'Yes, you trust your good experience and your competence that even though it's in a procedure, well maybe this that or maybe you can't follow it like that. It's not that difficult to get something changing the procedure'.

Two related codes showed another conspicuous contrast between Site C and the other two sites: A quarter of Site C interviewees made reference to *building situation awareness*, five times as many as the other two sites. One Site C manager described a particular instance of this: 'We introduced big screens and stuff like that in the control room, and we also have introduction of situation-based information on those big screens'. And almost a third of Site C interviewees described practices of *supporting risk awareness*, whereas this was not mentioned at all by either of the other sites. This is illustrated by two quotes from Site C managers: 'We don't know everything and so we have to be aware and do a lot of campaigns. So now when we have these findings, we do a lot of more inspections in same systems' and another manager described a questioning approach to interpreting operational information relating to risk '…is it trending upwards or downwards? Is it stable? Can we do better?'.

Finally, in the category of 'deference to expertise', Site C had the highest percentage of interviewees making 'helping' references in this category, contrasting particularly with Site A where it was barely mentioned, and this is exemplified by a quote from a site C manager: 'That respect for what level of organization is doing what and accept that you can't know everything at any time. That means a lot to me, that my boss appreciate that I tell him, "I don't know… The only thing I know, I have good people on it, and I will tell you when we have more information." '.

5.5.3.6 Entanglement of Adaptive Administrative working practices

A common view of people at all the sites was that procedures would not fit some unforeseen situations and that people should therefore manage such situations with competent workarounds, but also that these improvisations should be worked back into the formal system by modifying procedures.

Of great importance to the success of this entanglement, particularly seen at Site C, was that adaptation was viewed very much as a shared, collaborative, process. No-one was expected to improvise on their own; the modification of an established procedure to suit actual working conditions was always the subject of discussion, normally first with the immediate supervisor, and other technical experts would be consulted as required.

To facilitate this there was a formally established network of people nominated as 'technical authorities' for specific subjects, who were routinely consulted by operations and maintenance staff. This was often initially informally by phone or video link, with decisions and modified procedures frequently being agreed there and then, but sometimes a technical study was required in order to resolve the issue, so the operational or maintenance task in question had to be postponed until the technical study had been completed.

The practical implication of this is the operation of a cyclic process of continual adjustment of working practices to suit the actual and evolving task situation. Starting with the worker or work group following a norm of competent compliance with established procedures, but importantly, combined with a vigilance for potential unanticipated hazards, and a continual questioning approach of 'does this procedure make sense in this situation?'. If something unusual is noticed, then the worker or work group consults with others to decide on a suitable improvisation. When agreed, this is then adopted formally as an approved modification to the procedure, practice, equipment or system.

This process is analysed in terms of the influence of administrative, adaptive and enabling leadership practices on the entanglement of adaptive and administrative working practices, in the diagram in **Fig 5-3** and is described, step-by-step, below.

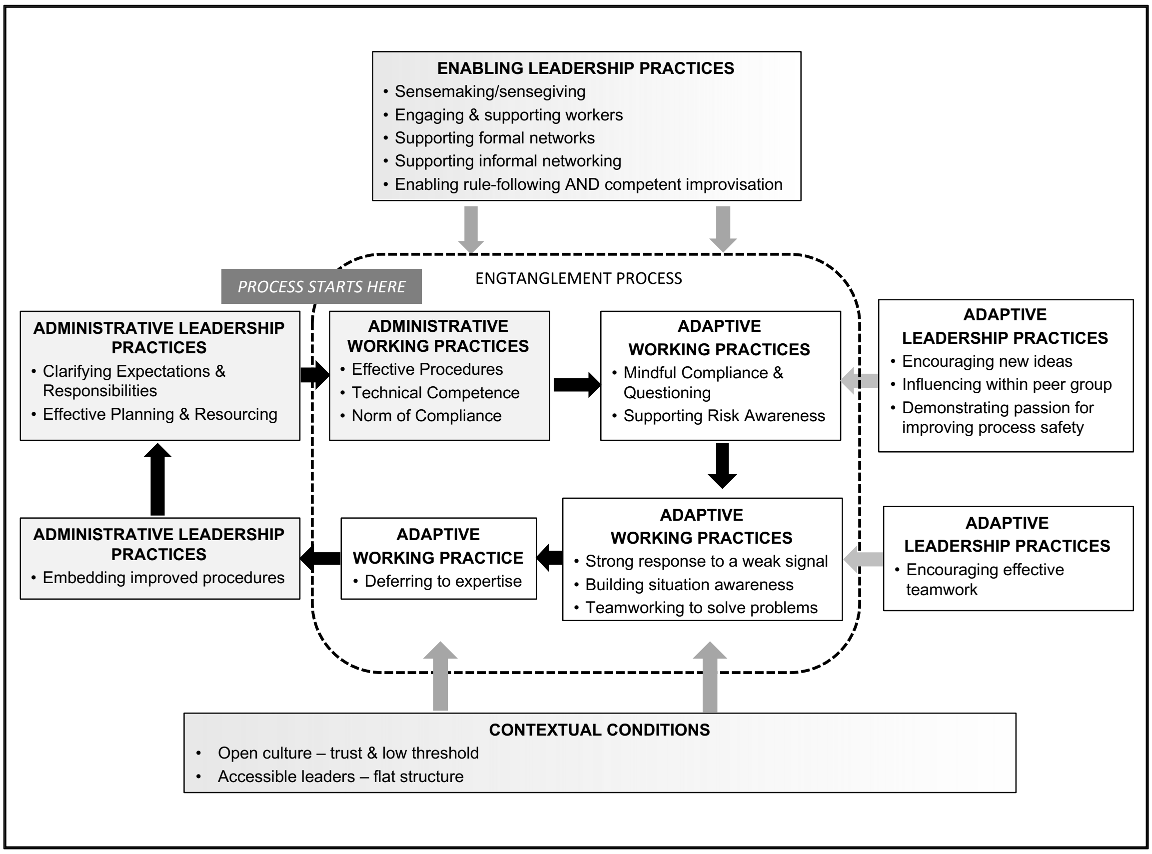

Figure 5-3 Entanglement Process Model

Performing an operational or technical task starts with the administrative working practices of using *effective procedures* with *technical competence* and a *norm of compliance*, influenced by administrative leadership practices such as *clarifying expectations and responsibilities* and *effective planning and resourcing*. During the work, the person performing the task also follows the adaptive working practices of *mindful compliance and questioning* and *supporting risk awareness*, with the aim of seeking and finding weaknesses in the procedures or wider system, influenced by adaptive leadership practices of *encouraging new ideas, influencing within peer group* and *demonstrating passion for improving process safety*.

When such a weakness is identified, this triggers the adaptive working practices of *strong response to a weak signal, building situation awareness* and *teamworking to solve problems*, influenced by the adaptive leadership practice of *encouraging effective teamwork*. These practices result in a technical solution and a decision how to proceed, supported by the adaptive working practice of *deferring to expertise*. Finally, the technical solution is implemented, and the procedure modified, influenced by the administrative leadership practice of *embedding improved procedures*.

The enabling leadership practices found to be most associated with this entanglement were sensemaking/sensegiving, engaging & supporting workers, supporting formal networks, supporting informal networking, and especially enabling rule-following AND competent improvisation.

Contextual conditions were also found to play an important role in this. At Site C the open culture – trust & low threshold and accessible leaders – flat structure were seen as providing a supportive environment in which the interplay of these practices could flourish.

In this way, working practices were continually adjusted to suit actual operational conditions, the adjustments being made not by operators or technicians in isolation, which may lead to unsafe decisions if people do not have full awareness of the overall system and its risks, but by a process that includes appropriate technical expertise so that risks are managed effectively. Therefore, the meaning of 'competent improvisation' used here is that it is the 'organizational competence' of the team involved, rather than the competence of an individual, that enables the improvisation to be done competently and safely.

Improvisation within high hazard operations, though proposed as being reflective of reality (Hollnagel, 2014) has also been challenged as potentially increasing risk (Leveson et al., 2009). Simple compliance carries the risk of following an accepted procedure that may omit some unanticipated but important local situational condition and therefore actually increase risk; individual local 'expert improvisations', even though they may be effective, may not be captured and reviewed for adequacy in the light of overall system aspects, and useful learning extracted; this weakness has been pointed out by Amalberti and Vincent (2019).

The mechanism of competent improvisation found in this study appears to address both of these criticisms; it is focused on reduction of risk, dynamically takes into account the actual situation, deploys appropriate technical expertise with an understanding of the overall system and captures the improvement with a suitable modification.

This analysis offers a contribution to theory in the form of a more detailed understanding of the mechanisms by which both leadership practices and contextual conditions influence successful entanglement of adaptive and administrative working practices in improving organizational outcomes, such as avoiding major process safety incidents, and extends the 'framework of rule management' proposed by Hale and Borys (2013, p224).

This analysis also supports and extends Leadership-As-Practice by focusing on 'realities of ordinary work' which 'has the great opportunity of connecting with practitioners in their worlds and building insights that draw from rigorous research and are relevant to their practical endeavours' (Kempster and Gregory, 2017, p512).

Leadership-As-Practice has been criticised as having a 'lack of critical engagement, particularly in relation to its neglect of asymmetrical power relations and control practices' and focussing almost entirely on agency (Collinson, 2018a, p363). This study has found that viewing leadership in terms of practices allowed a useful distinction to be made between structurally embedded contextual conditions and the agentic enactment of leadership within those structures, with the influence of both context and leadership on working practices being observed as important. The analysis of contextual conditions and practices into 'helping' and 'hindering' also made clear the hindering effect of such leadership practices as authoritarian over-directing as well as contextual conditions such as blame culture and production pressure. The study has found credible evidence that Leadership-As-Practice is a useful framework for critical analysis that can easily include aspects of power and control, and that it also acknowledges structure as an equally important organizing concept as agency.

5.6 Discussion

This study shows that in the high hazard context of oil & gas and petrochemical plant operations, the apparently competing practices of rule-following and competent improvisation are required to occur concurrently. This extends early writing on High Reliability Organizing (HRO) practices that describes how within a highly structured and rule-based military operating environment great adaptability and flexibility were observed, with established practices 'being both accepted and constantly challenged' (Rochlin, La Porte and Roberts, 1987, p87). These two different approaches are often seen as 'inherent contradictions' (Lewis and Smith, 2014, p60) but when constructed not as a dualism but as a duality (Farjoun, 2010) the two essential functions of implementing established controls over known hazards and the active continual modification of those controls to suit actual conditions are retained, but they are viewed as interdependent.

The study reveals that compliance and competent improvisation are mutually enabling and reconstitute one another; a norm of technical competence and mindful, questioning compliance not only strengthens existing controls that serve to contain hazards, but also creates the conditions for improvement of them, which in turn reinforces both compliance and competence. Respondents at Site C, and to a lesser extent Site B, emphasised the importance of effective procedures, technical competence and a norm of compliance as the foundation of all their plant operations and maintenance activities, but they also reported a wide recognition throughout their organization that to deliver effective control over the ever-present major hazards they faced, these administrative working practices needed to be built on and complemented with adaptative practices in the form of competent improvisation and continuous improvement.

The important influence of leadership on working practices was a major point made by all respondents, with significant differences between the three sites being evident. Respondents at Site C reported largely positive effects of both administrative and adaptive leadership practices, and specific practices of enabling leadership, on the successful entanglement of the two kinds of working practices in controlling hazards. They also placed great emphasis on the importance of Site C's open, trusting culture with its low threshold for questioning and discussing ways of working and the flat organizational structure with accessible leaders, for enabling adaptive practices and the major influence of leadership in creating and maintaining these contextual conditions was also clear. The organization-wide recognition of the need for adaptation together with the other supportive aspects of this culture appeared to provide the 'holding environment' that has been suggested is required for adaptation (Heifetz and Laurie, 1997, p134).

The study extends work on 'organizational ambidexterity' (Birkinshaw and Gupta, 2013; O'Reilly and Tushman, 2013) and theories of 'paradox' (Clegg, da Cunha and e Cunha, 2002; Milosevic, Bass and Combs, 2018; Smith and Lewis, 2012; Zhang et al., 2015). Respondents at Site C described operational flexibility, support for formal and informal networks and strong social relationships, all of which are seen by Turner, Swart and Maylor (2013) as enablers of ambidexterity, and the contextual conditions they described aligned closely with attributes of 'discipline' 'stretch' and 'support' proposed by Ghoshal and Bartlett (1994, p95) as providing the 'supportive organization context' necessary for 'contextual ambidexterity' (Gibson and Birkinshaw, 2004, p210). The extensive focus of Site C's leaders on adaptive leadership practices of encouraging improvement and teamwork as well as the more traditional practices of planning, monitoring and control, demonstrated their acceptance of paradox as normal and desirable, and that such 'structured flexibility' (Smith and Besharov, 2019) was necessary for success.

5.6.1 Comparing the balance of administrative and adaptive leadership practices

At Site A, a smaller percentage of respondents mentioned adaptive leadership practices than of administrative leadership practices, of which latter a third of respondents described 'hindering' practice of authoritarian over-directing. At Site B, respondents reporting of adaptive and administrative leadership practices in roughly similar proportions. At Site C the balance was tipped towards adaptive leadership practices. Site A had experienced a number of major actual incidents including fatalities and Site B a number of major incidents including some serious near misses. In contrast, Site C had had no recent major incidents but had identified, reviewed and analysed many potential incidents, finding system weaknesses before they could develop into actual incidents. This leads to a theoretical proposition that an emphasis on adaptive practices is more effective in supporting process safety. The underlying mechanism suggested is that adaptive working practices will identify more weaknesses (potential incidents) allowing correction of the weaknesses and so avoid their gestation into near misses or actual incidents, and that such adaptive working practices are encouraged more strongly by adaptive leadership practices than administrative.

5.6.2 Comparing enabling leadership practices at each site

The differences seen in enabling leadership practices at each site align well with the characterisations of different configurations of enabling leadership according to Complexity Leadership Theory (CLT) as portrayed in **Fig 5-4,** which is extracted from Uhl-Bien and Marion (2009).

At Site C, high levels of both adaptive and administrative leadership were evident, and only moderate levels of enabling leadership apart from the very high specific aspect of 'enabling rule-following AND competent improvisation' discussed earlier, so this fits well with Uhl-Bien and Marion's configuration 'A' in **Fig 5-4.** At Site A, although adaptive and administrative leadership were evident, significant levels of 'hindering' administrative leadership appear to be stifling the adaptive practices and there was less evidence of enabling leadership to compensate; this fits with configuration 'B' in **Fig 5-4**. At Site B there was evidence of both traditional / administrative and adaptive leadership, but they were not apparently integrated; there was enabling leadership occurring in the form of active sensemaking / sensegiving, which may be in compensation of the lack of integration, so this fits with configuration 'D' in **Fig 5-4.**

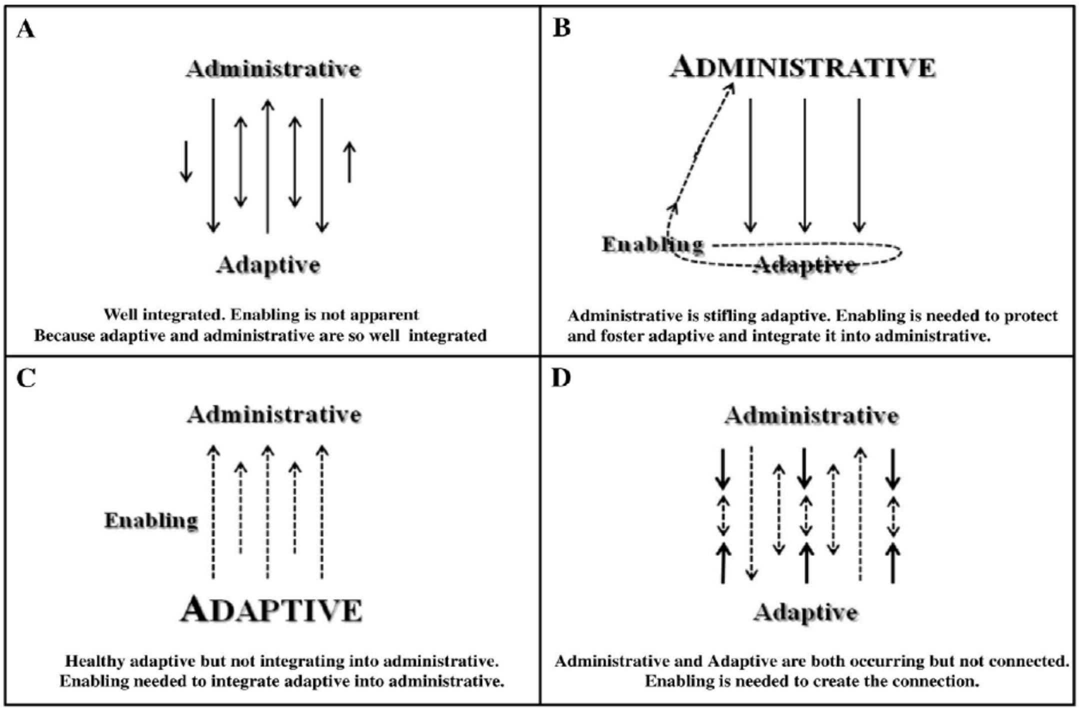

Fig. 2. Entanglement and enabling leadership functions in Complexity Leadership Theory.

Figure 5-4 Different configurations of CLT (Uhl-Bien and Marion, 2009, p635)

The study thus extends empirically the work on enabling leadership within CLT (Uhl-Bien, Marion and McKelvey, 2007). At site C in particular, leadership was 'not only incremental influence of a boss toward subordinates, but most important it is the collective incremental influence of leaders in and around the system.' (Osborn, Hunt and Jauch, 2002 p798). Leaders recognized and encouraged capabilities, 'potentially valuable experiments happening at all levels, within and outside the organization, and to encourage and motivate all units and external collaborators to actively participate in experimenting to identify novel solutions within the ongoing functioning of capabilities' (Uhl-Bien and Arena, 2018 p93).

Our research also offers a partial response to the challenge from Tourish (2019) that CLT as currently described remains leader-centric and does not explain how leadership emerges, and that it therefore does not fully embrace organizations as complex adaptive systems. Both Site B and Site C provided evidence of leadership emerging, as leaderly influence both within peer groups and upwards within the hierarchy, through acceptance of specific expertise. The encouragement of this emergent leadership by formal leaders, we interpret as a practice of adaptive leadership. The second part of this challenge has been addressed by Rosenhead et al., (In Press, 2019, p20) who point out that 'complexity offers a potentially valuable metaphor for leadership practice and research' rather than being a complete analogue for organizations. We have found complexity to be indeed a useful metaphor, in the empirical evidence of the positive influence that enabling leadership practices, especially 'enabling rule-following AND competent improvisation' at Site C, had on the successful entanglement of adaptive and administrative working practices, resulting in better process safety outcomes.

5.6.3 Limitations

The findings inevitably represent only an indication of the views of the individual respondents. Although some confidence in data saturation is claimed (ref **Fig 5-2)** the number and duration of the interviews was necessarily restricted by the availability of the respondents. The quality of the data is also inevitably limited by interview technique and the protocol used.

As discussed earlier, the method used to analyse the interview data included a quantification of the codes, which some researchers may criticize as being neither an accepted quantitative method nor respecting the accepted qualitative approach of rich description and textual meaning. The quantification was done 'in order to draw out the factors that are viewed as contributing to an outcome' (Bryman, 2004, p758) and so facilitate the identification of differences between the three sites. Although no statistical significance or correlation is claimed for the differences so analysed, some clear associations have been suggested between the process safety outcomes of the sites and both the broad theoretical dimensions that emerged from the analysis and some of the first and second-order codes that were obtained from the interview data. Caution should of course be exercised in interpreting the generalizability of these associations. To retain textual meaning and richness of description, evidence is also provided from the interview data in the form of quotes from each site illustrating each of the second-order codes.

Although qualitative research cannot generally seek strict replicability, it is claimed that the findings of this multiple case study are less idiosyncratic than a single case would be (Bryman, 2004) and that the cross-case comparisons do allow some cautious theoretical inferences to be made (Eisenhardt, 1989). A stronger basis for such inferences, and offering the possibility of causal inferences, would be comparison of configurations of factors, for example using techniques of Qualitative Comparative Analysis (QCA) (Fiss, 2011; Ragin and Sonnett, 2004) and application of this method is envisaged in future work.

5.7 Conclusions

This empirical study has found that specific leadership practices in combination with supportive contextual conditions were associated with successful entanglement of rule-following and competent improvisation, correlated with perceived process safety outcomes. A contribution to theory is offered in the form of more detailed explanation of the processes by which both contextual conditions and leadership practices may influence successful entanglement of adaptive and administrative working practices in avoiding major process safety incidents, and that this entanglement enables a form of competent improvisation that is collaborative rather than individual-based. These findings and this suggested entanglement process build on and extend theories of both Ambidexterity and Paradox; they also support and extend Complexity Leadership Theory in its use of complexity theory as a useful metaphor to improve understanding of leadership in organizations.

The study also found evidence and suggested mechanisms of leadership emerging within peer groups, providing at least a partial answer to the challenge from Tourish (2019). By focusing on 'realities of ordinary work' (Kempster and Gregory, 2017) it also supports and extends Leadership-As-Practice, answering the challenge from Collinson (2018) by providing evidence that Leadership-As-Practice is a useful framework for critical analysis that can easily include aspects of asymmetric power and control, and that it also acknowledges structure as an equally important organizing concept as agency.

Finally, the findings of this research also suggest that a combination of both administrative and adaptive leadership practices, with the balance in favour of adaptive, leads to better organizational outcomes such as avoiding major process safety incidents than the traditional emphasis on administrative leadership practices.

6 PROCESS SAFETY INCIDENT ANALYSIS – A CRITICAL REVIEW

Abstract

This study critically reviews current accident models and suggests that more focus on adaptive processes may enable more effective organizational learning. Results from analysing investigation reports of 117 incidents at three oil & gas and petrochemical sites in the Middle East, Asia-Pacific and Europe concluded that the causal factors identified and recommendations made were overwhelmingly administrative in nature, with adaptive processes being largely overlooked, although evidence was also found that both administrative and adaptive processes are important for process safety. The implications of this for organizational learning are explored in a review of the theory, indicating that organizational learning could be greatly improved by adopting more adaptive approaches including double loop reflection (Argyris, 1977), however there are existing barriers including asymmetric power in organizations inhibiting these. The study also explores how recent developments in philosophical thinking about causation may bring insights to this field through their operationalisation in the method of Qualitative Comparative Analysis (QCA). Recent work [see **Chapters 4 and 5**] revealed the importance of contextual conditions, leadership practices and of both adaptive and administrative working practices for organizational safety outcomes. It remains unclear though what combinations of these factors, and under what conditions, lead to positive or negative safety outcomes. Establishing these 'difference-makers' is the challenge facing accident modelling and investigation. The study includes a pilot QCA of the limited data sets from the two earlier interview-based empirical studies, consolidated with the results of this incident document study, to demonstrate the application of this method to accident analysis. The possibility of future research applying the QCA method with much larger data sets using artificial intelligence and machine learning is discussed, together with the possible implications for accident analysis and the safety of high hazard technology.

6.1 Introduction

Two recent qualitative empirical studies [see **Chapters 4 and 5**] examined the views of people directly involved in the operation of high hazard technology at three oil & gas and petrochemical sites in the Middle East, Asia-Pacific and Europe. A total of 73 operator/technicians, shift supervisors, engineers and managers were interviewed using a semi-structured protocol concerned with leadership practices and organizational context; 55 of these interviews also employed Repertory Grid Technique (Kelly, 1955) focused on the circumstances and unfolding of three types of events: actual incidents with significant consequences, near-misses in which a hazard was released but with minimal consequences and potential incidents, system weaknesses identified before they could lead to release of a hazard. (Note: the terms 'incident' and 'accident' are used interchangeably in this paper.)

These earlier studies revealed the importance of organizational contextual conditions, leadership practices and of both adaptive and administrative working practices for organizational safety outcomes. However, it remains unclear what combinations of these factors, and under what conditions, lead to safety outcomes. Establishing these 'difference-makers' is the challenge facing accident modelling and investigation.

A third empirical study, described in this paper, has compared the results of the earlier two interview-based studies with the results of analysing the investigation reports of 117 process safety incidents. The comparison shows that the 'causes' identified and the recommendations made in these formal documented reports were overwhelmingly administrative in nature, in contrast to the importance given by the interviewees to adaptive working practices, leadership practices and organizational contextual conditions.

The question addressed by this study is:

- How are process safety incidents investigated and analysed, and how could organizational learning be improved, such as by addressing conjunctural causation?

The approach taken to address this question was to analyse 194 documents relating to 117 process safety incidents, which were a mixture of Actual Incidents, Near Misses and Potential Incidents. The analysis was performed by coding using NVivo, combining a grounded and theory-based approach in an iterative cycle of abductive and retroductive reasoning to develop a template. In a second stage of analysis, after consolidating the results of the incident documents analysis with the results from the two previous interview-based empirical studies, a 'pilot' QCA was performed on this consolidated list of factors, to explore and demonstrate the use of this method the analysis of incidents.

This study critically reviews current approaches to incident investigation and existing thinking about causation of accidents, proposing that more focus on adaptive processes may enable more effective organizational learning. In relation to this, theory and practice of organizational learning is also reviewed.

The philosophical understanding of causation is also explored, including recent developments in this field (Barringer, Eliason and Leahey, 2013; Baumgartner, 2008) and their operationalisation by means of Qualitative Comparative Analysis (QCA) (Ragin, 1987; Ragin and Sonnett, 2004) which offers an alternative means of analysing the causal complexity of modern socio-technical systems in terms of combinations of factors acting in conjunction. The study includes a pilot QCA of the limited data sets from the three empirical studies to demonstrate the application of this method to accident modelling and investigation.

6.2 Theoretical Background

Causation of accidents in the operation of high hazard technology has long been a topic of interest to researchers, as well as to practitioners, lawyers and wider society. Over the past century, theory has undergone some distinct changes, from the 'domino' accident model (Heinrich, 1936) and the 'cause-and-effect' models of 'Failure Modes and Effects Analysis' (FMEA) (United States Department of Defense, 1949) and 'fault tree analysis' (Watson, 1961) through the 'behavioural safety' approach (Krause, 1990) criticised for its potential for blaming workers and its 'fallacy of mono-causality' (Hopkins, 2006 p585) widening to an epidemiological approach taking into account the influence of organizational processes and conditions on human error (Cullen, 1990; Perrow, 1984; Reason, 1990b, 1997) and further evolving into a 'systems' approach. Three main 'systems' accident models have emerged: 'STAMP' (Systems-Theoretic Accident Model and Processes) (Leveson, 2004) 'FRAM' (Functional Resonance Analysis Method) (Hollnagel and Goteman, 2004) and 'Accimap' (Chen, Wood and Zhao, 2019; Svedung and Rasmussen, 2002). The systems approach is discussed later.

A well-known epidemiological accident model very commonly used in high hazard safety is the 'Swiss Cheese model' (Reason, 1990b, 2016, 1997) 'undoubtedly the most popular accident causation model' (Underwood and Waterson, 2014, p76) the classic portrayal of which is shown in **Fig 6-1**.

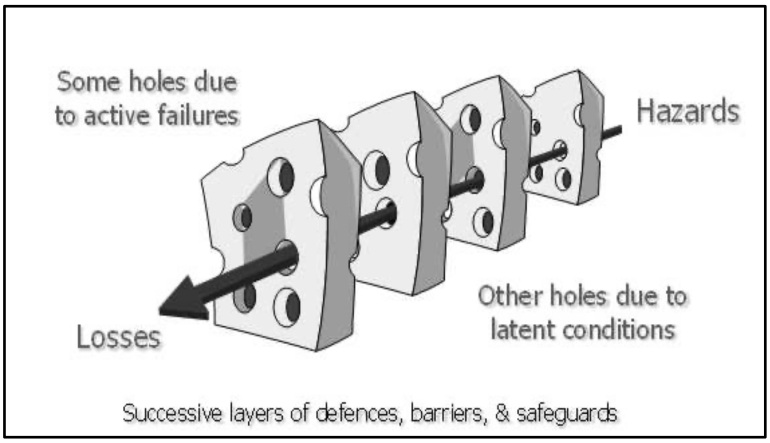

Figure 6-1 The Swiss Cheese model of accident causation (Reason, 2016, p2)

Although the Swiss Cheese model is 30 years old and has been criticised as being interpreted as being a simple linear model (Perneger, 2005; Reason, Hollnagel and Paries, 2006) it still finds much support (Larouzée and Guarnieri, 2015; Underwood and Waterson, 2014) with its metaphor capable of being extended to be representative of system complexity (Seshia et al., 2018) and as an epidemiological model it is 'valuable because they provide a basis for discussing the complexity of accidents' (Hollnagel, 2004, p58). Hudson also extends the metaphor: 'the holes in the cheese should also be seen as dynamic, opening and closing, and even moving as conditions change. A more sophisticated version now places the slices of cheese in an organizational context, which is where the latent conditions are created' (Hudson, 2014, p755).

The Swiss Cheese model and Reason's taxonomy of human and organizational factors relating to accidents (Reason, 1990b; Reason, Parker and Lawton, 1998) together form the basis of epidemiological models such as the 'Tripod' accident analysis model (Energy Institute, 2015; Wagenaar and Van Der Schrier, 1997) widely used in the oil & gas industry, and HFACS (Human Factors Analysis and Classification System) (Shappell and Wiegmann, 2000; Wiegmann and Shappell, 2001; Zhou, Fu and Xue, 2018) widely used in aviation. The Swiss Cheese model is also used in bow tie barrier analysis methods of accident analysis (CCPS and Energy Institute, 2018) such as 'Barrier-based Systematic Cause Analysis Technique' (BSCAT) (Pitblado et al., 2015) which essentially seek to identify the barriers that failed, and why; McLeod (2015) provides detailed guidance on identifying human factors issues underlying such barrier failures.

Tripod attempts to determine the effects of 'safety culture' (Guldenmund, 2000) by analysing the 'adverse organizational and environmental influences on human behaviour so that the underlying causes of an incident can be identified' (Energy Institute, 2015). The importance of such cultural influences is acknowledged, but assessing their causal value is problematic. Although this analytical approach, formulated in 'Tripod-Beta' software, 'provides a structured approach to investigations, a particular benefit to those with little experience conducting accident or incident investigations' (Strauch, 2015, p107) it is also criticised as being too inflexible to deal with conflicting data or different levels of data reliability or to enable investigators to determine an organization's culpability (Strauch, 2015).

Although HFACS claims to yield a detailed analysis of contributing factors in an accident, it has been criticised as confounding categorisation and analysis: 'Categorization of errors cannot double as understanding of errors' (Dekker, 2002, p12). In response, it has been suggested that a HFACS analysis can be combined with STAMP (Leveson, 2004) and that such a hybrid of epidemiological and system approaches 'produces a system with enhanced explanatory power' (Harris and Li, 2011, p126).

After this turbulent history of competing ideas, linear cause-and-effect models are now widely viewed as inadequate to describe events that occur in complex socio-technical systems (Dekker, Cilliers and Hofmeyr, 2011; Hollnagel and Goteman, 2004; Leveson, 2004; Lindberg, Hansson and Rollenhagen, 2010; Underwood and Waterson, 2014) and in academic writing, epidemiological models have given way to the 'systems' approach (Hollnagel and Goteman, 2004; Leveson, 2004, 2011). The systems approach is now 'arguably the dominant concept within accident analysis research' (Underwood and Waterson, 2013, p154).

The systems approach acknowledges the complexity of modern socio-technical systems typically used to control high hazard technology. Recognising from the 'law of requisite variety' (Ashby, 1956, p206) that complexity of system can only be understood with complexity of analysis, the systems approach sees accidents as resulting from 'unexpected, uncontrolled relationships between a system's constituent parts…including technical and social elements which interact with each other and the environment they exist in'

(Underwood and Waterson, 2012, p1709) and attempts to model the interaction of system components, including humans, within the constraints and behaviour-shaping mechanisms within the whole system, using multiple disciplines that include engineering, psychology, sociology, safety and decision research (Rasmussen, 1997).

Recognition that modern socio-technical systems tend to be complex rather than merely complicated was spurred on by the appointment to the team investigating the 1979 Three Mile Island nuclear power station accident of the sociologist Charles Perrow, who brought a new perspective to understanding the safety of high hazard technology. His 'Normal Accident Theory' ('NAT') claims that industrial disasters are an inevitable result of 'interactive complexity' and 'tight coupling' between system components, either technological or organizational (Perrow, 1984).

The value of the 'systems' approach for the successful analysis of accidents in complex systems, especially to identify and understand 'interactive complexity' and 'tight coupling' within such systems is underlined by the almost invariably software-intensive nature of modern safety-critical systems, which 'tend to have both attributes…The interdependencies among components of critical software systems should be analyzed to ensure that there is no fault propagation path from less critical components to more critical components, that modes of failure are well understood, and that failures are localized to the greatest extent possible' (Jackson, Thomas, and Millet, 2007, p8). That such systems are increasingly software-intensive adds complexity and consequent difficulty for designers to achieve expected safety integrity levels (IEC, 2015) and also for investigators to analyse what combinations of factors, and under what conditions, lead to accidents or indeed to safety. Establishing these 'difference-makers' is the challenge facing accident modelling and analysis aimed at organizational learning. Notwithstanding software complexity, 'safety is a property of sociotechnical systems not of software…' so for both system design and accident analysis 'we should set the system boundary where the dependence on assumptions is minimised and most certain' (Thomas, 2008, p31).

The theoretical bases of the three main systems models (STAMP, FRAM and Accimap) have been accepted as more complete than linear cause-and-effect models but their very complexity makes them difficult to use (Qureshi, 2008; Underwood and Waterson, 2012). Systemic models have also been criticised as being less precise in definition of causes (Ladkin, 2005) compared with a particular cause-and-effect approach referred to as the 'why-because' method (Ladkin and Loer, 2001) that uses a logic-based analysis based on a 'counterfactual' understanding of causal dependence (Lewis, 1973). Counterfactual causation theory claims that an event E depends on another, C, if and only if C had occurred, and if C had not occurred, then E would not have occurred. However, establishing causation is a problem that has occupied philosophers for centuries and it will be argued later that counterfactual theory should be seen alongside other competing theories and does not alone provide a complete answer to this difficult question.

A recent review of systemic accident analysis methods concluded that despite widespread acceptance of the need for analysis of the whole system, in practice, perhaps due to difficulty obtaining data about all parts of the whole system, investigations remain focused on 'contributory factors at the sharp-end of the sociotechnical systems' (Hulme et al., 2019, p181). This echoes an earlier view of the practical difficulty of analysing accidents with systems methods: 'Organizational factors remain well described in the academic literature, but much harder to identify in real investigations' (Braithwaite, 2010, p55). Another recent review of accident analysis methods concluded that cause-and-effect methods may be appropriate to find and fix immediate problems but that to find underlying latent conditions, epidemiological methods are needed and, further, that 'Systemic methods will not add enough value to this process to justify the considerable effort' (Wienen et al., 2017, p25).

It is thus acknowledged that the 'systems' approach lacks widespread adoption in practice and it is suggested that, as well as the usability difficulty, and the research-practice gap seen in many management topics, this may also be due to a 'lack of track record within industry and the possible incentive to use non-systemic techniques to facilitate the attribution of liability' (Underwood and Waterson, 2013, p163).

Linear cause-and-effect approaches tend to suffer from 'hindsight bias' (Dekker, 2011) and to limit opportunities for organizational learning to the 'single-loop learning' of finding and fixing problems 'rather than to challenge deep assumptions with rigorous and systemic thinking…', the aim of 'double loop learning' (Carroll, 2002 pp124-126). However, this limitation of learning may sometimes even be deliberate, since 'organizational learning is a political process shaped by the interpretations and interests of competing stakeholders…' who may seek to 'protect themselves from scapegoating by producing their own event narratives' (Buchanan and Denyer, 2013, p213).

Thus, for organizational learning to be effective in improving organizational performance, three major challenges need to be overcome: first, identifying the gap(s) that may be inhibiting improvement and discovering the required knowledge, skills, frameworks or other important attributes; second, disseminating and applying these attributes in practice to generate the improvement and third, retaining the attributes in an 'organizational memory' so that the improved performance can be sustained.

The idea of organizational learning has been credited to Revans' (1982) 'creation of the "action learning" process' (Wang and Ahmed, 2003, p8). Action learning incorporates both the scientific method approach of single loop 'plan-do-check-act' learning popularised by Deming and the pragmatism of experiential learning championed by Dewey (Pedler and Burgoyne, 2011). In the light of considerable research since Revans' early ideas, organizational learning is now understood more broadly by many writers to mean 'a process of change and improvement in organizational actions brought about by better knowledge and understanding that have been acquired, shared, and combined' (Carmeli and Gittell, 2009, p709)

The idea of 'double loop learning' proposed by Argyris (1977) extended the meaning of organization learning to the more fundamental questioning of and reflecting upon basic objectives, underlying assumptions and purpose, so that 'any incongruities between what an organization openly espoused as its objectives and policies and what its policies and practices actually were could also be challenged' (Argyris, 1977, p123). This was fully articulated in Argyris and Schön's (1978) conception, 'one of the most original and pioneering works in the field of organizational learning' (Rhodes, 1998) founded on a 'theory of action' (Argyris and Schon, 1974). This theory proposes that people's actual behavior within organizations is based on their 'theory-in-use', and that this is different from how they believe they behave, and indeed how they say they behave, which is their 'espoused theory'. The reflective process of double-loop learning is proposed as a means of creating the greater congruence between the two theories of action necessary for improved organizational effectiveness.

Fiol and Lyles (1985) offer a slightly different analysis, distinguishing between learning, that they see as cognitive, developing insights and knowledge that enable inference of causal links between past and future action (similar to double loop learning) and adaptation, that they see as behavioural, making incremental adjustments as a result of environmental or other changes (similar to single loop learning). They too recognise that both are important since survival and growth rely on making strategic choices as well as dealing with changes in the environment.

In their early review of organizational learning Levitt and March (1988) suggested that organizations learn by sharing interpretations of experience encoded into their operating processes and by improving these processes either by trial-and-error or by research driven by aspiring to better outcomes. However, 'lessons of experience are drawn from a relatively small number of observations in a complex, changing ecology…What has happened is not always obvious, and the causality of events is difficult to untangle' (Levitt and March, 1988, p 323) so the interpretation of experience and choice of what to retain is not straightforward.

This leads to the third challenge, perhaps the biggest, that of organizational memory. At a simple level this means that 'learning agents, discoveries, inventions, and evaluations must be embedded in organizational memory' (Argyris and Schön 1978, p19). Weick expanded on this, pointing out a number of potentially problematic aspects: 'If an organization is to learn anything then the distribution of its memory, the accuracy of its memory, and the conditions under which that memory is treated as a constraint become crucial characteristics of organizing' (Weick, 1979, p206). In their seminal review of organizational memory literature, Walsh and Ungson (1991) explore these issues, suggesting that the acquisition, retention and retrieval of organizational memory are all informed by individuals, structure, culture, the work processes that transform inputs into outputs, and the physical setting and layout of the workplace, that they term ecology; and they point out that all these features can be subject to misuse or abuse in the service of asymmetric power of individuals or groups.

A distinction has also been made between 'organizational learning' and 'the learning organization' (Garvin, 1993; Senge, 1990); the former having a focus on knowledge stored in organizational memory in the form of shared mental models consisting of routines, procedures, documents and culture, while in the latter 'knowledge exists, to a great extent, in the individuals (i.e. their bodies and brains)'… and the organization '…is more like an ideal school. The organization provides a climate that facilitates the learning of the individuals, and the managers are supposed to be coaches instead of directors' (Örtenblad, 2001, p130). But this distinction between the somewhat prescriptive and uncritical model of the learning organization, favoured more by practitioners, and the more sceptical scholarly organizational learning literature (Rhodes, 1998) is perhaps less important and maybe displaced by 'knowledge management' as a competing discipline, led by information technology, even though all of these have similar underlying concepts (Easterby-Smith, Crossan and Nicolini, 2000).

Even though their learning is likely to be incomplete and distorted by the influence of power, that organizations can and do learn is accepted. Wang and Ahmed (2003) in their critical review, identify five concepts of organizational learning, each with associated practices: individual learning: by training and development; learning as processes: of information analysis and problem solving; learning culture: of collaborative teamwork and worker involvement; knowledge management: by facilitating interaction with retained knowledge; and continuous improvement: by techniques such as 'total quality management'. Another more recent mapping of theory to practice similarly found systematic knowledge management to be an important enabler of organizational learning, particularly when integrated with people practices of job rotation and nominated roles of knowledge managers and the like and with processes such as communities of practice, action learning and post-mortems (Basten and Haamann, 2018).

Perhaps the best known technique of post-mortem continuous improvement is the US Army's debriefing process, the 'After Action Review', 'arguably one of the most successful organizational learning methods yet devised (Senge, 2002). This semi-formal process assumes learning may be derived both from success and failure. It is led by a facilitator and involves all the people involved in a specific task, to identify specifically what went well and potential improvements (Mastaglio et al., 2011). This technique has been adopted in many non-military fields such as healthcare (Reiter-Palmon et al., 2015) international aid (Mullerbeck, 2015) and elite sports (Middlemas, Croft and Watson, 2018).

Despite the developments in understanding organizational learning, there remain difficulties. Referring to a model of organizational learning proposed by Crossan, Lane and White (1999) of four processes (so-called '4I model') of 'intuiting', developing new insights from personal experience; 'interpreting' these by explaining to others; 'integrating' in groups of individuals to generate coherent understanding; and finally 'institutionalizing' in systems, structures, procedures and strategies to guide organizational action, Schilling and Kluge (2009) identify a number of barriers to organizational learning and categorise them by the 4I model processes. These include personal biases, 'superstitious learning' (Levitt and March, 1988), high level of stress, restrictive and controlling management style, and blame culture, all of which inhibit the intuiting of insights; lack of confidence or political/social skills of the innovator, and status culture, which inhibit interpretation; lack of recognition or fear of punishment, rigid and outdated beliefs or assumptions of senior managers, inhibiting the integration of new ideas and finally, cynicism towards the organization or innovation, lack of time and resources, and organizational hypocrisy, all of which inhibit the institutionalizing of learning.

So although many processes are suggested by which organizational learning may take place, there are also many barriers, not least of which are the power and politics prevalent in most organizations. Vince (2018, p 275) suggests accepting this paradox as normal: 'Our own desires to learn through collaboration are mixed up with our ambivalence towards others, our defensiveness in the face of learning, and our habits and attachments to individualised and self-serving ways of thinking and working. It is holding these tensions together that is most likely to support and sustain learning because this is a more realistic depiction of the organisational context within which learning takes place.' This builds on earlier work suggesting that organizational learning can only ever take place within the political reality of organizations. Learning requires that differences become reconciled by generating new ideas, and this may be best facilitated by open argument, mirroring civic political systems, 'based on rights and obligations within a framework of legitimate authority…However, entrenched power structures and the associated patterns of dependency tend to constrain such radical processes. Unless political action enables these structures to be challenged, higher-level learning will be inhibited' (Coopey and Burgoyne, 2000, p 879)

Baumard and Starbuck (2005, p294) are even more discouraged, suggesting that 'learning is unlikely to occur at all in a large, divisionalized firm' since such an organization is a 'political system in which senior managers compete with each other to control resources and to gain political power'. They suggest that organizational learning can be achieved, but only if the top managers are 'intellectually and financially motivated to learn'.

Cannon and Edmondson (2005, p310) reinforce the latter more positive view, pointing out that 'organizational policies such as 3M's directive that 25 percent of a division's revenues come from products developed in the last five years, and Bank of America's setting the expected level for failed experiments at 30 percent can go a long way in sending the signal that the organization values creative experimentation'. Similarly, Weinzimmer and Esken (2017, p342) stress that 'managers need to make a conscious effort to communicate to employees the value in learning from mistakes as an important part of improving and changing existing organizational practices'.

Weick (2009, p239) makes a similar point: 'Emergent change, and it close relative sensemaking, are likely to be more effective when the culture of the corporation makes it clear that people are valued when they…speak up when things aren't working'. However, to be successful such efforts need to be made within an integrated approach to learning, of supportive structures, shared beliefs and leader coaching (Edmondson, 1999) which contribute to a climate of 'psychological safety' (Argote, 2011; Baer and Frese, 2003; Edmondson, 1999) in which people feel safe to speak up about concerns, question practices or decisions and propose new ideas.

Baer and Frese (2003, p61) demonstrated the importance of a climate of initiative and psychological safety for process innovations – since they focus on 'interdependency, personal responsibility, autonomy, and flexibility'…which are 'critical in ensuring enhanced organizational performance'. And Carmeli and Gittell (2009, p724) suggest that psychological safety is enhanced by a supportive structure of 'shared goals, shared knowledge, and mutual respect', which in turn is encouraged by practices such as 'boundary spanner roles, inclusive cross-functional meetings, and cross-functional routines'.

But the effective sharing of ideas, learning and decision-making are often inhibited by common human caution (Schilling and Kluge, 2009). It is well accepted that in our interactions with others we are normally at least somewhat guarded. As Goffman (1959, p9) points out, when people are working together, 'each participant is expected to suppress his immediate heartfelt feelings, conveying a view of the situation which he feels the others will be able to find at least temporarily acceptable. The maintenance of this surface of agreement, this veneer of consensus, is facilitated by each participant concealing his own wants behind statements which assert values to which everyone present feels obliged to give lip service.' Similarly, Kahn (1990, p708) found that psychological safety depends on the specific working environment: 'situations promoting trust were predictable, consistent, clear, and nonthreatening…When situations were unclear, inconsistent, unpredictable, or threatening, personal engagement was deemed too risky or unsafe.'

The degree to which this caution is influenced by the asymmetric power within hierarchies was described by Hofstede (1980) as 'power distance', noting marked differences in different national cultures and organizations. The need to overcome unhealthy power distance on flight decks manifesting in 'unwillingness of junior crewmembers to speak up in critical situations' was an important driver for the introduction of Crew Resource Management (Kanki, Helmreich and Anca, 2010, p8).

In their major review of psychological safety research Edmondson and Lei (2014, p39) conclude that psychological safety is an essential enabler of organizational learning: 'For people to feel comfortable speaking up with ideas or questions—an essential aspect of organizational learning—without fear of ridicule or punishment, managers must work to create a climate of psychological safety'. This importance is underlined by a major longitudinal study by Google that found psychological safety was 'more crucial to how well teams innovated than anything else' (Bergmann and Schaeppi, 2016, p4). And in another more recent review of psychological safety research, Newman, Donohue and Eva (2017) found psychological safety to be especially important in safety-critical work.

Finally, returning to the work of Chris Argyris, a critical interpretation is offered that reinforces once more the importance of power for organizational learning. Bokeno (2003) suggests 'that Argyris' Model I patterns of interaction, far from simply barriers to effective organizational problem solving, are linked to maintenance of power asymmetry and managerialism in organizational practice, underscoring his OL [Organizational Learning] project one of ideology critique…' and that '…double-loop learning involves "critical" reflection and illumination of the distortions and constraints on ideal communication that ensue from power asymmetry'

Many of the barriers to learning discussed above are seen in organizations suffering major incidents. For example, those mentioned above by Schilling and Kluge (2009) such as 'restrictive and controlling management style' and 'status culture' are all too familiar features of the traditional 'rule-following' and 'command and control' paradigm prevalent in high hazard industries, along with 'high level of stress', 'lack of time and resources', 'fear of punishment' and 'blame culture' which are so often associated with the asymmetric power referred to by Baumard and Starbuck (2005), Buchanan and Denyer (2013) and indeed Argyris in the reading by Bokeno (2003).

So perhaps for these reasons as well as others, current accident investigation practice commonly adopts 'root cause analysis' techniques (CCPS, 2019; OSHA, 2016; Pillay, 2015) based on linear cause-and-effect models, and makes recommendations that only address these apparent 'root causes', a failing that has been called 'what you look for is what you find' (Lundberg, Rollenhagen and Hollnagel, 2009, p1298).

Further, the 'causes' and recommendations resulting from such investigations are likely to be administrative in nature (rather than adaptive) reflecting the traditional 'rule-following' and 'command and control' paradigm prevalent in high hazard industries. This is particularly so since recommendations of this type are explicitly encouraged by current authoritative industry guidance: 'Typically, recommendations are written to prevent incident recurrence by: improving the process technology, upgrading the operating or maintenance procedures or practices, improving compliance with existing organizational systems (operational discipline); and upgrading the management systems, (often the most critical area)' (CCPS, 2019, p5).

This is despite the growing research consensus that safety of high hazard technology comes not only from the traditional reliance on administrative practices of engineering and rule-following, which has been referred to as the 'Safety I' paradigm (Hollnagel, 2014) but also from adaptive processes such as 'sensemaking' (Weick, Sutcliffe and Obstfeld, 2005) 'mindfulness' (Weick and Sutcliffe, 2006) and 'expert improvisation' (Foster, Plant and Stanton, 2019; Hale and Borys, 2013; Hollnagel, 2014; Leveson, 2011; Rego and Garau, 2007). These ideas have been well documented in 'High Reliability Organizing' ('HRO') research (La Porte, 1996; Roberts, 1990; Weick, Sutcliffe and Obstfeld, 1999) and in theories of 'System Safety' (Leveson, 2011) and 'Safety II' (Hollnagel, 2014).

A prime motivator of this research is therefore to explicate and contextualize process safety incident investigation with the aim of understanding how organizational learning may be improved. The learning that is sought from current incident investigations appears to be largely restricted to that of a single-loop 'continuous improvement' nature, and so overlooks the potential for more fundamental improvements that may emerge from a more critical double-loop learning approach.

The discrepancies between accident investigation practice and research in the fields of both accident analysis and organizational learning underline the need for better methodologies for the identification of causal difference-makers. The findings of a recent review of learning from chemical accidents 'suggest that routine accident analysis is in large part not identifying potential deficiencies associated with new and complex causes of major concern in process safety today…' and that 'more effort should be invested to develop conceptual frameworks, possibly accompanied by descriptive criteria, to identify precursors that can both help in identifying potential areas of weakness and also quantify the strength and breadth of the vulnerability' (Wood, 2018, p395).

This points to an underlying ambiguity about causation. All the accident models discussed, whether explicitly or implicitly, make assumptions about causation. Linear models tend to select specific cause-and-effect sequences and so are accused of hindsight bias since other causal pathways may have existed that offer different interpretations of how and why events occurred. Epidemiological models are concerned with identifying underlying factors that may influence the performance of system components, including humans, but still tend to be based on the implicit assumption of sequential cause-and-effect, albeit perhaps between multiple layers of defence and allowing non-linear influences. Systems models, while acknowledging the complexity of possible combinations of causal factors, are generally not explicit on their assumed causation philosophy. For example, the STAMP approach to causal analysis, 'Causal Analysis based on STAMP' (CAST) 'identifies three types of factors that need to be considered in accident causation: the proximate event chain, conditions that allowed the events to occur, and indirect factors critical to fully understanding why the accident occurred' (Stoop and Benner, 2015, p98) and cases in which the method has been used have been 'Mostly implicit in their application, substantive issues are concerned with: a judicial use of the notion of cause…' (Stoop and Benner, 2015, p100).

None of the models discussed: linear, epidemiological or systems, adequately address causation as a conjunctural or configurational phenomenon. This study does address this, by demonstrating how data derived from epidemiological Swiss cheese models could be re-analysed using Qualitative Comparative Analysis (QCA) to reveal configurations of factors that lead to negative safety outcomes, actual incidents or near misses, or more positive outcomes such as the identification of potential incidents, so that such system weaknesses can be rectified before they incubate into more negative outcomes.

The idea of configuration, describing the functioning of systems in terms of how system elements interact, is accepted as the basis of important conceptual frameworks that help understand organizational behaviour (Mintzberg, 1980) and is 'arguably one of the central ideas of organization studies, stemming back to the writings of founding fathers such as Max

Weber…Yet, this idea also remains one of the field's least understood aspects' (Fiss, Marx and Cambré, 2013, p2). Although configuration is therefore not at all a new idea, recent developments in philosophical thought and analytical methods offer a means of improving the understanding of causation in terms of configuration, that is, combinations of factors acting in conjunction.

Before discussing these recent developments, the philosophy of causation is a briefly reviewed. A common starting point is the philosopher David Hume's deterministic proposition of a 'regularity' theory of causation: that A causes E if and only if A is followed by E, A is sufficient for E and A is necessary in the circumstances for E (Hume, 1777). The incompleteness of this theory can be seen in the many examples of causes that are not just single sufficient or necessary factors but complex configurations of many factors. This observation led John Stuart Mill to propose that 'for every event there exists some combination of objects or events…the occurrence of which is always followed by that phenomenon. We may not have found out what this concurrence of circumstances may be; but we never doubt that there is such a one' (Mill, 1843, p237).

However, this still did not rule out the many sufficient and necessary conditions that are not causes and are therefore redundant. To overcome the redundancy problem, Mackie proposed that 'causes' are better thought of as 'INUS' conditions, 'Insufficient but Non-redundant parts of a condition which is itself Unnecessary but Sufficient for an occurrence' (Mackie, 1974). Although INUS theory brought more clarity, a number of objections have been raised, for example that it cannot distinguish between causal and spurious regularities, and that it has difficulty with cases of pre-emption and omission (Spector, 2011).

The philosophical causation debate has continued, yielding many theories, some examples of which are physical causation theory (Dowe, 2000) based on the conservation of energy, e.g. in collisions of billiard balls, which has been criticised as 'unable to describe causal interactions involving classical fields such as the gravitational and electromagnetic fields much less quantum fields…' and 'restricting attention only to the dynamical aspects of causation' (Lupher, 2009, p79), counterfactual theory (Lewis, 1973) which is difficult to apply to real world situations since it requires causes and effects to be occurrences, so does not allow for causation by absence or omission (Strevens, 2003) and probabilistic theory (Suppes, 1970) which does allow for causation by absence or omission and is the basis for Bayesian causal inference procedures that are used in much social science research, but is open to the criticism of establishing correlation without causation and omitting important context (Mumford and Anjum, 2013).

Causation is a major field of philosophical, scientific and sociological scholarship with many theories, each with their advantages and disadvantages, having significant agreement as well as much contention. The critical realist analysis that sees causation as 'a process in which the real emergent causal powers of a variety of entities interact to produce events' (Elder-Vass, 2005, p332) resonates with Mill's idea that causation operates in 'some combination of objects or events' and also with the acknowledged complexity of modern socio-technical systems and the attempt to understand causal complexity in them.

Recent work in the philosophy of causation, building on Mill's 'method of difference' and Mackie's INUS theory, claims to have overcome the remaining problems with regularity theory. This major achievement of logic significantly strengthens the case for regularity theory as a basis for understanding causation in terms of combinations of factors: 'Empty, single-case, and other accidental regularities, common cause structures and the non-symmetry of general causation can all be adequately captured in regularity theoretic terms. Regularity theories can do justice to the whole complexity of generic causal structures… Finally, we have seen that a regularity theoretic analysis of general causation can pave the way towards a straightforward account of singular causation.' (Baumgartner, 2008, p348).

A practical approach to understanding real-world causation based on these developments in regularity theory has been operationalized in the form of Qualitative Comparative Analysis (QCA) (Ragin, 1987; Schneider and Wagemann, 2012; Thiem and Dusa, 2013) and fuzzy-set QCA (fsQCA) (Fiss, 2011; Ragin, 2007). Using Boolean algebra, this method achieves rigorous elimination of redundancy in regularity theory, leaving only 'difference-making' regularities and offering particular value in 'the ability of QCA and fsQCA to cull patterns from data in a way that captures the complexity of factors working in conjunction and identifies multiple recipes associated with a given outcome' (Barringer, Eliason and Leahey, 2013, p22)

The QCA method is very well-suited to the investigation of multiple conjunctural or configurational causation, that is, how the different combinations of conditions of cases lead to different case outcomes. It combines both detailed case-specific knowledge and numerical analysis of multiple cases in a way that can establish causal relationships between the conditions or factors characterising cases and the case outcomes (Ragin, 1987). Further, the logic of QCA is explicitly intended to reveal equifinality, that is that different combinations of conditions or factors can form different pathways to the same outcome (Mahoney and Goertz, 2012).

This contrasts with traditional quantitative statistical methods that are generally limited to examining relationships between independent and dependent variables, rather than configurations of variables. Choice of method of course depends on the research interest. QCA is particularly appropriate to investigating combinations of conditions that lead to a specific outcome, especially to 'probe how combinations of conditions produce an outcome versus a singular test of an independent variable's relationship to a dependent variable' (Jordan et al., 2011, p1161).

In summary, this paper argues that current practice in accident analysis is limited in its value for organizational learning, and thus for improving the safety of high hazard technology, for two main reasons. Firstly, the methods used and existing guidance both tend to emphasise administrative causal factors and have insufficient focus on adaptive processes. The growing body of literature that understands safety of high hazard technology as resulting not only from traditional administrative organizing processes of engineering and compliance with procedures but also from mindful competent improvisation and other adaptive processes, such as described in HRO, 'system safety' and Safety II, appears to be largely overlooked in current accident analysis practice.

Secondly, insufficient attention is given to the causal complexity within modern socio-technical systems. System models such as STAMP and FRAM are under-utilised, partly at least since they are resource intensive. More generally, assumptions of causation largely do not consider causal complexity in terms of the conjunction of multiple factors.

The proposition is that organizational learning and consequently safety would be improved by incident analysis by having more focus on adaptive processes and also by analysing causation as conjunctural.

This empirical study has analysed documents relating to 117 process safety incidents, firstly to examine the causal factors identified and recommendations made and compare their administrative or adaptive nature; secondly, to demonstrate the application of the method to accident analysis, a 'pilot' QCA has been performed using a consolidated set of factors based on the causal factors that emerged from the incident documents analysis together with the factors resulting from the two previous interview-based studies [**Chapters 4 and 5].**

The empirical study is now described.

6.3 Method

6.3.1 Data collection

Three empirical data sets were used in this study:

- 194 documents relating to 117 incidents, a mixture of Actual Incidents, Near-Misses and Potential Incidents.
- 55 Repertory Grid interviews (Kelly, 1955) focused on a number of 'Actual Incidents', 'Near-Misses' and 'Potential Incidents' (defined below) [ref **Chapter 4**]
- 73 semi-structured interviews focused on leadership practices and organizational context [ref **Chapter 5**]

The data was collected from three fieldwork sites. Some important features of the organizations at these sites were as follows: Site A was a large Middle East petrochemical manufacturing site in transition from project to operations. The organization was fairly hierarchical, emphasising compliance with procedures; it had had a number of significant process safety incidents in the early years of operation, including some fatalities. Site B was an onshore oil & gas production operation in Asia-Pacific with a fairly flat hierarchy and a moderately open culture that had been growing rapidly over the previous decade; it had suffered a number of significant process safety incidents including some high potential consequence near-misses and potential incidents. Site C was a European offshore oil & gas production operation with a mature organization and a markedly open culture of mutual respect; the safety performance was perceived as above average: it had recently been given a major award for its process safety performance. A summary of the profiles of the three sites is given in **Table 6-1**.

Table 6-1 Summary profiles of the three sites

	Site A	Site B	Site C
Overview	Large single site Petrochemicals complex	Onshore Oil & Gas production, Large number of remote production units dispersed geographically; single large treatment and export plant	Offshore Oil & Gas production; onshore treatment plant and office for technical and operations support
Location	Middle East	Asia Pacific	Europe
Organizational form	Strong hierarchy	Hierarchy / open culture	Weak hierarchy / open culture
Personnel	Largely ex-patriot	Largely local	Largely local
No. of people	2000+	4000+	200+
Organizational maturity	In transition from very large Project to Operations	Mixed; rapidly growing number of physical assets	Stable; mature
Years of operation	5+	10+	25+
Relation with Parent	Significant specialist support	In the process of adopting Parent Org technical standards	Fairly independent; supported as needed
Perceived Safety performance	Mixed	Below average	Above average

6.3.1.1 Selection of cases: Incidents with different outcomes

Incidents were of three different types, 'Actual Incident', 'Near Miss' and 'Potential Incident' (defined below) involving process safety hazards such as flammable or toxic fluids, that had or could have had significant consequences, defined as level 3 to 5 on a severity scale commonly used in the industry (Summers, Vogtmann and Smolen, 2011) which shown in **Table 6-2**.

Table 6-2 Consequence Severity Scale

	People	Environmental damage	Asset loss/Operation impact
5	Multiple fatalities	Catastrophic off-site damage	>$10M and substantial offsite damage
4	1 or more fatalities	Significant off-site damage	$1M - $10M and severe impact
3	Hospitalization injury	On-site or offsite release with damage	$100K - $1M and significant impact
2	Lost workday injury	On-site or offsite release without damage	$10 - $100K and some impact
1	Recordable injury	On-site release	< $10K and minor impact

6.3.1.2 Types of Incident

The three types of incident examined in this study, Actual Incident (AI) Near Miss (NM) and Potential Incident (PI) are defined with reference to the 'bow tie' hazard management diagram (ICI, 1979) an example of which is shown in **Figure 6-2.**

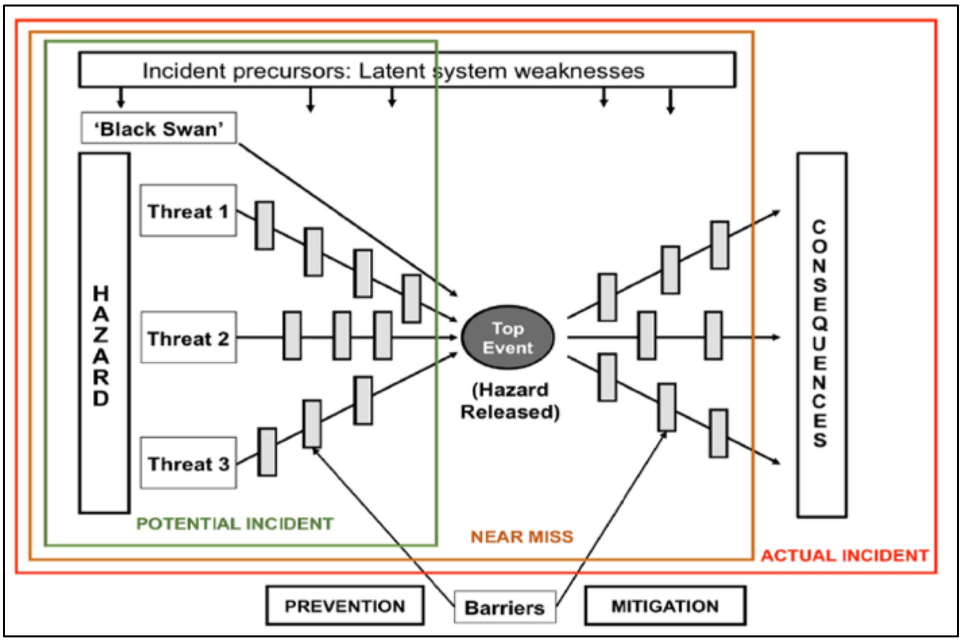

Figure 6-2 Bow Tie hazard management diagram with incident types

A bow tie diagram portrays for a particular hazard such as 'pressurised flammable gas contained in a pipe' a number of possible incident causation pathways. It also shows the progression of an incident from left to right through several stages of incubation (Turner and Pidgeon, 1997).

The left-hand side shows the mechanisms by which the hazard could be released, such as for an underground pipeline: corrosion, fatigue or excavator damage. These mechanisms are shown as 'threat lines', along which are placed 'barriers' designed to prevent the threats from releasing the hazard. Examples of such 'prevention' barriers are a steel containment envelope, a process alarm with operator response, and an automatic shut-down system (CCPS and Energy Institute, 2018).

Each such 'threat line' can be seen as a partial Swiss Cheese model (Hudson and Hudson, 2015). If the barriers (slices of Swiss Cheese) designed to contain the hazard from being released by a specific threat were all to fail simultaneously (the 'holes' in the slices of cheese all lining up) then a 'top event' would occur. In the process industries a typical 'top event' is a release of flammable gas. The hazard could also be released by a previously unknown mechanism or one considered so unlikely as not to warrant preventative controls, a so-called 'Black Swan' (Taleb, 2007). On the right-hand side of the diagram, the known possible pathways that could lead to consequences are shown as continuations of the Swiss Cheese diagram. Along these pathways, 'mitigation' barriers are shown that are designed to reduce potential consequences such as injuries or damage from an incident such as explosion, fire or plume of toxic gas. Examples of mitigation barriers are an automatic firefighting system, evacuation by lifeboat and use of an escape respirator.

The bow tie diagram in **Fig 6-2** portrays the three different types of process safety event discussed in this paper and are defined here following the logic widely used in high hazard operations (HSE, 2004; OSHA, 2015; Reason, 1997). An 'Actual Incident', shown within the outer (red) box, is the occurrence of a 'top event' that then results in significant consequences; evidently in such a case, all of the prevention and mitigation barriers on at least one pathway proved ineffective. A 'Near Miss', shown within the middle (orange) box, is the occurrence of a 'top event' that could have resulted in significant consequences but in fact did not; even so, evidently all of the prevention barriers proved ineffective.

By contrast, a 'Potential Incident', shown within the inner (green) box, is the detection of a system weakness before it could incubate into a release of the hazard. Such a system weakness could be a 'system pathogen' (Reason, 1997) such as an ambiguous procedure, loss of currency in a technical skill, a maintenance backlog or an unclear critical communication. In the traditionally accepted analysis, such factors can lead to degradation of barriers. In the 'Safety II' view, they can also lead to degradation of mindfulness and expert improvisation that may normally be operating to maintain safety despite imperfect equipment or system design (Hollnagel, 2014).

A Near Miss could result from the effective operation of a designed mitigation barrier or from a successful improvised intervention such as an operator opening a valve to release an unexpected build-up of pressure, or just by luck, such as a gas cloud dispersing before reaching a source of ignition. A Potential Incident could also result from luck, a chance observation, but more likely from an effective control room alarm or a routine inspection designed to detect such weaknesses, or from the vigilance of a human operator/technician or engineer discovering some anomaly.

Putting aside the element of chance, these are examples of adaptive practice inherent in Safety II, System Safety and HRO. That said, even though a Near Miss may involve an adaptive practice in its mitigation, it nonetheless means that uncorrected weaknesses did release a hazard, so the occurrence of Near Misses indicates less effective hazard management than that indicated by the identification of Potential Incidents.

The Swiss Cheese and the bow tie models can both be interpreted in either the Safety I or the Safety II paradigm. Safety I seeks reactive understanding of incidents by root cause analysis to identify the barriers that failed and the 'cause' of the failure, the 'hole in the Swiss Cheese slice'. In contrast to this static view of systems, the Safety II / system safety / HRO paradigm acknowledges that system complexity means that 'holes in the Swiss Cheese' may combine dynamically in unexpected configurations to release a hazard, so sees the routine proactive employment of adaptive practices seeking such system weaknesses as essential for safe operation of complex socio-technical systems (e.g. Hollnagel, 2014; Leveson, 2013). Thus both the Swiss Cheese and bow tie models remain as useful metaphors that aid the analysis of accidents in complex socio-technical systems. The bow tie model 'is neutral in terms of any underlying model of accident causation. It need make no assumption about the mechanisms that might lie on the path between threats and the top events and consequences they can lead to. There is no reason why a bowtie model should not be based on a STAMP (Leveson, 2011) or FRAM (Hollnagel, 2012) analysis.' (McLeod and Bowie, 2018, p180).

In summary, for this study, and referring to the bow tie diagram shown in **Figure 6-2**, an 'Actual Incident' is defined as a 'top event' that occurred with significant consequences (level 3 to 5 ref **Table 6-2**); a 'Near Miss' is defined as a 'top event' that occurred (hazard was released) with the potential of significant consequences but that actually had minimal or no consequences; and a 'Potential Incident' is defined as an occurrence that had the potential of significant consequences but in which no 'top event' took place (hazard was not released).

6.3.1.3 Incident Documents

194 documents relating to 117 incidents were obtained. The documents were of five types: 'Incident Report', 'Incident Report with Update', 'Incident Investigation Report', 'Learning From Incidents', and 'Incident Review Panel'.

'Incident Reports' and 'Incident Report with Updates' were downloaded from the host organization's incident management database and contained just basic descriptions of the incident: date and time, location, what happened, equipment and people involved, the consequences, actions taken and the nominated person responsible for managing the incident (the incident manager). Incident Reports were updated in the database from time to time by the incident manager as the investigation progressed and the required actions arising were implemented. Most of these documents were 1 to 2 pages, some around 5 pages.

'Incident Investigation Reports' contained detailed technical description of the equipment and work process and people involved, the composition of the investigation team and the findings and recommendations from the investigation. Many contained drawings and photographs. Most of these documents were 6 to 10 pages, some very detailed around 60 pages.

'Learning From Incidents' were summary documents disseminated to share the findings and recommendations, most with one to two photographs or drawings. These documents were typically 1 to 2 pages, some slightly more.

'Incident Review Panel' were mostly slide presentations used at meetings held to review the incident, containing records of the investigation and its findings and recommendations. These ranged from 1 page to around 10 pages in length.

The numbers of each type of incident and document are summarised in **Table 6-3**.

Table 6-3 Incidents and Related Documents

	Site			
Incidents	**A**	**B**	**C**	**Totals**
Actual Incident	19	27	13	59
Near Miss	9	24	1	34
Potential Incident	4	18	2	24
Totals	**32**	**69**	**16**	**117**
Incident-related documents				
Incident Report	3	15	1	19
Incident Report with Update	10	38	10	58
Incident Investigation Report	15	52	8	75
'Learning From Incidents' document	2	15	0	17
'Incident Review Panel' record	2	14	9	25
Totals	**32**	**134**	**28**	**194**

The interviewees were as shown in **Table 6-4**. Not all interviews were able to include the Repertory Grid part (55 Rep Grid out of a total of 73 interviews) due to interviewee time constraint, unavailability of incident information or other reasons, sufficient data was obtained to achieve saturation (ref **Chapter 4**).

Table 6-4 Interviewee Population Sample

Interviewee Job Type	Repertory Grid				Semi-structured			
	Site				Site			
	A	B	C	Totals	A	B	C	Totals
Ops/Maintenance Operator/Technician	3	1	0	**4**	4	0	1	**5**
Ops/Maintenance Supervisor	3	9	0	**12**	2	11	5	**18**
Ops/Maintenance Engineer	0	5	1	**6**	0	6	1	**7**
Ops/Maintenance Manager	3	12	8	**23**	4	12	11	**27**
Project Engineer	0	1	0	**1**	0	2	0	**2**
Contractor Manager	4	0	0	**4**	5	0	1	**6**
Contractor Supervisor	3	0	0	**3**	3	0	0	**3**
Project Manager	1	1	0	**2**	3	0	2	**5**
Totals	**17**	**29**	**9**	**55**	**21**	**31**	**21**	**73**

The Repertory Grid interviewees were requested to come to the interview prepared to discuss six incidents that they were familiar with that met the above criteria. These incidents were therefore selected by the interviewees. Documents relating to these same incidents were requested but were not available for all, due to confidentiality or other reasons. However, documents relating to other similar incidents were made available. The overlap of incidents discussed in Rep Grid interviews with the incidents for which documents were obtained was 81%.

6.3.2 Data Analysis

Data analysis was performed in two stages:

1. Coding and analysis of the incident documents
2. Pilot QCA, using a consolidated list of potentially causal factors that emerged from
    - the analysis of the incident documents
    - the two previous interview-based studies [**Chapters 4 and 5**]

The process for stage 1, coding and analysis of the incident documents, was as follows:

a. Data preparation
b. Coding using NVivo
c. Comparison between the sites and between incident types

6.3.2.1 Data Analysis Stage 1a – Preparation of data from incident documents

Most incident documents were received in electronic form as pdfs, with some as Word or PowerPoint files and some paper files. Each document was entered into a spreadsheet, with quality checks to avoid data entry errors. An extract from this spreadsheet is in **Table 6-5**.

Table 6-5 Extract from Raw Incident Data spreadsheet

IR	IRU	IIR	LFI	IRP	Doc type	Ref No	Coded		Short description	AI	NM	PI
					SITE X							
		1			5 whys investigation	nnnnn	X01 IIR		fire	1		
		1			5 whys investigation	nnnnn	X02 IIR		Pressure surge	1		
				1	Incident Investigation presentation	nnnnn	X03 IRP		compressor damaged	1		
		1			Incident Investigation RCA	nnnnn	X06 IIR		pump seal failure and fire		1	
		1			Incident Report and update	nnnnn	X07 IIR	P	Incorrect wiring of motor			1
				1	Incident Investigation presentation	nnnnn	X08 IRU	P	valve gland leak	1		
		1			Incident Investigation Report	nnnnn	X10 IIR		Exposure to H2S	1		
		1			5 whys investigation	nnnnn	X12 IIR		Leak during flange debolting	1		
		1			Incident Investigation Report	nnnnn	X13 IIR		Small fire	1		
				1	Incident Investigation presentation	nnnnn	X14 IIR		heat exchanger tube leak		1	
	1				Incident Report and update	nnnnn	X17 IRU	p	Hydrocarbon hose leak	1		
	1				Incident Report and update	nnnnn	X19 IRU	P	H2S			1
		1			Incident Investigation Report	nnnnn	X23 IIR	P	Incorrect RV			1
	1				Incident Report and update	nnnnn	X24 IRU	P	Review updates of job aids			1

The host organization's incident management database reference numbers were retained in the spreadsheet, but to respect confidentiality in further analysis in this study, each document was given a unique sequential number, including the site reference but otherwise disidentified. Progress with coding was recorded by shading these numbers.

6.3.2.2 Data Analysis Stage 1b – Coding of the incident documents using NVivo

The incident documents were coded following the method recommended by Miles and Huberman (1994) and using NVivo 12 (Jackson and Bazely, 2019). Starting by analysing a sample of 10 incident documents with a grounded approach, an initial template structure of first-order codes was created inductively, which immediately divided into two obvious classes: 'apparent causes identified' and 'recommendations made'. Coding then continued for the remainder of the 194 incident documents following a process similar to that used by Walsh and Bartunek (2011) pursuing a cycle of abductive and retroductive reasoning, referring to the existing literature on accident investigation, system safety, Safety II, HRO and complexity leadership [as well as **Chapters 2, 4** and **5**] to help explain what was being seen in the data, and frequently modifying the template during the process. Using this approach, second-order theoretical categories of the initial codes within both of the main classes emerged from the data. Similar second-order theoretical categories were found to be helpful in organizing both the 'Causal Factors' codes and the 'Recommendations' codes, and these were further grouped into 'Adaptive' and 'Administrative' types. The final version of the coding template is shown in **Table 6-6**.

To confirm that enough data had been collected, a Pareto analysis was conducted in a similar manner to that used by others (Goffin and Koners, 2011; Micheli et al., 2012) plotting cumulative total number of codes identified against the cumulative number of documents as coding progressed (**Figure 6-3**). This procedure revealed that the last 30 documents yielded only 2 new codes, giving some confidence that theoretical saturation was achieved.

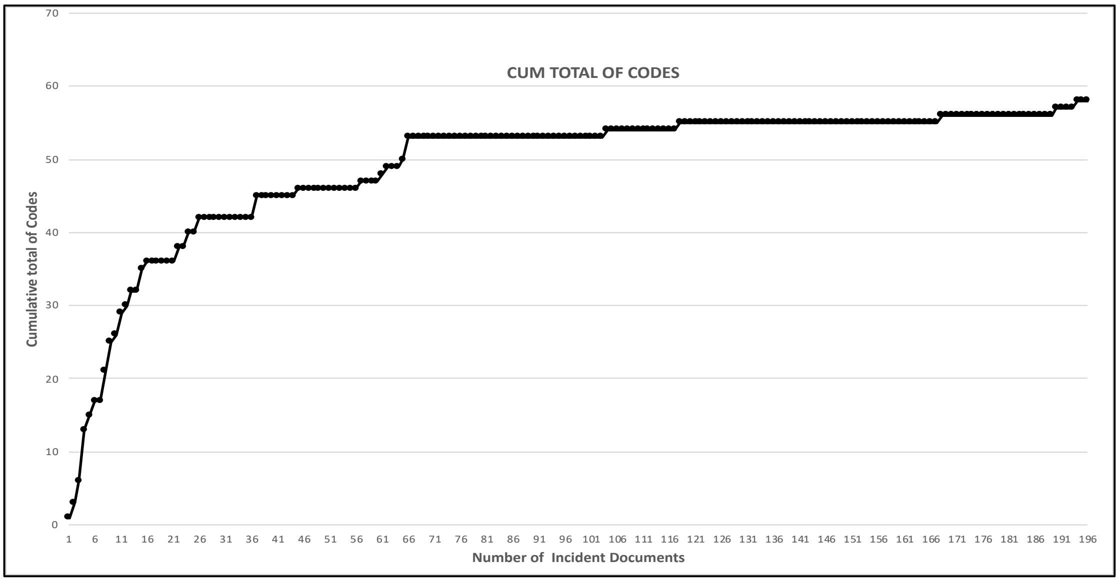

Figure 6-3 Pareto Analysis: Cumulative Codes per Incident Document

Check coding was done by an independent researcher on a sample of incident documents and the results compared. Four separate data workshop sessions were spent first coding documents independently, then discussing the results to identify differences, share understanding and refine definitions. Due to the confidential nature of the documents, they could not be shared beyond the primary researcher's computer, so the check coding was done by sharing screens; also, due to the technical nature of the documents, the primary researcher gave assistance to the check coder by explaining jargon and acronyms. During these workshops there were numerous instances of the two independent codings being slightly different, though close in meaning when discussed. This we believe is a result of the large number of first-order codes, many of which are indeed close in meaning. When discussion led to recognition that each coder could have coded in the same way as the other, this was accepted as adequate agreement. On this basis, inter-coder reliability of 80% was achieved, which is deemed acceptable (Miles and Huberman, 1994).

Table 6-6 Final NVivo Coding Template

CAUSAL FACTORS	RECOMMENDATIONS
Adaptive Practices	**Adaptive Practices**
Over-Directive Adaptive Leadership	**Adaptive Leadership**
Lack of empowerment	Recognise or give appreciation of good work
Non-Technical Skills	Support people involved in incidents
Inadequate mindfulness and vigilance	**Non-Technical Skills**
Ineffective communication	Improve communication
Lack or loss of Situation Awareness	Improve reflective mindfulness
Risk normalization	improve teamwork
Organizational learning	Undergo behavioural safety training
Inadequate checking for wider implications	**Organizational learning**
Lack of implementation of LFI actions	Explore wider learning implications
Lack of implementation of LFI actions	Improve implementing of learning into practice
Supportive Culture	Improve LFI communication
+ Effective vigilance	Improve routine learning from practice
+ Potential Incident investigation	Reflective incident review
+ Effective system design detecting potential incident	
	Administrative Practices
Over-Directive Admin Leadership	**Administrative Leadership**
Blame culture	Decisive action for safety
Production pressure	Reinforce safety priority
Compliance	**Compliance**
Distractions or other error-enforcing conditions	Clarify roles & responsibilities
Inadequate supervision, checking or monitoring	Improve supervision, checking or monitoring
Operation outside design envelope	
Reckless non-compliance	
Unclear responsibilities	
Well-meaning improvisation without full risk awareness	
Emergency Response	**Emergency Response**
Inadequate emergency response	Review or improve Emergency Response
Equipment or System Design	**Equipment or System Design**
Inadequate equipment or system design	Improve equipment or system design
Hazard and Risk Management	Review engineering design
inadequate communication of risk information	**Hazard and Risk Management**
Inadequate hazard identification	Improve communication of risk information
Inadequate Management of Change	Improve hazard identification and risk assessment
Inadequate risk awareness	Review risk management studies
inadequate risk management controls	**Inspection and testing**
Inspection and testing	Improve maintenance, inspection or testing
Inadequate construction QC	
Inadequate maintenance, inspection or testing	**Planning & Resourcing**
Planning & Resourcing	Improve technical competence & training
Inadequate job planning	Review or improve work planning
Inadequate resourcing	Review technical resources
Inadequate technical competence & training	**Procedures**
Procedures	Improve procedures or tech documents
Inadequate procedures	Review procedures or tech documents

6.3.2.3 Data Analysis Stage 1c – Comparison of the incident documents between sites and between incident types

To facilitate comparisons between the three sites and allow conclusions to be drawn, the data was quantified by determining, for each code, the number of incidents for which the related documents contained at least one reference to that code. For many incidents, the documents contained several references to the same code, but in these instances only a single reference to each code per incident was counted, to avoid the over-emphasis that would otherwise result from such repetition. This is thus the 'unique frequency' of each code.

It is acknowledged that this quantification of qualitative data can lead to a loss of the rich description and textual meaning that is so valued in qualitative data. To avoid this loss, each of the second-order theoretical categories of codes is illustrated with quotes from the incident documents, selected from the coding categories occurring most frequently at each site.

These illustrative quotes from the incident documents are given in **Table 6-13, Table 6-14** and **Table 6-15** in the **Results** section **6.4.1**, and in descriptive analysis in this section the coding results are compared with the illustrative quotes.

The number of incidents examined at each site was different, so to allow cross-site comparison, the unique frequencies of each code for each site were normalised with reference to one site, chosen as Site B, by applying factors for sites A and C, using the ratio of the number incidents examined at each of these sites to the number at Site B. Likewise, the unique frequencies of each code for each incident type were normalised with reference to one incident type, chosen as Near Miss (NM) by applying factors for the incident types Actual Incident (AI) and Potential Incident (PI) using the ratio of the number of AIs and PIs to the number of NMs.

The results these comparisons across incident type and site from the coding analysis are given **Tables 6-16 and 6-17** in the **Results** section **6.4.1**.

6.3.2.4 Data Analysis Stage 2 – Pilot QCA

This involved three steps, which are typical for performing a QCA (Jordan et al., 2011):

a. Selecting the cases to examine, the potentially causal factors and the outcomes
b. Populating data tables with values that represent these.
c. Generating a 'Truth Table' and conducting Boolean minimisation (normally using QCA software); if necessary refine iteratively using simplifying assumptions

The QCA is then completed by interpreting and assessing the results.

a. Selection of cases, factors and outcomes

The cases selected were the 117 incidents. The outcome was the incident type. The selection of potentially causal factors was done by consolidating the factors that resulted from the three empirical studies. This provided three different views of the same phenomena of interest: the organizational and technological aspects of the sociotechnical system that potentially influence the causation of accidents. Consolidating these three sets of results enables a triangulation of the data to give a more complete description of the possible causal factors that may operate in the 'real' domain (Bhaskar, 2008). The lists of factors resulting from the studies, before consolidation, are shown in **Table 6-7**

Table 6-7 Factors from the three empirical studies

Factors from Empirical Studies		
Incident Documents	Paper 1	Paper 2
Supportive Culture	WORK PRESSURE	Structure & Maturity
Overdirective Admin Leadership	DEFERENCE TO HIERARCHY	Culture
Overdirective Adaptive Leadership	PROCEDURES	Directing, prioritising and resourcing
Procedures	COMPLIANCE	Embedding improvements
Compliance	COMPETENCE	Procedures, Competence & Compliance
Planning & Resourcing	HAZARD DETECTION	Sensitivity to Operations
Hazard and Risk Management	UNDERSTANDING OF RISK	Risk Management
Non-Technical Skills	RISK ASSESSMENT	Encouraging teamwork
Organizational Learning	MITIGATION	Encouraging improvement
Equipment or System Design	COMMUNICATION	Emergent leadership
Inspection & Testing	VIGILANCE	Enabling Ambidexterity
Emergency Response	SUPERVISION	Supporting individuals & networks
	ORGANIZATIONAL LEARNING	Sensemaking & challenging
	CHECKING, CHALLENGE & FOLLOW-UP	Deference to Expertise
	INCIDENT INVESTIG. & ANALYSIS	Preoccupation with Failure
	EQUIPMENT DESIGN	Reluctance to Simplify
	EMERGENCY RESPONSE	Commitment to Resilience
	UNIQUE OCCURRENCE	
	MISTAKE	

To prepare for performing the QCA it was necessary to compile these three lists into a single list and also to reduce the number of factors to allow a practical number of configurations of factors. For n factors there are 2^n configurations and the practical limit to the number of factors for a performing QCA is around 10 (Ragin, 2017) yielding 1,024 configurations.

The consolidation was done by grouping together factors with similar meanings, informed by the analysis of the incident documents, interviews and illustrative quotes. A process was followed similar to that used by Walsh and Bartunek (2011) which was used in the analysis of both the semi-structured interview study (**Chapter 5**) and in the Incident Document study described in this paper.

In compiling the three set of factors it was necessary to maintain the positive or negative meaning of each factor as they relate to process safety, since this was not uniform over the three studies. The list of factors from the Incidents Documents study contains 12 'causal factors' which are essentially negative and one positive factor ('supportive culture'). The list of 19 factors from the Repertory Grid interviews study (**Chapter 4**) contains a mixture of positive, negative and neutral factors. The semi-structured interviews study (**Chapter 5**) resulted in a list of 17 factors all of which have both positive ('Helping') and negative ('Hindering') ratings; for the purpose of this analysis these ratings were combined by summing so that all the factors become positive.

The resultant list of consolidated factors is shown in **Table 6-8**. The content of this table reflects the similar, though slightly different, results of the three studies. The 9 consolidated factors are shown on the right-hand side of the table. All but two of them are consolidated from at least two out of the three studies, 3 of them from all three studies. Only the two leadership factors are taken from only one study, the semi-structured interviews, and this is unsurprising since leadership was the focus of this study.

All the empirical factors that emerged from the studies, without attaching any relative importance to them, are included within the overall list of consolidated factors, with three exceptions, shown as 'rejected': 'Emergency response' was rejected on the grounds that it is unlikely in practical terms to be an accident causal factor, and neither 'Unique Occurrence' and 'Mistake' have significant explanatory power as causal factors.

The consolidated factors are named with adjectival phrases to make clear their meaning as conditions rather than variables (Rubinson, 2019) and short names are also given, to facilitate their use in the QCA software.

Table 6-8 Consolidated Factors

Factors from Empirical Studies			Consolidated Factors	Short Name
Incident Documents	**Rep Grid interviews**	**Semi-structured interviews**		
Overdirective Admin Leadership	WORK PRESSURE		**Over-directing Leadership**	**OVDIRLD**
Overdirective Adaptive Leadership	DEFERENCE TO HIERARCHY			
Procedures	PROCEDURES	Directing, prioritising and resourcing	**Inadequate Administrative Practices**	**INADMINPRAC**
Compliance	COMPLIANCE	Embedding improvements		
Planning & Resourcing	COMPETENCE	Procedures, Competence & Compliance		
		Sensitivity to Operations		
Hazard and Risk Management	HAZARD DETECTION	Risk Management	**Inadequate Hazards & Risks Management**	**INHAZRISKMAN**
	UNDERSTANDING OF RISK			
	RISK ASSESSMENT			
	MITIGATION			
Non-Technical Skills	COMMUNICATION		**Inadequate Non Technical Skills**	**INNONTECH**
	VIGILANCE			
	SUPERVISION			
Organizational Learning	ORGANIZATIONAL LEARNING	Deference to Expertise	**Inadequate Organizational Learning**	**INORGLEARN**
	CHECKING, CHALLENGE & FOLLOW-UP	Preoccupation with Failure		
	INCIDENT INVESTIG. & ANALYSIS	Reluctance to Simplify		
		Commitment to Resilience		
Equipment or System Design	EQUIPMENT DESIGN		**Inadequate Asset Integrity Management**	**INASSETINTEG**
Inspection & Testing				
Supportive Culture		Structure & Maturity	**Supportive Cultural**	**SUPCULT (+)**
		Culture		
		Encouraging teamwork	**Adaptive Leadership Practices**	**ADAPTLDPR (+)**
		Encouraging improvement		
		Emergent leadership		
		Sensemaking & challenging	**Enabling Leadership Practices**	**ENABLDPR (+)**
		Supporting individuals & networks		
		Enabling Ambidexterity		
Rejected			**Reason**	
Emergency Response	EMERGENCY RESPONSE		non-causal	
	UNIQUE OCCURRENCE		low empirical importance	
	MISTAKE		low empirical importance	

b. Populating data tables with the cases, factors and outcomes.

To explain the preparation of the data tables, an explanation of the QCA method and its requirements is necessary. The process of performing a QCA, as seen earlier, involves three main steps: first, selecting the cases, factors and outcomes, second, populating data tables with values for these, and third generating a 'Truth Table' and conducting Boolean minimisation using QCA software. Boolean algebra minimisation is done to eliminate redundancy in regularity theory, thus enabling the rigorous identification of difference-makers. Several software programs have been developed for QCA (COMPASSS, 2019) and *QCA Add-In* for Excel (Cronqvist, 2019) was chosen as the simplest that is available for macOS.

In this demonstration of the QCA method, the 117 incidents were the cases. The factors were the 9 consolidated factors established above, and the outcomes were defined as the type of incident. For a QCA, the statement of each case consists of the values of the set of conditions, that is the possible causal factors, under examination. In a 'crisp set' QCA the value attributed to each factor needs to be 'dichotomised' as either being 'present' or 'absent' and represented as a binary value, '1' or '0' (Rihoux et al., 2009). QCA can also be performed using 'fuzzy sets' which would involve the more complicated step of calibration of the values, but for this basic demonstration, only the crisp set QCA method was used. Preparation of the raw data table therefore entailed determination of whether a factor is present (1) or absent (0) in each incident, or case.

The method used for determining whether a factor was present (1) or absent (0) in each case is shown in **Appendix B.** The output of this is shown in **Table 6-9** and is the raw data for performing the QCA. These final values for the consolidated factors were entered into the *QCA Add-In* software

To compare the incident types and examine for differences in their combinations of causal factors, three separate QCA calculations were performed using the *QCA Add-In* software, in turn setting the outcome as Actual Incident (AI) Near Miss (NM and Potential Incident (PI). The outcome must be stated as a 1 or a 0, and this was achieved for each calculation in turn setting the 'outcome' value as 1 for the type in question, and 0 for the other two types.

The three separate sets of data used for the QCA calculations are shown in **Table 6-10, Table 6-11** and **Table 6-12**, which contain the same data as in **Table 6-9** but sorted by incident type, and with the outcome value set to 1 for each incident type respectively (and 0 for the others).

Table 6-9 Final Values of Consolidated Factors for QCA – Raw Data Table

CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	TYPE
A01	0	0	0	0	0	1	0	0	0	AI
A02	0	1	0	0	0	0	0	0	0	AI
A03	0	0	0	0	0	0	0	0	0	AI
A04	0	0	0	0	0	0	0	0	0	AI
A05	0	1	1	0	1	0	0	0	0	AI
A06	0	0	0	0	0	0	0	0	0	NM
A07	0	1	0	0	0	1	1	0	0	PI
A08	0	0	0	0	0	1	0	0	0	AI
A09	1	1	0	1	0	0	0	0	0	NM
A10	1	1	1	0	0	0	0	0	0	AI
A11	0	1	1	1	0	0	0	0	0	AI
A12	1	1	0	1	0	0	0	0	0	AI
A13	0	0	1	0	0	1	0	0	0	AI
A14	0	1	0	0	0	1	0	0	0	NM
A15	0	0	0	0	0	0	0	0	0	AI
A16	0	1	0	1	0	0	0	0	0	AI
A17	0	0	0	0	0	0	0	0	0	AI
A18	0	0	0	0	0	0	0	0	0	AI
A19	0	0	0	0	0	0	0	0	0	PI
A20	0	0	0	0	0	0	0	0	0	NM
A21	0	1	1	0	0	0	0	0	0	NM
A22	0	0	0	0	0	1	0	0	0	NM
A23	0	1	0	0	0	0	1	0	0	PI
A24	0	0	0	0	0	0	0	0	0	PI
A25	0	1	0	0	0	0	0	0	0	AI
A26	0	1	0	0	0	0	0	0	0	AI
A27	0	0	1	0	1	1	0	0	0	AI
A28	0	0	0	0	0	1	0	0	0	NM
A29	0	0	0	0	0	0	1	0	0	NM
A30	0	0	0	0	0	0	0	0	0	AI
A31	0	1	1	0	0	0	0	0	0	AI
A32	0	0	0	0	0	1	0	0	0	NM
B01	0	0	0	0	0	1	0	0	1	NM
B02	0	1	1	0	0	0	0	0	1	NM
B03	0	0	0	0	0	0	0	0	1	NM
B04	0	1	0	0	0	0	0	0	1	NM
B05	0	1	0	0	0	1	0	0	1	NM
B06	0	0	0	1	0	0	0	0	1	NM
B07	0	0	1	1	0	1	1	0	1	NM
B08	0	1	0	0	0	1	0	0	1	NM
B09	0	0	0	0	0	1	0	0	1	NM
B10	0	1	0	0	0	0	0	0	1	AI
B11	1	1	1	0	1	1	0	0	1	AI
B12	0	1	1	0	0	0	0	0	1	PI
B13	0	0	0	0	1	1	0	0	1	AI
B14	0	0	0	0	0	1	0	0	1	PI
B15	0	0	1	0	1	1	0	0	1	AI
B16	0	0	0	0	0	0	0	0	1	AI
B17	0	0	1	0	0	0	0	0	1	PI
B18	0	0	0	0	0	0	0	0	1	NM
B19	0	1	1	0	0	1	0	0	1	AI
B20	0	0	0	0	0	0	0	0	1	NM
B21	0	1	1	0	0	0	0	0	1	PI
B22	0	0	0	0	0	1	1	0	1	PI
B23	0	0	0	0	0	1	0	0	1	NM
B24	0	0	0	0	0	1	0	0	1	NM
B25	0	0	0	0	0	0	1	0	1	PI
B26	0	0	0	0	0	1	1	0	1	PI
B27	0	1	1	0	0	1	0	0	1	AI

CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	TYPE
B28	0	1	0	0	0	1	0	0	1	AI
B29	0	0	0	0	0	0	0	0	1	NM
B30	0	1	0	0	0	1	0	0	1	AI
B31	0	0	0	0	0	0	0	0	1	AI
B32	0	0	0	0	0	1	0	0	1	NM
B33	0	1	0	0	0	0	0	0	1	PI
B34	1	1	1	0	1	1	0	0	1	AI
B35	0	0	0	0	0	1	0	0	1	AI
B36	0	0	0	0	0	0	1	0	1	PI
B37	0	0	0	0	0	1	1	0	1	PI
B38	1	1	0	0	0	1	0	0	1	AI
B39	0	0	0	0	1	1	0	0	1	NM
B40	0	1	0	1	0	1	0	0	1	NM
B41	0	1	0	1	0	0	0	0	1	AI
B42	0	0	0	0	0	0	0	0	1	PI
B43	0	0	0	0	0	1	0	0	1	AI
B44	0	1	0	0	0	1	0	0	1	NM
B45	0	1	0	1	1	0	0	0	1	NM
B46	0	1	0	0	0	0	1	0	1	NM
B47	1	1	1	1	0	1	0	0	1	AI
B48	0	0	0	0	0	0	0	0	1	AI
B49	0	0	0	0	0	0	0	0	1	AI
B50	0	1	1	0	0	1	0	0	1	AI
B51	0	1	0	0	0	1	0	0	1	AI
B52	1	1	1	0	0	0	0	0	1	AI
B53	0	1	0	0	0	0	0	0	1	PI
B54	0	0	0	0	0	1	0	0	1	NM
B55	0	0	0	0	0	1	0	0	1	AI
B56	0	0	0	0	0	1	0	0	1	AI
B57	0	0	0	0	0	0	1	0	1	PI
B58	0	0	0	0	0	0	0	0	1	AI
B59	0	1	0	1	0	0	0	0	1	NM
B60	0	0	0	0	0	0	1	0	1	PI
B61	0	0	0	1	0	1	0	0	1	AI
B62	0	0	0	0	0	0	1	0	1	PI
B63	0	1	1	0	0	0	0	0	1	NM
B64	0	1	0	0	0	0	0	0	1	PI
B65	0	0	0	0	0	1	0	0	1	AI
B66	0	1	0	0	0	1	0	0	1	NM
B67	0	0	0	0	0	0	0	0	1	AI
B68	1	1	0	0	0	0	1	0	1	PI
B69	1	1	0	0	0	0	1	0	1	PI
C01	0	0	0	0	0	1	0	1	0	AI
C02	0	1	0	1	0	1	0	1	0	AI
C03	0	0	0	0	0	1	0	1	0	AI
C04	1	1	1	0	0	1	1	1	0	AI
C05	0	0	0	0	0	1	0	1	0	AI
C06	0	0	0	0	0	0	0	1	0	AI
C07	0	1	1	0	0	1	0	1	0	AI
C08	0	0	0	0	0	1	0	1	0	NM
C09	0	1	1	0	1	1	0	1	0	AI
C10	1	1	0	0	0	0	0	1	0	PI
C11	0	0	0	0	1	1	0	1	0	AI
C12	0	0	0	1	0	0	0	1	0	AI
C13	0	1	0	0	0	1	0	1	0	AI
C14	0	0	0	0	0	0	0	1	0	PI
C15	0	0	0	0	0	0	0	1	0	AI
C16	0	0	0	0	0	1	0	1	0	AI

Table 6-10 QCA Input Data for Actual Incident Cases

	CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	AI			CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	AI
AI	A01	0	0	0	0	0	1	0	0	0	1		NM	A06	0	0	0	0	0	0	0	0	0	0
AI	A02	0	1	0	0	0	0	0	0	0	1		NM	A09	1	1	0	1	0	0	0	0	0	0
AI	A03	0	0	0	0	0	0	0	0	0	1		NM	A14	0	1	0	0	0	1	0	0	0	0
AI	A04	0	0	0	0	0	0	0	0	0	1		NM	A20	0	0	0	0	0	0	0	0	0	0
AI	A05	0	1	1	0	1	0	0	0	0	1		NM	A21	0	1	1	0	0	0	0	0	0	0
AI	A08	0	0	0	0	0	1	0	0	0	1		NM	A22	0	0	0	0	0	1	0	0	0	0
AI	A10	1	1	1	0	0	0	0	0	0	1		NM	A28	0	0	0	0	0	1	0	0	0	0
AI	A11	0	1	1	1	0	0	0	0	0	1		NM	A29	0	0	0	0	0	0	1	0	0	0
AI	A12	1	1	0	1	0	0	0	0	0	1		NM	A32	0	0	0	0	0	1	0	0	0	0
AI	A13	0	0	1	0	0	1	0	0	0	1		NM	B01	0	0	0	0	0	1	0	0	1	0
AI	A15	0	0	0	0	0	0	0	0	0	1		NM	B02	0	1	1	0	0	0	0	0	1	0
AI	A16	0	1	0	1	0	0	0	0	0	1		NM	B03	0	0	0	0	0	0	0	0	1	0
AI	A17	0	0	0	0	0	0	0	0	0	1		NM	B04	0	1	0	0	0	0	0	0	1	0
AI	A18	0	0	0	0	0	0	0	0	0	1		NM	B05	0	1	0	0	0	1	0	0	1	0
AI	A25	0	1	0	0	0	0	0	0	0	1		NM	B06	0	0	0	1	0	0	0	0	1	0
AI	A26	0	1	0	0	0	0	0	0	0	1		NM	B07	0	0	1	1	0	1	1	0	1	0
AI	A27	0	0	1	0	1	1	0	0	0	1		NM	B08	0	1	0	0	0	1	0	0	1	0
AI	A30	0	0	0	0	0	0	0	0	0	1		NM	B09	0	0	0	0	0	1	0	0	1	0
AI	A31	0	1	1	0	0	0	0	0	0	1		NM	B18	0	0	0	0	0	0	0	0	1	0
AI	B10	0	1	0	0	0	0	0	0	1	1		NM	B20	0	0	0	0	0	0	0	0	1	0
AI	B11	1	1	1	0	1	1	0	0	1	1		NM	B23	0	0	0	0	0	1	0	0	1	0
AI	B13	0	0	0	0	1	1	0	0	1	1		NM	B24	0	0	0	0	0	1	0	0	1	0
AI	B15	0	0	1	0	1	1	0	0	1	1		NM	B29	0	0	0	0	0	0	0	0	1	0
AI	B16	0	0	0	0	0	0	0	0	1	1		NM	B32	0	0	0	0	0	1	0	0	1	0
AI	B19	0	1	1	0	0	1	0	0	1	1		NM	B39	0	0	0	0	1	1	0	0	1	0
AI	B27	0	1	1	0	0	1	0	0	1	1		NM	B40	0	1	0	1	0	1	0	0	1	0
AI	B28	0	1	0	0	0	1	0	0	1	1		NM	B44	0	1	0	0	0	1	0	0	1	0
AI	B30	0	1	0	0	0	1	0	0	1	1		NM	B45	0	1	0	1	1	0	0	0	1	0
AI	B31	0	0	0	0	0	0	0	0	1	1		NM	B46	0	1	0	0	0	0	1	0	1	0
AI	B34	1	1	1	0	1	1	0	0	1	1		NM	B54	0	0	0	0	0	1	0	0	1	0
AI	B35	0	0	0	0	0	1	0	0	1	1		NM	B59	0	1	0	1	0	0	0	0	1	0
AI	B38	1	1	0	0	0	1	0	0	1	1		NM	B63	0	1	1	0	0	0	0	0	1	0
AI	B41	0	1	0	1	0	0	0	0	1	1		NM	B66	0	1	0	0	0	1	0	0	1	0
AI	B43	0	0	0	0	0	1	0	0	1	1		NM	C08	0	0	0	0	0	1	0	1	0	0
AI	B47	1	1	1	1	0	1	0	0	1	1		PI	A07	0	1	0	0	0	1	1	0	0	0
AI	B48	0	0	0	0	0	0	0	0	1	1		PI	A19	0	0	0	0	0	0	0	0	0	0
AI	B49	0	0	0	0	0	0	0	0	1	1		PI	A23	0	1	0	0	0	0	1	0	0	0
AI	B50	0	1	1	0	0	1	0	0	1	1		PI	A24	0	0	0	0	0	0	0	0	0	0
AI	B51	0	1	0	0	0	1	0	0	1	1		PI	B12	0	1	1	0	0	0	0	0	1	0
AI	B52	1	1	1	0	0	0	0	0	1	1		PI	B14	0	0	0	0	0	1	0	0	1	0
AI	B55	0	0	0	0	0	1	0	0	1	1		PI	B17	0	0	1	0	0	0	0	0	1	0
AI	B56	0	0	0	0	0	1	0	0	1	1		PI	B21	0	1	1	0	0	0	0	0	1	0
AI	B58	0	0	0	0	0	0	0	0	1	1		PI	B22	0	0	0	0	0	1	1	0	1	0
AI	B61	0	0	0	1	0	1	0	0	1	1		PI	B25	0	0	0	0	0	0	1	0	1	0
AI	B65	0	0	0	0	0	1	0	0	1	1		PI	B26	0	0	0	0	0	1	1	0	1	0
AI	B67	0	0	0	0	0	0	0	0	1	1		PI	B33	0	1	0	0	0	0	0	0	1	0
AI	C01	0	0	0	0	0	1	0	1	0	1		PI	B36	0	0	0	0	0	0	1	0	1	0
AI	C02	0	1	0	1	0	1	0	1	0	1		PI	B37	0	0	0	0	0	1	1	0	1	0
AI	C03	0	0	0	0	0	1	0	1	0	1		PI	B42	0	0	0	0	0	0	0	0	1	0
AI	C04	1	1	1	0	0	1	1	1	0	1		PI	B53	0	1	0	0	0	0	0	0	1	0
AI	C05	0	0	0	0	0	1	0	1	0	1		PI	B57	0	0	0	0	0	0	1	0	1	0
AI	C06	0	0	0	0	0	0	0	1	0	1		PI	B60	0	0	0	0	0	0	1	0	1	0
AI	C07	0	1	1	0	0	1	0	1	0	1		PI	B62	0	0	0	0	0	0	1	0	1	0
AI	C09	0	1	1	0	1	1	0	1	0	1		PI	B64	0	1	0	0	0	0	0	0	1	0
AI	C11	0	0	0	0	1	1	0	1	0	1		PI	B68	1	1	0	0	0	0	1	0	1	0
AI	C12	0	0	0	1	0	0	0	1	0	1		PI	B69	1	1	0	0	0	0	1	0	1	0
AI	C13	0	1	0	0	0	1	0	1	0	1		PI	C10	1	1	0	0	0	0	0	1	0	0
AI	C15	0	0	0	0	0	0	0	1	0	1		PI	C14	0	0	0	0	0	0	0	1	0	0
AI	C16	0	0	0	0	0	1	0	1	0	1													

Table 6-11 QCA Input Data for Near Miss Cases

	CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	NM			CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	NM
AI	A01	0	0	0	0	0	1	0	0	0	0		NM	A06	0	0	0	0	0	0	0	0	0	1
AI	A02	0	1	0	0	0	0	0	0	0	0		NM	A09	1	1	0	1	0	0	0	0	0	1
AI	A03	0	0	0	0	0	0	0	0	0	0		NM	A14	0	1	0	0	0	1	0	0	0	1
AI	A04	0	0	0	0	0	0	0	0	0	0		NM	A20	0	0	0	0	0	0	0	0	0	1
AI	A05	0	1	1	0	1	0	0	0	0	0		NM	A21	0	1	1	0	0	0	0	0	0	1
AI	A08	0	0	0	0	0	1	0	0	0	0		NM	A22	0	0	0	0	0	1	0	0	0	1
AI	A10	1	1	1	0	0	0	0	0	0	0		NM	A28	0	0	0	0	0	1	0	0	0	1
AI	A11	0	1	1	1	0	0	0	0	0	0		NM	A29	0	0	0	0	0	0	1	0	0	1
AI	A12	1	1	0	1	0	0	0	0	0	0		NM	A32	0	0	0	0	0	1	0	0	0	1
AI	A13	0	0	1	0	0	1	0	0	0	0		NM	B01	0	0	0	0	0	1	0	0	1	1
AI	A15	0	0	0	0	0	0	0	0	0	0		NM	B02	0	1	1	0	0	0	0	0	1	1
AI	A16	0	1	0	1	0	0	0	0	0	0		NM	B03	0	0	0	0	0	0	0	0	1	1
AI	A17	0	0	0	0	0	0	0	0	0	0		NM	B04	0	1	0	0	0	0	0	0	1	1
AI	A18	0	0	0	0	0	0	0	0	0	0		NM	B05	0	1	0	0	0	1	0	0	1	1
AI	A25	0	1	0	0	0	0	0	0	0	0		NM	B06	0	0	0	1	0	0	0	0	1	1
AI	A26	0	1	0	0	0	0	0	0	0	0		NM	B07	0	0	1	1	0	1	1	0	1	1
AI	A27	0	0	1	0	1	1	0	0	0	0		NM	B08	0	1	0	0	0	1	0	0	1	1
AI	A30	0	0	0	0	0	0	0	0	0	0		NM	B09	0	0	0	0	0	1	0	0	1	1
AI	A31	0	1	1	0	0	0	0	0	0	0		NM	B18	0	0	0	0	0	0	0	0	1	1
AI	B10	0	1	0	0	0	0	0	0	1	0		NM	B20	0	0	0	0	0	0	0	0	1	1
AI	B11	1	1	1	0	1	1	0	0	1	0		NM	B23	0	0	0	0	0	1	0	0	1	1
AI	B13	0	0	0	0	1	1	0	0	1	0		NM	B24	0	0	0	0	0	1	0	0	1	1
AI	B15	0	0	1	0	1	1	0	0	1	0		NM	B29	0	0	0	0	0	0	0	0	1	1
AI	B16	0	0	0	0	0	0	0	0	1	0		NM	B32	0	0	0	0	0	1	0	0	1	1
AI	B19	0	1	1	0	0	1	0	0	1	0		NM	B39	0	0	0	0	1	1	0	0	1	1
AI	B27	0	1	1	0	0	1	0	0	1	0		NM	B40	0	1	0	1	0	1	0	0	1	1
AI	B28	0	1	0	0	0	1	0	0	1	0		NM	B44	0	1	0	0	0	1	0	0	1	1
AI	B30	0	1	0	0	0	1	0	0	1	0		NM	B45	0	1	0	1	1	0	0	0	1	1
AI	B31	0	0	0	0	0	0	0	0	1	0		NM	B46	0	1	0	0	0	0	1	0	1	1
AI	B34	1	1	1	0	1	1	0	0	1	0		NM	B54	0	0	0	0	0	1	0	0	1	1
AI	B35	0	0	0	0	0	1	0	0	1	0		NM	B59	0	1	0	1	0	0	0	0	1	1
AI	B38	1	1	0	0	0	1	0	0	1	0		NM	B63	0	1	1	0	0	0	0	0	1	1
AI	B41	0	1	0	1	0	0	0	0	1	0		NM	B66	0	1	0	0	0	1	0	0	1	1
AI	B43	0	0	0	0	0	1	0	0	1	0		NM	C08	0	0	0	0	0	1	0	1	0	1
AI	B47	1	1	1	1	0	1	0	0	1	0		PI	A07	0	1	0	0	0	1	1	0	0	0
AI	B48	0	0	0	0	0	0	0	0	1	0		PI	A19	0	0	0	0	0	0	0	0	0	0
AI	B49	0	0	0	0	0	0	0	0	1	0		PI	A23	0	1	0	0	0	0	1	0	0	0
AI	B50	0	1	1	0	0	1	0	0	1	0		PI	A24	0	0	0	0	0	0	0	0	0	0
AI	B51	0	1	0	0	0	1	0	0	1	0		PI	B12	0	1	1	0	0	0	0	0	1	0
AI	B52	1	1	1	0	0	0	0	0	1	0		PI	B14	0	0	0	0	0	1	0	0	1	0
AI	B55	0	0	0	0	0	1	0	0	1	0		PI	B17	0	0	1	0	0	0	0	0	1	0
AI	B56	0	0	0	0	0	1	0	0	1	0		PI	B21	0	1	1	0	0	0	0	0	1	0
AI	B58	0	0	0	0	0	0	0	0	1	0		PI	B22	0	0	0	0	0	1	1	0	1	0
AI	B61	0	0	0	1	0	1	0	0	1	0		PI	B25	0	0	0	0	0	0	1	0	1	0
AI	B65	0	0	0	0	0	1	0	0	1	0		PI	B26	0	0	0	0	0	1	1	0	1	0
AI	B67	0	0	0	0	0	0	0	0	1	0		PI	B33	0	1	0	0	0	0	0	0	1	0
AI	C01	0	0	0	0	0	1	0	1	0	0		PI	B36	0	0	0	0	0	0	1	0	1	0
AI	C02	0	1	0	1	0	1	0	1	0	0		PI	B37	0	0	0	0	0	1	1	0	1	0
AI	C03	0	0	0	0	0	1	0	1	0	0		PI	B42	0	0	0	0	0	0	0	0	1	0
AI	C04	1	1	1	0	0	1	1	1	0	0		PI	B53	0	1	0	0	0	0	0	0	1	0
AI	C05	0	0	0	0	0	1	0	1	0	0		PI	B57	0	0	0	0	0	0	1	0	1	0
AI	C06	0	0	0	0	0	0	0	1	0	0		PI	B60	0	0	0	0	0	0	1	0	1	0
AI	C07	0	1	1	0	0	1	0	1	0	0		PI	B62	0	0	0	0	0	0	1	0	1	0
AI	C09	0	1	1	0	1	1	0	1	0	0		PI	B64	0	1	0	0	0	0	0	0	1	0
AI	C11	0	0	0	0	1	1	0	1	0	0		PI	B68	1	1	0	0	0	0	1	0	1	0
AI	C12	0	0	0	1	0	0	0	1	0	0		PI	B69	1	1	0	0	0	0	1	0	1	0
AI	C13	0	1	0	0	0	1	0	1	0	0		PI	C10	1	1	0	0	0	0	0	1	0	0
AI	C15	0	0	0	0	0	0	0	1	0	0		PI	C14	0	0	0	0	0	0	0	1	0	0
AI	C16	0	0	0	0	0	1	0	1	0	0													

Table 6-12 QCA Input Data for Potential Incident Cases

	CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	PI			CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	PI
AI	A01	0	0	0	0	0	1	0	0	0	0		NM	A06	0	0	0	0	0	0	0	0	0	0
AI	A02	0	1	0	0	0	0	0	0	0	0		NM	A09	1	1	0	1	0	0	0	0	0	0
AI	A03	0	0	0	0	0	0	0	0	0	0		NM	A14	0	1	0	0	0	1	0	0	0	0
AI	A04	0	0	0	0	0	0	0	0	0	0		NM	A20	0	0	0	0	0	0	0	0	0	0
AI	A05	0	1	1	0	1	0	0	0	0	0		NM	A21	0	1	1	0	0	0	0	0	0	0
AI	A08	0	0	0	0	0	1	0	0	0	0		NM	A22	0	0	0	0	0	1	0	0	0	0
AI	A10	1	1	1	0	0	0	0	0	0	0		NM	A28	0	0	0	0	0	1	0	0	0	0
AI	A11	0	1	1	1	0	0	0	0	0	0		NM	A29	0	0	0	0	0	0	1	0	0	0
AI	A12	1	1	0	1	0	0	0	0	0	0		NM	A32	0	0	0	0	0	1	0	0	0	0
AI	A13	0	0	1	0	0	1	0	0	0	0		NM	B01	0	0	0	0	0	1	0	0	1	0
AI	A15	0	0	0	0	0	0	0	0	0	0		NM	B02	0	1	1	0	0	0	0	0	1	0
AI	A16	0	1	0	1	0	0	0	0	0	0		NM	B03	0	0	0	0	0	0	0	0	1	0
AI	A17	0	0	0	0	0	0	0	0	0	0		NM	B04	0	1	0	0	0	0	0	0	1	0
AI	A18	0	0	0	0	0	0	0	0	0	0		NM	B05	0	1	0	0	0	1	0	0	1	0
AI	A25	0	1	0	0	0	0	0	0	0	0		NM	B06	0	0	0	1	0	0	0	0	1	0
AI	A26	0	1	0	0	0	0	0	0	0	0		NM	B07	0	0	1	1	0	1	1	0	1	0
AI	A27	0	0	1	0	1	1	0	0	0	0		NM	B08	0	1	0	0	0	1	0	0	1	0
AI	A30	0	0	0	0	0	0	0	0	0	0		NM	B09	0	0	0	0	0	1	0	0	1	0
AI	A31	0	1	1	0	0	0	0	0	0	0		NM	B18	0	0	0	0	0	0	0	0	1	0
AI	B10	0	1	0	0	0	0	0	0	1	0		NM	B20	0	0	0	0	0	0	0	0	1	0
AI	B11	1	1	1	0	1	1	0	0	1	0		NM	B23	0	0	0	0	0	1	0	0	1	0
AI	B13	0	0	0	0	1	1	0	0	1	0		NM	B24	0	0	0	0	0	1	0	0	1	0
AI	B15	0	0	1	0	1	1	0	0	1	0		NM	B29	0	0	0	0	0	0	0	0	1	0
AI	B16	0	0	0	0	0	0	0	0	1	0		NM	B32	0	0	0	0	0	1	0	0	1	0
AI	B19	0	1	1	0	0	1	0	0	1	0		NM	B39	0	0	0	0	1	1	0	0	1	0
AI	B27	0	1	1	0	0	1	0	0	1	0		NM	B40	0	1	0	1	0	1	0	0	1	0
AI	B28	0	1	0	0	0	1	0	0	1	0		NM	B44	0	1	0	0	0	1	0	0	1	0
AI	B30	0	1	0	0	0	1	0	0	1	0		NM	B45	0	1	0	1	1	0	0	0	1	0
AI	B31	0	0	0	0	0	0	0	0	1	0		NM	B46	0	1	0	0	0	0	1	0	1	0
AI	B34	1	1	1	0	1	1	0	0	1	0		NM	B54	0	0	0	0	0	1	0	0	1	0
AI	B35	0	0	0	0	0	1	0	0	1	0		NM	B59	0	1	0	1	0	0	0	0	1	0
AI	B38	1	1	0	0	0	1	0	0	1	0		NM	B63	0	1	1	0	0	0	0	0	1	0
AI	B41	0	1	0	1	0	0	0	0	1	0		NM	B66	0	1	0	0	0	1	0	0	1	0
AI	B43	0	0	0	0	0	1	0	0	1	0		NM	C08	0	0	0	0	0	1	0	1	0	0
AI	B47	1	1	1	1	0	1	0	0	1	0		PI	A07	0	1	0	0	0	1	1	0	0	1
AI	B48	0	0	0	0	0	0	0	0	1	0		PI	A19	0	0	0	0	0	0	0	0	0	1
AI	B49	0	0	0	0	0	0	0	0	1	0		PI	A23	0	1	0	0	0	0	1	0	0	1
AI	B50	0	1	1	0	0	1	0	0	1	0		PI	A24	0	0	0	0	0	0	0	0	0	1
AI	B51	0	1	0	0	0	1	0	0	1	0		PI	B12	0	1	1	0	0	0	0	0	1	1
AI	B52	1	1	1	0	0	0	0	0	1	0		PI	B14	0	0	0	0	0	1	0	0	1	1
AI	B55	0	0	0	0	0	1	0	0	1	0		PI	B17	0	0	1	0	0	0	0	0	1	1
AI	B56	0	0	0	0	0	1	0	0	1	0		PI	B21	0	1	1	0	0	0	0	0	1	1
AI	B58	0	0	0	0	0	0	0	0	1	0		PI	B22	0	0	0	0	0	1	1	0	1	1
AI	B61	0	0	0	1	0	1	0	0	1	0		PI	B25	0	0	0	0	0	0	1	0	1	1
AI	B65	0	0	0	0	0	1	0	0	1	0		PI	B26	0	0	0	0	0	1	1	0	1	1
AI	B67	0	0	0	0	0	0	0	0	1	0		PI	B33	0	1	0	0	0	0	0	0	1	1
AI	C01	0	0	0	0	0	1	0	1	0	0		PI	B36	0	0	0	0	0	0	1	0	1	1
AI	C02	0	1	0	1	0	1	0	1	0	0		PI	B37	0	0	0	0	0	1	1	0	1	1
AI	C03	0	0	0	0	0	1	0	1	0	0		PI	B42	0	0	0	0	0	0	0	0	1	1
AI	C04	1	1	1	0	0	1	1	1	0	0		PI	B53	0	1	0	0	0	0	0	0	1	1
AI	C05	0	0	0	0	0	1	0	1	0	0		PI	B57	0	0	0	0	0	0	1	0	1	1
AI	C06	0	0	0	0	0	0	0	1	0	0		PI	B60	0	0	0	0	0	0	1	0	1	1
AI	C07	0	1	1	0	0	1	0	1	0	0		PI	B62	0	0	0	0	0	0	1	0	1	1
AI	C09	0	1	1	0	1	1	0	1	0	0		PI	B64	0	1	0	0	0	0	0	0	1	1
AI	C11	0	0	0	0	1	1	0	1	0	0		PI	B68	1	1	0	0	0	0	1	0	1	1
AI	C12	0	0	0	1	0	0	0	1	0	0		PI	B69	1	1	0	0	0	0	1	0	1	1
AI	C13	0	1	0	0	0	1	0	1	0	0		PI	C10	1	1	0	0	0	0	0	1	0	1
AI	C15	0	0	0	0	0	0	0	1	0	0		PI	C14	0	0	0	0	0	0	0	1	0	1
AI	C16	0	0	0	0	0	1	0	1	0	0													

The results output from the *QCA Add-In* software (typical for any QCA software) is in three parts, firstly a 'Truth Table' which shows all the logically possible combinations of factors for the outcome, listing the cases that fit each combination; secondly a list of the 'prime implicants', the combinations of factors that are calculated using Boolean minimisation to be sufficient for the specified outcome, that is, omitting redundant factors; and thirdly, 'solutions' which are complete statements of the prime implicants that are necessary and sufficient for the outcome that remain after a second step of Boolean minimisation to eliminate redundant prime implicants.

The prime implicants and the solutions are stated in Boolean notation: a ***** sign means AND, the **+** sign means OR, and the presence of a factor is indicated by it being written in **CAPITALS** and the absence by it being written in **lower case**. For example, A*B +B*c means A AND B OR B and NOT C are sufficient, which in ordinary language means that either Factor A and Factor B are sufficient, or Factor B without the factor C are sufficient.

The results of the calculations performed by the *QCA Add-In* software are given in the **Results** section **6.4.2.**

6.4 Results

6.4.1 Results of analysing the incident documents

Table 6-13 Site A Illustrative Quotes from Incident Documents

CAUSAL FACTORS	(Key: grey shading indicates 'Adaptive' / unshaded indicates 'Administrative'
Over-Directive Adaptive Leadership	Lack of Empowerment & Ownership
Non-Technical Skills	Over confidence because of this job was carried out several time in past.
Organizational Learning	This was a repeat incident, The previous investigation of a small acid leak at the same location did not identify the correct root cause, therefore the weak signal was not followed through.
Supportive Culture (+)	Field operator vigilant observation identifies this fire very early stage and put off immediately. There was no visual seal leak during the incident
Over-Directive Admin Leadership	Time pressure resulted in Area 1 mech supervisor executing the work himself instead of searching for different support personnel
Compliance	Coordinator and System Owner left the work location and supervision of Operation Support personnel was left to Area 1 mech execution lead
Emergency Response	None
Equipment or System Design	pump was installed and operated with insufficient discharge line support. Pulsating action combined with insufficient support led to line stress and loosened bolts on discharge flange.
Hazard and Risk Management	Personnel involved in this incident failed to identify dissolved H2S in sour water as a hazard
Inspection & Testing	The motor has been installed at site and power cable has been terminated at motor end without verifying the winding connection for 690V supply voltage.
Planning & Resourcing	Requirement for permit not identified as part of [Engineering] spading plan
Procedures	Method statement and JSA (Job Safety Analysis) lacking appropriate work method detail and associated hazard controls.
RECOMMENDATIONS	
Adaptive Leadership	Appreciation to be given to the Area 1 FO (Field Operator)
Non-Technical Skills	Any sudden change in Flow other than normal to be communicated by [Plant] PO to [Facilities] PO (Panel Operators)
Organizational Learning	Share Investigation results with other areas to create awareness where XYZ pumps or temporary equipment is used.
Admin Leadership	Safety stand down conducted to communicate incident
Compliance	Assign a PPE focal point as per the PPE Procedure, and complete an audit and feedback regarding the use and effectiveness of various PPE
Emergency Response	None
Equipment or System Design	Design and install permanent heat tracing for the external balance line at first opportunity
Hazard and Risk Management	Operations personnel involved in this incident to develop a safety briefing highlighting exactly what went wrong and the potential consequences
Inspection & Testing	Trace material certificates of valve stem to check for sub-standard part
Planning & Resourcing	Maintenance team to review current JHA with update to include hazard of xxx services.
Procedures	add new step in maintenance procedure: to stroke test valves in the field after installation to confirm actuator is moving freely

Table 6-14 Site B Illustrative Quotes from Incident Documents

CAUSAL FACTORS	(Key: grey shading indicates 'Adaptive' / unshaded indicates 'Administrative'
Over-Directive Adaptive Leadership	None
Non-Technical Skills	Risk identified during turn around, partial isolation applied by one shift though removed by the following shift due to confusion of the intention of the isolation & believing it was not required
Organizational Learning	Of significant concern is that as there has been at least three similar incidents have occurred at [Site B] in the past five years, it is clear that with regard to this issue that organisation learning has not happened
Supportive Culture (+)	During De-Isolation of a 690Vac Switchboard, the High Voltage Switching Team identified that HV Transformer Bus Isolations were applied incorrectly
Over-Directive Admin Leadership	more focussed with production / cost saving initiatives than asset integrity. Concern was explicitly voiced that these fires are continually occurring.
Compliance	The Isolation Authority did not cross-check with P&ID to identify the correct vessel.
Emergency Response	Delay in mobilising ERT to incident.
Equipment or System Design	The relief valves are undersized for the blocked outlet case at warm starting conditions
Hazard and Risk Management	No clear MOC process was followed that permitted a deviation from the original design specification with respect to particulate service…
Inspection & Testing	The third-party inspection was ineffective in identifying manufacturing defects.
Planning & Resourcing	Additional training / experience with the TEG Pump skid would have prevented the error
Procedures	The Work Instruction assigned to the job added limited value and more importantly did not relate the critical components of the work scope
RECOMMENDATIONS	
Adaptive Leadership	None
Non-Technical Skills	staff to avoid (perception of) informal instruction and multiple accountable persons
Organizational Learning	Review PSV dossier for all other similar PSV on other facilities to determine if there is any evidence of an installed failure
Admin Leadership	In light of lessons learnt from incident, senior management team to address shutdown safety village to provide message on the importance of safety above all else
Compliance	Review expectations and roles of performing authorities in relation to performing and supervising work.
Emergency Response	Establish clear expectation about the required wellsite emergency response by staff in case of gas release at wellsite.
Equipment or System Design	Revise interlock logic sequencing of XV-1234 to ensure that secondary interlock activates regardless of whether XV-1234 finishes closing
Hazard and Risk Management	Develop communication to staff to clarify use of electrical and non-intrinsically safe equipment inside the plant.
Inspection & Testing	Implement revised Maintenance strategy to overhauls of drive head motors and ensure associated QA/QC & testing meets strategy requirements
Planning & Resourcing	Develop and implement a skills maintenance program for all activities. Reinforce proper operations practices via recurring training program.
Procedures	New procedure to facilitate the depressurizing of the Piping ex. the discharge XV's to fin fan rack after N2 purging of the respective compressors

Table 6-15 Site C Illustrative Quotes from Incident Documents

CAUSAL FACTORS	(Key: grey shading indicates 'Adaptive' / unshaded indicates 'Administrative'
Over-Directive Adaptive Leadership	None
Non-Technical Skills	The 'organizational memory' had a negative impact this time, since the assumption that one of the instruments did not work due to methanol in the mixture. 'Organizational memory' determined the opening earlier, since the operators might want to avoid overfilling the separator, as it happened during start-up after SD 2009
Organizational Learning	Knowledge of similar incidents was not sufficiently taken into account in planning process.
Supportive Culture (+)	The functional barrier preventing the electrocution was the earthing protection… that functioned as designed to disconnect the cable from the power supply
Over-Directive Admin Leadership	Operator stressed to complete job within the night shift and stressed by weather conditions (heavy rains, papers wet), which caused the decision to break the isolation plan
Compliance	Several isolations plans set in the same area created confusion and conflicts
Emergency Response	Emergency Coordinator did not log manually the communication (to XXX) / decisions / actions
Equipment or System Design	The current design of switchboard cabinets gives false sense of security with only one isolation device in the cabinet having two energy sources.
Hazard and Risk Management	Routine operations suffer underestimation of associated risks
Inspection & Testing	failed to identify the wiring error at different stages (this is one of the underlying causes for the incident). (12 months before)
Planning & Resourcing	Planning process did not involve all relevant parties (subsea, environment and operation).
Procedures	Insufficient warnings in field/drawings to alert users to hazard of trapped pressure
RECOMMENDATIONS	
Adaptive Culture or Leadership	Update the Duty Manager responsibilities to include ensuring that all persons involved in an incident have been spoken to by their line manager and have received appropriate support.
Non-Technical Skills	To avoid future similar incidents Projects /Asset to share practices between Platform and Onshore plant and possibly agree one leading practice
Organizational Learning	Giving a problem statement, a solution or an action will probably not shift your belief. Giving you insights and understanding on what caused the problem will.
Admin Culture or Leadership	Stand-down with all shifts. Emphasize respect for isolation plans: set isolation plans shall not be broken for any reason.
Compliance	A matrix on the difference between normal operation functions and the SD functions regarding roles and responsibilities should be implemented.
Emergency Response	Conduct a separate review of the emergency response activities carried out after the incident
Equipment or System Design	CCTV surveillance inside the hood against leak critical components and areas in turbine must be prioritized and put into action
Hazard and Risk Management	Communicate to all relevant parties the incident learnings and how to work safely on live systems with compression fittings.
Inspection & Testing	Good practice is to double check all links when one considers the job as done, preferably by one colleague if you work more together
Planning & Resourcing	The matrix for start-up should be reviewed.
Procedures	Update current PTW procedure to clarify roles and responsibilities for small repairs activities on the handed over equipment

Table 6-16 Summary Results of Incident Documents Coding – Causal Factors

Data from Incident Documents	**Unique frequency of code per incident**												
Codes	**Normalised by Incident**			**Normalised by Site**			**Totals for Theoretical Categories**						
								Incident			**Site**		
CAUSAL FACTORS	**AI**	**NM**	**PI**	**A**	**B**	**C**		**AI**	**NM**	**PI**	**A**	**B**	**C**
Adaptive													
Lack of empowerment	**1**			**2**			**Over-Directive Adaptive Leadership**	**1**			**2**		
Inadequate mindfulness and vigilance	**2**	**3**	**1**	**6**	**3**	**4**	**Non-Technical Skills**	**6**	**10**	**3**	**13**	**13**	**12**
Ineffective communication	**2**	**4**	**1**	**4**	**6**	**4**							
Lack or loss of Situation Awareness	**1**	**2**			**3**	**4**							
Risk normalization	**1**	**1**		**2**	**1**								
Inadequate checking for wider implications		**1**			**1**		**Organizational Learning**	**5**	**2**		**4**	**6**	
Lack of implementation of LFI actions	**5**	**1**		**4**	**5**	**9**							
+ Effective vigilance		1	4	4	2		**Supportive Culture (+)**	1	3	21	6	15	4
+ Potential Incident investigation		1	17	2	12								
+ Effective system design detecting pot. incident	1	1			1	4							
							TOTAL ADAPTIVE	**12**	**15**	**24**	**26**	**34**	**50**
Administrative													
Blame culture	**2**		**1**	**4**	**2**		**Over-Directive Administrative Leadership**	**6**	**1**	**4**	**11**	**8**	**9**
Production pressure	**5**	**1**	**3**	**6**	**6**	**9**							
Distractions or other error-enforcing conditions	**2**		**1**	**4**		**13**	**Compliance**	**11**	**11**	**10**	**26**	**18**	**25**
Inadequate supervision, checking or monitoring	**4**	**5**	**7**	**17**	**8**	**4**							
Operation outside design envelope	**1**	**2**		**2**	**2**								
Reckless non-compliance	**1**			**2**									
Unclear responsibilities	**2**	**2**	**1**		**5**	**4**							
Well-meaning improvisation without full risk awareness	**2**	**2**			**3**	**4**							
Inadequate emergency response	**2**				**2**	**4**	**Emergency Response**	**2**				**2**	**4**
Inadequate equipment or system design	**13**	**14**	**1**	**6**	**27**	**35**	**Equipment or System Design**	**13**	**14**	**1**	**6**	**27**	**35**
Inadequate communication of risk information	**3**	**2**	**1**	**6**	**6**		**Hazard and Risk Management**	**18**	**8**	**6**	**28**	**26**	**27**
Inadequate hazard identification	**7**	**1**		**11**	**6**	**9**							
Inadequate Management of Change	**2**	**2**	**3**	**2**	**7**								
Inadequate risk awareness or assessment	**3**	**3**	**1**	**2**	**6**	**9**							
Inadequate risk management controls	**3**			**6**	**1**	**9**							
Inadequate construction QC	**1**	**2**	**4**	**2**	**6**	**4**	**Inspection & Testing**	**10**	**7**	**9**	**17**	**19**	**21**
Inadequate maintenance, inspection or testing	**9**	**5**	**4**	**15**	**13**	**17**							
Inadequate job planning	**3**	**3**	**6**	**9**	**5**	**13**	**Planning & Resourcing**	**10**	**6**	**7**	**11**	**16**	**30**
Inadequate resourcing	**2**	**1**			**3**	**4**							
Inadequate technical competence & training	**5**	**2**	**1**	**2**	**8**	**13**							
Inadequate procedures	**7**	**8**	**10**	**13**	**21**	**4**	**Procedures**	**7**	**8**	**10**	**13**	**21**	**4**
							TOTAL ADMINISTR.	**77**	**55**	**47**	**112**	**137**	**155**
	AI	**NM**	**PI**	**A**	**B**	**C**							
Total number of incidents	**59**	**34**	**24**	**32**	**69**	**16**							

Table 6-17 Summary Results of Incident Documents Coding – Recommendations

Data from Incident Documents	Unique frequency of code per incident												
Codes	Normalised by Incident			Normalised by Site			Totals for Theoretical Categories	Incident			SITE		
RECOMMENDATIONS	AI	NM	PI	A	B	C		AI	NM	PI	A	B	C
Adaptive													
Recognise or give appreciation of good work			1	2			Adaptive Leadership	1		1	2		4
Support people involved in incidents	1					4							
Improve communication	1	1		4	1		Non-Technical Skills	3	2	1	9	2	9
Improve reflective mindfulness	1	1		2	1								
improve teamwork	1		1			9							
Undergo behavioural safety training	1			2									
Explore wider learning implications	3	7	3	6	9	13	Organizational Learning	9	7	10	9	16	52
Improve implementing of learning into practice	2		3	2	3	4							
Improve Learning From Incidents communication	2		1		3	9							
Improve routine learning from practice	1					4							
Reflective incident review	2		3		1	22							
							TOTAL ADAPTIVE	12	9	13	19	18	65
Administrative													
Decisive action for safety			1		1		Administrative Leadership	2	1	3	4	3	4
Reinforce safety priority	2	1	1	4	2	4							
Clarify roles & responsibilities	3	2	9	4	8	17	Compliance	6	4	13	6	14	30
Improve supervision, checking or monitoring	3	2	4	2	6	13							
Review or improve Emergency Response	3				4	9	Emergency Response	3				4	9
Improve equipment or system design	8	10	4	9	19	17	Equipment or System Design	14	22	7	11	42	21
Review engineering design	6	12	3	2	23	4							
Improve communication of risk information	4		7	2	8	13	Hazard and Risk Management	9	3	9	4	18	17
Improve hazard identification and risk assessment	2	2			4	4							
Review risk management studies	3	1	1	2	6								
Improve maintenance, inspection or testing	9	3	6	15	12	13	Inspection & Testing	9	3	6	15	12	13
Improve technical competence & training	5	6	9	6	16	9	Planning & Resourcing	12	8	12	15	20	44
Review or improve work planning	5	1	3	9	1	26							
Review technical resources	2	1			3	9							
Improve procedures or other tech documents	10	7	18	24	23	13	Procedures	15	12	20	33	30	26
Review procedures or other tech documents	5	5	1	9	7	13							
							TOTAL ADMINISTR.	69	53	68	89	143	164
	AI	NM	PI	A	B	C							
Total number of incidents	59	34	24	32	69	16							

The left-hand side of **Table 6-16** and **Table 6-17** lists, respectively, the unique frequencies of first order Causal Factors and Recommendations identified in the documents, analysed by type of incident and by site. These are then grouped on the right-hand side of these tables into the second-order 'Theoretical Categories'. The relative importance of these categories is shown by the 'Totals for Theoretical Categories' figures, which are the totals of the normalised unique frequencies of the constituent codes of each category, analysed by incident type and site.

An immediate observation can be made that in the incident documents both the causal factors identified and the recommendations made were mainly administrative in nature, for all three sites and for all three incident types. This is borne out by the illustrative quotes from the incident documents shown in **Tables 6-13, 6-14** and **6-15**. For example, *Inadequate Procedures* was a very frequent causal factor identified in incident documents at both Site A: 'Method statement and JSA (Job Safety Analysis) lacking appropriate work method detail and associated hazard controls' and Site B: 'The Work Instruction assigned to the job added limited value and more importantly did not relate the critical components of the work scope', and many recommendations were to improve procedures: 'add new step in maintenance procedure: to stroke test valves in the field after installation to confirm actuator is moving freely' (Site A report) and 'New procedure to facilitate the depressurizing of the Piping ex. the discharge XV's to fin fan rack after N2 purging of the respective compressors are completed' (Site B report). *Production pressure* occurred as a frequent causal factor in reports from all three sites in statements such as 'Time pressure resulted in Area 1 mech supervisor executing the work himself instead of searching for different support personnel' (Site A report) 'more focussed with production / cost saving initiatives than asset integrity. Concern was explicitly voiced that these fires are continually occurring' (Site B report) and 'Operator stressed to complete job within the night shift and stressed by weather conditions (heavy rains, papers wet), which caused the decision to break the isolation plan' (Site C report).

A closer examination, though, reveals that a greater proportion of adaptive casual factors were identified for potential incidents (over a third) than for either actual incidents or near misses (both less than a fifth). For example: 'Field operator vigilant observation identifies this fire very early stage and put off immediately. There was no visual seal leak during the incident' (Site A report) and 'During De-Isolation of a 690Vac Switchboard, the High Voltage Switching Team identified that HV Transformer Bus Isolations were applied incorrectly' (Site B report) and 'The functional barrier preventing the electrocution was the earthing protection… that functioned as designed to disconnect the cable from the power supply (Site C report).

A similar pattern can be seen comparing sites: Site C documents identified a greater proportion of adaptive causal factors (approximately a quarter) than either Site A or Site B (both around a fifth). A slightly different pattern is seen for the recommendations: only minor variation in the proportion of adaptive recommendations is seen across incident types, but across the sites more differences can be seen: Sites A less than a fifth of recommendations were adaptive, Site B just over 10%, while almost a third of the recommendations made at Site C were adaptive in nature. For example: 'To avoid future similar incidents Projects /Asset to share practices between Platform and Onshore plant and possibly agree one leading practice' and 'Giving a problem statement, a solution or an action will probably not shift your belief. Giving you insights and understanding on what caused the problem will' (both quotes from Site C reports).

Looking in more detail at the frequency of occurrence of the individual categories of factors, there is no discernible pattern with causal factors when comparing the totals of normalised unique frequencies for the theoretical categories. However, the same comparison for recommendations does reveal a pattern, that Site C made more recommendations than either Site A or Site B in the categories of 'Organizational Learning' (between 3 and 5 times as many), 'Compliance' (between 2 and 5 times as many) and 'Planning & Resourcing' (between 2 and 3 times as many). These cross-site comparisons are interesting since Site C had a perceived safety performance better than the other sites.

6.4.2 Results of the QCA

The output from the QCA is given in **Tables 6-18, 6-19 and 6-20.**

Table 6-18 is the result of the QCA performed with the outcome set to 1 for all the Actual Incidents and 0 for all the Near Misses and Potential Incidents. The top part of the table is the Truth Table. Contradictory cases have been removed, leaving 21 rows, some of which represent more than one case, indicating that these cases are identical.

Table 6-18 Output from QCA - Results for Actual Incidents

AI=1 NM = 0 AND PI=0 CONTRADICTORY CASES REMOVED

CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	AI
C11	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**1**
C12	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**
B61	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**
A13	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**
A27	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**1**
B15	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**
A02, A25, A26	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
C13	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**1**
A16	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**
C02	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
B19, B27, B50	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**1**
C07	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**1**
A05	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**
C09	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**1**
A11	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**
B38	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**
A10	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
B52	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
C04	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**1**
B11, B34	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**
B47	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**
A29	0	0	0	0	0	0	1	0	0	0
B25, B36, B57, B60, B62	0	0	0	0	0	0	1	0	1	0
B22, B26, B37	0	0	0	0	0	1	1	0	1	0
B06	0	0	0	1	0	0	0	0	1	0
B17	0	0	1	0	0	0	0	0	1	0
B07	0	0	1	1	0	1	1	0	1	0
A23	0	1	0	0	0	0	1	0	0	0
B46	0	1	0	0	0	0	1	0	1	0
A14	0	1	0	0	0	1	0	0	0	0
A07	0	1	0	0	0	1	1	0	0	0
B40	0	1	0	1	0	1	0	0	1	0
B45	0	1	0	1	1	0	0	0	1	0
B02, B63, B12, B21	0	1	1	0	0	0	0	0	1	0
C10	1	1	0	0	0	0	0	1	0	0
B68, B69	1	1	0	0	0	0	1	0	1	0

Outcome: 1NO

#Implicants: 17

ovdirld*inadminprac*inhazriskman*innontech*INORGLEARN*INASSETINTEG*supcult*ADAPTLDPR*enabld	0	C11
ovdirld*inadminprac*inhazriskman*INNONTECH*inorglearn*inassetinteg*supcult*ADAPTLDPR*enabld	0	C12
ovdirld*inadminprac*inhazriskman*INNONTECH*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD	0	B61
ovdirld*INADMINPRAC*INHAZRISKMAN*innontech*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD	0	B19, B27, B50
ovdirld*INADMINPRAC*INHAZRISKMAN*innontech*INORGLEARN*inassetinteg*supcult*adaptldpr*enabld	0	A05
OVDIRLD*INADMINPRAC*inhazriskman*innontech*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD	0	B38
OVDIRLD*INADMINPRAC*INHAZRISKMAN*innontech*inorglearn*INASSETINTEG*SUPCULT*ADAPTLDPR*enabld	0	C04
OVDIRLD*INADMINPRAC*INHAZRISKMAN*innontech*INORGLEARN*INASSETINTEG*supcult*adaptldpr*ENABLD	0	B11, B34
OVDIRLD*INADMINPRAC*INHAZRISKMAN*INNONTECH*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD	0	B47
ovdirld*inadminprac*INHAZRISKMAN*innontech*INASSETINTEG*supcult*adaptldpr*enabld	0	A13, A27
ovdirld*inadminprac*INHAZRISKMAN*innontech*INORGLEARN*INASSETINTEG*supcult*adaptldpr	0	A27, B15
ovdirld*INADMINPRAC*inhazriskman*inorglearn*inassetinteg*supcult*adaptldpr*enabld	0	A02, A25, A26, A16
ovdirld*INADMINPRAC*innontech*inorglearn*INASSETINTEG*supcult*ADAPTLDPR*enabld	0	C13, C07
ovdirld*INADMINPRAC*inhazriskman*inorglearn*INASSETINTEG*supcult*ADAPTLDPR*enabld	0	C13, C02
ovdirld*INADMINPRAC*INNONTECH*inorglearn*inassetinteg*supcult*adaptldpr*enabld	0	A16, A11
ovdirld*INADMINPRAC*INHAZRISKMAN*innontech*INASSETINTEG*supcult*ADAPTLDPR*enabld	0	C07, C09
OVDIRLD*INADMINPRAC*INHAZRISKMAN*innontech*inorglearn*inassetinteg*supcult*adaptldpr	0	A10, B52

#Solutions: 1

ovdirld*inadminprac*inhazriskman*innontech*INORGLEARN*INASSETINTEG*supcult*ADAPTLDPR*enabld +
ovdirld*inadminprac*inhazriskman*INNONTECH*inorglearn*inassetinteg*supcult*ADAPTLDPR*enabld +
ovdirld*inadminprac*inhazriskman*INNONTECH*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD +
ovdirld*INADMINPRAC*INHAZRISKMAN*innontech*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD +
ovdirld*INADMINPRAC*INHAZRISKMAN*innontech*INORGLEARN*inassetinteg*supcult*adaptldpr*enabld +
OVDIRLD*INADMINPRAC*inhazriskman*innontech*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD +
OVDIRLD*INADMINPRAC*INHAZRISKMAN*innontech*inorglearn*INASSETINTEG*SUPCULT*ADAPTLDPR*enabld +
OVDIRLD*INADMINPRAC*INHAZRISKMAN*innontech*INORGLEARN*INASSETINTEG*supcult*adaptldpr*ENABLD +
OVDIRLD*INADMINPRAC*INHAZRISKMAN*INNONTECH*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD +
ovdirld*inadminprac*INHAZRISKMAN*innontech*INASSETINTEG*supcult*adaptldpr*enabld +
ovdirld*inadminprac*INHAZRISKMAN*innontech*INORGLEARN*INASSETINTEG*supcult*adaptldpr +
ovdirld*INADMINPRAC*inhazriskman*inorglearn*inassetinteg*supcult*adaptldpr*enabld +
ovdirld*INADMINPRAC*inhazriskman*inorglearn*INASSETINTEG*supcult*ADAPTLDPR*enabld +
ovdirld*INADMINPRAC*INNONTECH*inorglearn*inassetinteg*supcult*adaptldpr*enabld +
ovdirld*INADMINPRAC*INHAZRISKMAN*innontech*INASSETINTEG*supcult*ADAPTLDPR*enabld +
OVDIRLD*INADMINPRAC*INHAZRISKMAN*innontech*inorglearn*inassetinteg*supcult*adaptldpr

The next part of **Table 6-18** shows a list of implicants, minimum combinations of factors that imply the outcome, together with the cases to which these apply. For example, the implicant for Incident C11 is shown as

> **ovdirld*inadminprac*inhazriskman*innontech*INORGLEARN*INASSETINTEG *supcult*ADAPTLDPR*enabld**

This states that this combination or configuration of factors is one of the implicants for an Actual Incident. It can also be seen in the Truth Table that Case C11 shows the presence of INORGLEARN, INASSETINTEG and ADAPTLDPR but absence of all the other factors.

The interpretation of this is that for an Actual Incident to occur, it is sufficient for there to be inadequate organizational learning, inadequate asset integrity and also adaptive leadership practices present, with all the other factors absent. This is an intuitively puzzling result, and invites refinement of the 'causal model' that is described by case C11.

A total of 17 implicants are listed, indicating that after the first stage of Boolean minimisation the number of combinations of factors that imply the outcome has been reduced from the 21 rows in the Truth Table to 17 'prime implicants'.

At the bottom of the table there is a single solution given. This solution includes only 16 prime implicants. This means that one of the prime implicants was identified as redundant in the second stage of Boolean minimisation and has been removed. Inspecting the results reveals that the redundant prime implicant was:

> **ovdirld*INADMINPRAC*innontech*inorglearn*INASSETINTEG*supcult* ADAPTLDPR*enabld**

The + sign has meaning of 'OR' , so the solution states that any of the 16 prime implicants included is sufficient for an Actual Incident to occur.

The analytical value and practical use of this result is discussed in section **6.4 Discussion**

Table 6-19 Output from QCA - Results for Near Misses

NM=1 AI = 0 AND PI=0 CONTRADICTORY CASES REMOVED										
CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	NM
A29	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
B06	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**1**
B07	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**
B46	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**
A14	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**
B40	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**
B45	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**1**
C06, C15, C14	0	0	0	0	0	0	0	1	0	0
B25, B36, B57, B60, B62	0	0	0	0	0	0	1	0	1	0
B22, B26, B37	0	0	0	0	0	1	1	0	1	0
C11	0	0	0	0	1	1	0	1	0	0
C12	0	0	0	1	0	0	0	1	0	0
B61	0	0	0	1	0	1	0	0	1	0
B17	0	0	1	0	0	0	0	0	1	0
A13	0	0	1	0	0	1	0	0	0	0
A27	0	0	1	0	1	1	0	0	0	0
B15	0	0	1	0	1	1	0	0	1	0
A02, A25, A26	0	1	0	0	0	0	0	0	0	0
A23	0	1	0	0	0	0	1	0	0	0
C13	0	1	0	0	0	1	0	1	0	0
A07	0	1	0	0	0	1	1	0	0	0
A16	0	1	0	1	0	0	0	0	0	0
C02	0	1	0	1	0	1	0	1	0	0
B19, B27, B50	0	1	1	0	0	1	0	0	1	0
C07	0	1	1	0	0	1	0	1	0	0
A05	0	1	1	0	1	0	0	0	0	0
C09	0	1	1	0	1	1	0	1	0	0
A11	0	1	1	1	0	0	0	0	0	0
C10	1	1	0	0	0	0	0	1	0	0
B68, B69	1	1	0	0	0	0	1	0	1	0
B38	1	1	0	0	0	1	0	0	1	0
A10	1	1	1	0	0	0	0	0	0	0
B52	1	1	1	0	0	0	0	0	1	0
C04	1	1	1	0	0	1	1	1	0	0
B11, B34	1	1	1	0	1	1	0	0	1	0
B47	1	1	1	1	0	1	0	0	1	0
Outcome: 1NO										
# Implicants: 7										
ovdirld*inadminprac*inhazriskman*innontech*inorglearn*inassetinteg*SUPCULT*adaptldpr*enabld	0	A29								
ovdirld*inadminprac*inhazriskman*INNONTECH*inorglearn*inassetinteg*supcult*adaptldpr*ENABLD	0	B06								
ovdirld*inadminprac*INHAZRISKMAN*INNONTECH*inorglearn*INASSETINTEG*SUPCULT*adaptldpr*ENABLD	0	B07								
ovdirld*INADMINPRAC*inhazriskman*innontech*inorglearn*inassetinteg*SUPCULT*adaptldpr*ENABLD	0	B46								
ovdirld*INADMINPRAC*inhazriskman*innontech*inorglearn*INASSETINTEG*supcult*adaptldpr*enabld	0	A14								
ovdirld*INADMINPRAC*inhazriskman*INNONTECH*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD	0	B40								
ovdirld*INADMINPRAC*inhazriskman*INNONTECH*INORGLEARN*inassetinteg*supcult*adaptldpr*ENABLD	0	B45								
# Solutions: 1										
ovdirld*inadminprac*inhazriskman*innontech*inorglearn*inassetinteg*SUPCULT*adaptldpr*enabld + ovdirld*inadminprac*inhazriskman*INNONTECH*inorglearn*inassetinteg*supcult*adaptldpr*ENABLD + ovdirld*inadminprac*INHAZRISKMAN*INNONTECH*inorglearn*INASSETINTEG*SUPCULT*adaptldpr*ENABLD + ovdirld*INADMINPRAC*inhazriskman*innontech*inorglearn*inassetinteg*SUPCULT*adaptldpr*ENABLD + ovdirld*INADMINPRAC*inhazriskman*innontech*inorglearn*INASSETINTEG*supcult*adaptldpr*enabld + ovdirld*INADMINPRAC*inhazriskman*INNONTECH*inorglearn*INASSETINTEG*supcult*adaptldpr*ENABLD + ovdirld*INADMINPRAC*inhazriskman*INNONTECH*INORGLEARN*inassetinteg*supcult*adaptldpr*ENABLD										

Table 6-19 is the result of the QCA performed with the outcome set to 1 for all the Near Misses and 0 for all the Actual Incidents and Potential Incidents, once again with contradictory cases removed.

There is a shorter list of 7 prime implicants, the same as the number of rows in the Truth Table with outcome = 1. Again a single solution is given that this time includes all 7 prime implicants, indicating that no further Boolean minimisation was possible.

Table 6-20 is the result of the QCA performed with the outcome set to 1 for all the Potential Incidents and 0 for all the Actual Incidents and Near Misses, again with contradictory cases removed.

There are 7 rows in the Truth Table with outcome = 1, and 5 prime implicants, indicating that Boolean minimisation identified 2 redundant implicant combinations and removed them. The single solution contains all 5 prime implicants.

The analytical value and practical use of these results are discussed in section **6.4 Discussion**

Table 6-20 Output from QCA - Results for Potential Incidents

PI=1 AI = 0 AND NM=0 CONTRADICTORY CASES REMOVED										
CASE	OVDIRLD	INADMINPRAC	INHAZRISKMAN	INNONTECH	INORGLEARN	INASSETINTEG	SUPCULT	ADAPTLDPR	ENABLD	PI
B25, B36, B57, B60, B62	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**
B22, B26, B37	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**1**
B17	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
A23	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
A07	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**
C10	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**
B68, B69	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**
A29	0	0	0	0	0	0	1	0	0	0
A01, A08, A22, A28, A32	0	0	0	0	0	1	0	0	0	0
C01, C03, C05, C16, C08	0	0	0	0	0	1	0	1	0	0
B13, B39	0	0	0	0	1	1	0	0	1	0
C11	0	0	0	0	1	1	0	1	0	0
B06	0	0	0	1	0	0	0	0	1	0
C12	0	0	0	1	0	0	0	1	0	0
B61	0	0	0	1	0	1	0	0	1	0
A13	0	0	1	0	0	1	0	0	0	0
A27	0	0	1	0	1	1	0	0	0	0
B15	0	0	1	0	1	1	0	0	1	0
B07	0	0	1	1	0	1	1	0	1	0
A02, A25, A26	0	1	0	0	0	0	0	0	0	0
B46	0	1	0	0	0	0	1	0	1	0
A14	0	1	0	0	0	1	0	0	0	0
B28, B30, B51, B05, B08, B44, B66	0	1	0	0	0	1	0	0	1	0
C13	0	1	0	0	0	1	0	1	0	0
A16	0	1	0	1	0	0	0	0	0	0
B41, B59	0	1	0	1	0	0	0	0	1	0
B40	0	1	0	1	0	1	0	0	1	0
C02	0	1	0	1	0	1	0	1	0	0
B45	0	1	0	1	1	0	0	0	1	0
A31, A21	0	1	1	0	0	0	0	0	0	0
B19, B27, B50	0	1	1	0	0	1	0	0	1	0
C07	0	1	1	0	0	1	0	1	0	0
A05	0	1	1	0	1	0	0	0	0	0
C09	0	1	1	0	1	1	0	1	0	0
A11	0	1	1	1	0	0	0	0	0	0
B38	1	1	0	0	0	1	0	0	1	0
A12, A09	1	1	0	1	0	0	0	0	0	0
A10	1	1	1	0	0	0	0	0	0	0
B52	1	1	1	0	0	0	0	0	1	0
C04	1	1	1	0	0	1	1	1	0	0
B11, B34	1	1	1	0	1	1	0	0	1	0
B47	1	1	1	1	0	1	0	0	1	0
Outcome: 1NO										
#Implicants: 5										
ovdirld*inadminprac*INHAZRISKMAN*innontech*inorglearn*inassetinteg*supcult*adaptldpr*ENABLD	0	B17								
OVDIRLD*INADMINPRAC*inhazriskman*innontech*inorglearn*inassetinteg*supcult*ADAPTLDPR*enabld	0	C10								
OVDIRLD*INADMINPRAC*inhazriskman*innontech*inorglearn*inassetinteg*SUPCULT*adaptldpr*ENABLD	0	B68, B69								
ovdirld*inadminprac*inhazriskman*innontech*inorglearn*SUPCULT*adaptldpr*ENABLD	0	B25, B36, B57, B60, B62, B22, B26, B37								
ovdirld*INADMINPRAC*inhazriskman*innontech*inorglearn*SUPCULT*adaptldpr*enabld	0	A23, A07								
#Solutions: 1										
ovdirld*inadminprac*INHAZRISKMAN*innontech*inorglearn*inassetinteg*supcult*adaptldpr*ENABLD + OVDIRLD*INADMINPRAC*inhazriskman*innontech*inorglearn*inassetinteg*supcult*ADAPTLDPR*enabld + OVDIRLD*INADMINPRAC*inhazriskman*innontech*inorglearn*inassetinteg*SUPCULT*adaptldpr*ENABLD + ovdirld*inadminprac*inhazriskman*innontech*inorglearn*SUPCULT*adaptldpr*ENABLD + ovdirld*INADMINPRAC*inhazriskman*innontech*inorglearn*SUPCULT*adaptldpr*enabld										

6.5 Discussion

6.5.1 Analysis of the incident documents

This study has analysed investigation reports and other documents relating to 117 process safety incidents. The analysis was done in two ways: Firstly the documents were coded using a template that was developed iteratively in a combined grounded and theory-driven abductive manner to derive categories that enabled meaningful comparisons between investigations of different incident types and at the three different sites. Secondly, a QCA was performed comparing between the three incident types, based on a list of factors consolidated from those derived from the document coding analysis together with those derived from the results of the two earlier interview-based studies (**Chapters 4** and **5**). This was done simply as a demonstration of the QCA method.

There are four main findings that result from the analysis of the incident document coding: First, the documented causal factors and recommendations are predominantly administrative in nature. This aligns with the view that current incident investigations remain focused on proximate factors (Hulme et al., 2019) and the recognition that identifying underlying organizational factors is difficult (Braithwaite, 2010). It is also unsurprising given that current authoritative industry guidance from such bodies as the CCPS (2019) emphasises administrative factors.

Second, significantly more adaptive causal factors were identified for potential incidents than for actual incidents or near misses. This appears to indicate that adaptive processes are helpful in the identification of potential incidents, which aligns with theories of HRO and Safety II, in particular the HRO practice of 'strong response to weak signals' (Weick and Sutcliffe, 2001) and the vigilant cross-checking and teamwork focussed on catching errors observed by Roberts (1990).

Third, Site C identified a greater proportion of adaptive causal factors and recommendations than the other two sites, especially adaptive recommendations which at Site C represented almost a third of the recommendations made. Site C had the best perceived safety performance of the three sites, so this finding also supports HRO and Safety II theory that adaptive processes are important for safety (Hollnagel, 2014).

Fourth, although no other patterns were discernible, it was striking that Site C made many more recommendations than the other sites concerning 'Organizational Learning' (adaptive in nature) and 'Compliance' and 'Planning & Resourcing' (both of which are administrative in nature). Again put alongside Site C's perceived safety performance, this supports the proposition that it is the combination of administrative and adaptive processes that is important for the safety of high hazard technology.

6.5.2 The QCA demonstration

This study has attempted to demonstrate the potential of QCA for exploring and revealing the causal complexity of process safety incidents. Examining the results from the three QCA calculations performed using *QCA Add-In* software shows the kind of information that QCA can provide, and demonstrates the approach to analysing configurational causation.

The results for Actual Incidents show 17 prime implicants each of which includes all or most of the factors, in a confusion of combinations. The single solution shows great equifinality, stating 16 possible 'recipes' of these implicants for causing an Actual Incident. The results for Near Misses and Potential Incidents, although simpler, with fewer prime implicants, similarly do not yield useful information to explain important configurations of key factors that could explain differences of causation of the three incident types. Thus in immediately practical terms this demonstration is not of value.

Examining one prime implicant, such as the Actual Incident case of incident C11:

> **ovdirld*inadminprac*inhazriskman*innontech*INORGLEARN*INASSETINTEG *supcult*ADAPTLDPR*enabld**

This is intuitively a puzzling result, and invites refinement of the 'model' that is described by case C11. It is quite normal for a QCA to have contradictory and puzzling results. QCA is an iterative method, and results that cannot immediately be explained raise questions that can guide the researcher to a more accurate and realistic description of the cases under examination. (Rihoux and De Meur, 2009).

The information about the cases in this study, the 117 incidents, was obtained from mostly rather simple reports, and even though some were very detailed technically, extracting information from the coding with which to decide the dichotomised value of the consolidated factors was a tenuous process. Therefore gaining a more accurate and realistic description of the cases would be difficult.

For a QCA to yield useful information about the configurational causation of complex process safety incidents, more accurate, realistic knowledge of each case would be required. The crisp set QCA method may be too simple, so using fuzzy set QCA could also be a significant advantage. In either method, a realistic model of each case is necessary, and in this study this was lacking. It is accepted that 'coding decisions using this method require in-depth knowledge of each case, a constraint that QCA analysts openly admit and constantly seek to overcome through careful dialogue between theory and evidence. As such, coding decisions are not arbitrary but instead grounded in case expertise, which should increase rather than devalue their use for better knowledge' (Krook, 2010, p891)

This study has not yielded immediately useful results in the form of configurations of factors that explain causation, but it does demonstrate that the QCA method could be of value in improving understanding causation, both of actual process safety incidents and of incident precursors such as potential incidents.

The findings of a recent major review of chemical accident analysis 'suggest that routine accident analysis is in large part not identifying potential deficiencies associated with new and complex causes' (Wood, 2018, p395). And in another recent paper the argument is made 'for evaluation methods that estimate the prevalence of certain risk factors, for example, using patterns of causality' (Wood and Fabbri, 2019, p1).

These are exactly the kinds of problem that QCA is designed to address: 'The primary aim of QCA and fs/QCA consists in modelling the outcome to be explained as the result of different combinations of causal conditions' (Schneider and Grofman, 2006, p10). QCA is therefore potentially very appropriate for the analysis of causation in complex socio-technical systems. Although a qualitative method, QCA uses mathematical logic, so results are consistent and replicable. The method can be used to analyse any size of data set, which is very useful for 'small n' multiple case studies. An important assumption in QCA is that causation is context specific. Thus it does not seek to identify a single causal model that best fits the data, as is usual with statistical techniques, but instead to 'determine the number and character of the different causal models that exist among comparable cases' (Rihoux et al., 2009, p8).

This makes QCA of particular value to incident analysis since by addressing causal complexity it identifies combinations of factors that lead to outcomes such as actual or potential incidents, rather than seeking so-called 'root causes' that imply causation as simple 'linear cause-and effect'. Further, it identifies equifinality of outcomes, that is, several different configurations of factors that result in similar outcomes. And still further, its use of the logic of Boolean minimisation enables the identification of 'parsimonious' models, that is those that contain only necessary and sufficient combinations of factors, or indeed INUS conditions. This feature is potentially very useful for identifying 'difference-makers'.

6.5.3 Organizational learning

The predominantly administrative nature of the causal factors and recommendations appearing in the incident documents relating to all three sites and also the three different types of incident, indicates that the learning identified is largely limited to single loop learning, of the continuous improvement kind, aimed at identifying gaps in the implementation of safety management systems.

This is to be expected, since it aligns with current industry guidance: 'Typically, recommendations are written to prevent incident recurrence by: improving the process technology, upgrading the operating or maintenance procedures or practices, improving compliance with existing organizational systems (operational discipline); and upgrading the management systems, (often the most critical area)' (CCPS, 2019, p5). Such 'single-loop learning', what Lundberg, Rollenhagen and Hollnagel (2009, p1298) refer to as 'what you look for is what you find' limits opportunities for organizational learning, failing to 'challenge deep assumptions with rigorous and systemic thinking…', the aim of 'double loop learning' (Carroll, 2002 p124).

It is striking that Site C made many more recommendations than the other sites concerning 'Organizational Learning'. Two quotes from a Site C incident investigation report also illustrates intent towards organizational learning. Firstly: 'Giving a problem statement, a solution or an action will probably not shift your belief. Giving you insights and understanding on what caused the problem will.' This appears to be a direct reference to an intent towards the Argyris (1977) double loop learning approach. Secondly: 'The 'organizational memory' had a negative impact this time, since the assumption that one of the instruments did not work due to methanol in the mixture. Organizational memory determined the [valve] opening earlier, since the operators might want to avoid overfilling the separator, as it happened during start-up after SD 2009' . This quote also illustrates intent towards organizational learning, and also awareness of the difficulties of making it happen. Although learning had taken place from an earlier incident, it was misplaced in the incident in question as a critical instrument had a different mode of operation from that in the previous incident. Both of these quotes indicate both a positive intent to learn.

However, quotes from other incident investigation reports at all three sites shows a recognition that learning failed to happen. From a Site C incident document: 'Knowledge of similar incidents was not sufficiently taken into account in planning process.' From a Site B document: 'Of significant concern is that as there has been at least three similar incidents have occurred at [Site B] in the past five years, it is clear that with regard to this issue that organisation learning has not happened'. And from a Site A document: 'This was a repeat incident, The previous investigation of a small acid leak at the same location did not identify the correct root cause, therefore the weak signal was not followed through.'

In summary, analysis of the incident documents shows an overwhelming focus on single-loop organizational learning, which was proving largely ineffective in avoiding repeat incidents. However at Site C there was an apparent greater focus both on finding causal factors that were adaptive in nature and especially on making adaptive recommendations, and some evidence of an intent to pursue double-loop learning. This is interesting given Site C's safety performance being perceived as above average, its recent major award for process safety performance and its weak hierarchy with a markedly open culture of mutual respect, comparted with the other two sites, both of which had strong hierarchical culture.

6.5.4 Limitations of the research

It is recognised that the value of both the cross-site and cross-incident-type comparisons were limited by the unequal numbers of incidents and documents obtained from each site, and of the three different incident types. This was normalised to some extent by calculating percentages rather than using raw numbers, but this is less than ideal.

The QCA demonstration used 'crisp set' QCA (csQCA). Although this is the simplest version, the use of csQCA demands that factors and outcomes must be dichotomized as either present (1) or absent (0). This presented some difficulty for this demonstration as the sources of data were not structured to facilitate a 'present' or 'absent' choice. Use of the fuzzy set method (fsQCA) would potentially overcome this limitation; using this method means assigning the value of outcomes and factors on a calibrated scale from 0 to 1, representing the extent to which a case falls within the set rather than being fully in or fully out of a set (Rihoux et al., 2009). This offers the advantage of a more accurate representation of reality when outcomes or factors are not naturally dichotomous. It also reduces the effect of researcher bias or measurement error; a bias or error in assigning a value for set membership being less than the gross effect of misclassifying it as 0 or 1. However, the process of calibration makes fsQCA significantly more complicated. Another version is multi-value QCA (mvQCA) that extends csQCA by adding a third allowable value. However its logic is debated and this version has not been much used (Roig-Tierno, Gonzalez-Cruz and Llopis-Martinez, 2017; Vink and van Vliet, 2009).

6.6 Conclusions

It was concluded from the literature that current practice in accident analysis is limited in its value for organizational learning, and thus for improving the safety of high hazard technology firstly because the methods used and existing guidance both tend to emphasise administrative causal factors and have insufficient focus on adaptive processes, and secondly, because insufficient attention is given to the causal complexity within modern socio-technical systems. System models such as STAMP and FRAM are under-utilised and assumptions of causation largely do not consider causal complexity in terms of the conjunction of multiple factors.

The empirical study analysed 194 documents relating to 117 process safety incidents, of three types, Actual Incidents, Near Misses and Potential Incidents. Evidence was found supporting the view that causal factors and recommendations are overwhelmingly administrative in nature and that adaptive processes are largely overlooked. Evidence was also found supporting the proposition that including adaptive processes in incident analysis is associated with the early identification of system weaknesses in the form of potential incidents and thus with the avoidance or trapping of incidents before they can lead to adverse consequences., and, further, that a combination of both adaptive and administrative processes are required for safety.

The study also included a demonstration of QCA to incident analysis. Although the results did not yield immediately useful explanation of configurational causation of the incidents analysed, it did demonstrate that QCA is potentially useful and could improve understanding of causation in complex systems.

This study sought to understand how process safety incidents are currently investigated and analysed and to explore how organizational learning from incidents could be improved. This was motivated by the continued occurrence of major chemical incidents and repeat incidents that indicate weakness in organizational learning from routine accident analysis (Wood, 2018) and that better methods for understanding patterns of causality (Wood and Fabbri, 2019).

The findings indicate that organizational learning could be improved by using conjunctural analysis with QCA and also by adopting more adaptive approaches including double loop reflection (Argyris, 1977); however there are existing barriers including asymmetric power in organizations inhibiting both of these.

6.6.1 Implications for practitioners

There are three main implications for improving the practice of process safety incident investigation and analysis and consequently opportunities for organizational learning:

1. Beyond administrative factors like procedures, compliance and resourcing, seek to identify causal factors and make recommendations that are adaptive, such as relating to:
    a. non-technical skills such as situation awareness, vigilance and communication
    b. implementation of earlier learning and checking for wider implications
    c. adaptive and enabling leadership
2. Consider using QCA to analyse for configurational causation
3. Recognise the barriers to organizational learning, that are often political, and seek to overcome them.

6.6.2 Implications for future research

There is a need for future research to explore further the application of QCA to accident analysis. The limited data used in this demonstration of the method indicates that obtaining more accurate and realistic case-specific information would be likely to produce more useful results.

A proposal is for an industry-wide collaboration to share incident data in the form of a standardised set of around 10 factors, as practical number for QCA software to handle, that describe each case (incident) perhaps making use of artificial intelligence and machine learning to assist the analysis of large numbers of documents. Such a research project could yield valuable insights into configurational causation, differentiating between configurations that lead to the successful early identification of system weaknesses especially in the form of potential incidents as well as near misses and those that lead to actual incidents.

Using QCA in this way offers the opportunity for a significant improvement in the understanding of accident causation within the complex socio-technical systems in which process safety incidents occur, with consequent better organizational learning leading to improved safety of high hazard technology.

7 OVERALL DISCUSSION

7.1 Introduction

The problem of interest that led to this research is the continued occurrence of major process safety incidents in the oil & gas and chemical industries, with many repeat incidents indicating widespread ineffective organizational learning, along with the persistence in these industries of the traditional 'command and control, hierarchy and rule-following' process safety paradigm, despite the growing body of academic literature emphasising the importance of more flexible forms of organizing and leadership, supporting more adaptive practices.

This qualitative empirical research project has therefore explored how both administrative and adaptive practices influence process safety, the influence of organizational factors including leadership on the successful combination these paradoxically different approaches, and current issues in investigation and analysis of incidents, all with the overall aim of improving organizational learning, to avoid major process safety accidents.

The individual studies contribute empirical findings that support theories of HRO, System Safety and 'Safety II', support and extend theories of Leadership-As-Practice and Complexity Leadership Theory and support theories of Ambidexterity and Paradox.

Finally, synthesising the findings from the three empirical studies of the research project, the research makes two further overall contributions that support and extend theories of organizational learning, psychological safety and power in organizations.

The contributions have implications both for management practice and for future research in the areas of entanglement of adaptive and administrative practices in process safety, leadership, accident analysis and organizational learning.

The overall structure of the research and the thesis is portrayed in **Figure 7-1.**

The four papers that make up the research project are summarised and discussed below.

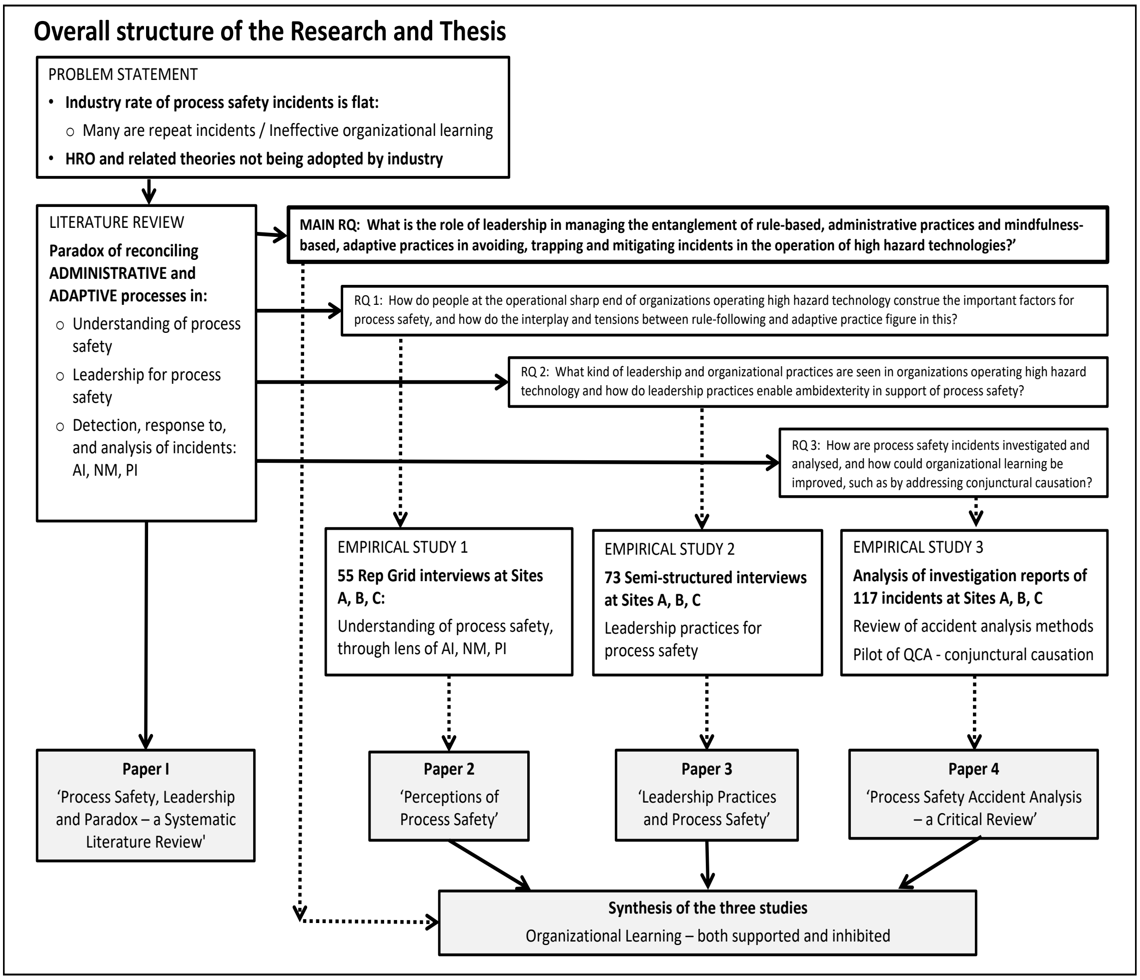

Figure 7-1 Overall structure of the research and thesis

7.2 Paper 1: Process Safety, Leadership and Paradox - A Systematic Literature Review (Thesis Chapter 2)

The literature review confirmed that the dominant paradigms of safety management: leader-centric command and control and hierarchical organizing appear not to provide a complete enough description of the processes that lead to the safety of high hazard technology. These forms of leadership and organizing may be inhibiting valuable adaptive processes of mindfulness and sensemaking inherent in HRO and related theories, failing to reconcile paradoxes of control and adaptation, resulting in ineffective organizational learning.

A recent body of research considers leadership to be a relational and processual phenomenon enacted by means of practices, emergent from the working context, offering ways that such paradoxes may be reconciled. In particular, theories of Complexity Leadership and Leadership-As-Practice appeared promising as explanations of how certain leadership practices may enable contextual ambidexterity, by encouraging adaptive processes and practices of sensemaking and competent improvisation within traditional bureaucracies, in which administrative processes and practices are also important. However, empirical evidence supporting these theories remained weak, and some challenges had been made. The review also identified ambiguities in the understanding of accident causation and hence the analysis of accidents, notably the dominance of 'root cause' analysis which largely identifies administrative causal factors at the expense of possible adaptive factors. This offers opportunities for improved organizational learning from alternative methods of analysis, seeking adaptive factors as well as administrative and addressing causal complexity with analysis of conjunctural causation using QCA methods.

The main research question that emerged from the review was: 'What is the role of leadership in managing the entanglement of rule-based, administrative practices and mindfulness-based, adaptive practices in avoiding, trapping and mitigating incidents in the operation of high hazard technologies?'

In support of this primary research question, three other questions were formulated, focussing on key component issues: First: 'How do people at the operational sharp end of organizations operating high hazard technology construe the important factors for process safety, and how do the interplay and tensions between rule-following and adaptive practice figure in this?' This is addressed in the second paper, which is **Chapter 4** of the thesis. Second: 'What kind of leadership and organizational practices are seen in organizations operating high hazard technology and how do leadership practices enable ambidexterity in support of process safety?' This is addressed in Paper 3, which is **Chapter 5**. Third: 'How are process safety incidents investigated and analysed, and how could organizational learning be improved, such as by addressing conjunctural causation?' This is addressed in the fourth and final paper which is **Chapter 6** of the thesis.

7.3 Research philosophy and design (Thesis Chapter 3)

To address these questions three studies were designed, each with different methods of data collection: firstly interviews employing Repertory Grid Technique (Kelly, 1955) focusing on different types of process safety incident, secondly semi-structured interviews focusing on leadership practices, and thirdly collection of investigation reports and other documents relating to incidents.

With a critical realist perspective (Bhaskar, 2008) the aim was to explore the domains of 'empirical', 'actual', and 'real'. The integration of the empirical results and conclusions from the two kinds of interview with the reported actual descriptions obtained from incident documents was designed to enable a 'triangulation' that provided a more complete description of the mechanisms that may operate in the 'real' domain. This approach is well-suited both to appraising the widely differing theories and also to interpreting the qualitative data in the light of the theoretical challenges (Kempster and Parry, 2011) and was therefore adopted as the ontological and epistemological framework for the research.

The research philosophy and design are portrayed in **Figure 7-2**

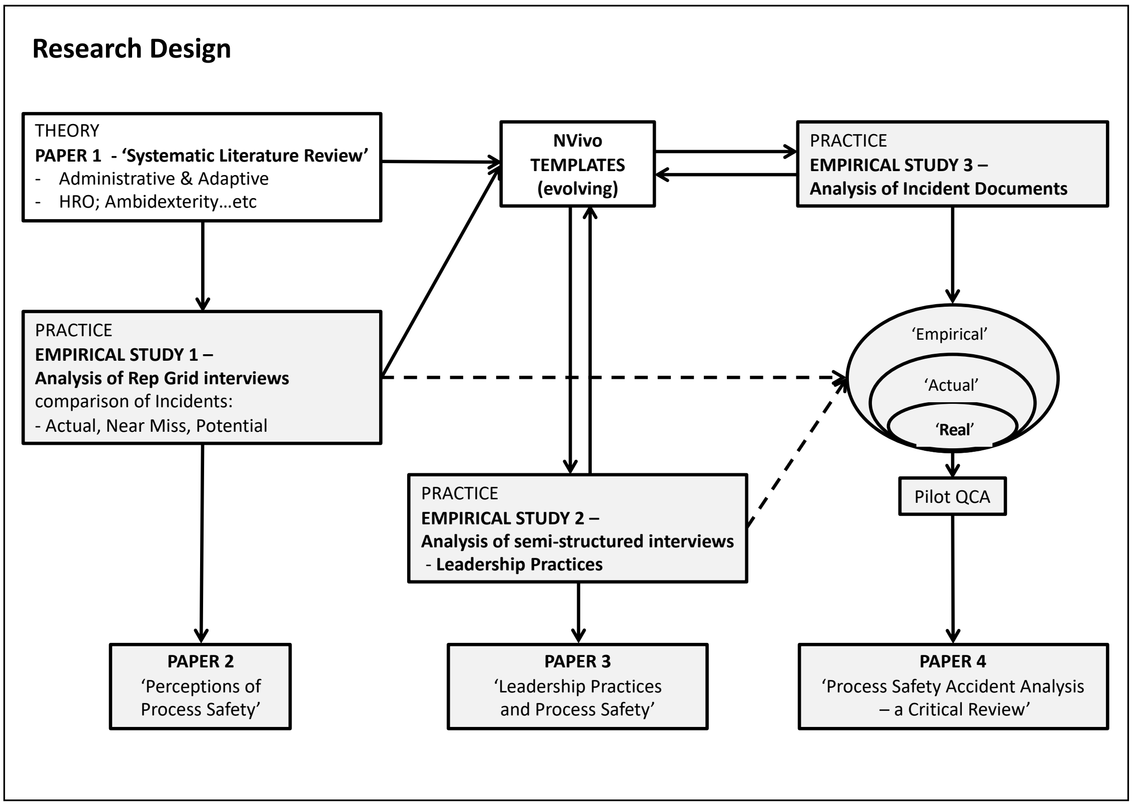

Figure 7-2 Research philosophy and design

7.4 Paper 2: Perceptions of Process Safety (Thesis Chapter 4)

55 Repertory Grid interviews were conducted with people at the sharp end of organizations operating high hazard technology to examine what they construe as important for process safety, through the lens of three types of process safety events. 19 validated constructs emerged. The relative importance of these constructs for the interviewees was analysed, comparing between type of process safety event and between the three sites.

This study makes three empirical contributions:

First, support for the theory that both administrative and adaptive processes and practices are important for process safety, and relying on administrative processes alone is insufficient, as described in the theories of HRO (Weick, Sutcliffe and Obstfeld, 1999) system safety (Leveson, 2004) and Safety II (Hollnagel, 2014). This is evidenced by the observation that of the 9 constructs rated most important ('key') by interviewees, 6 were administrative and 3 were adaptive; further, 5 out of 6 key constructs at Site C, with the best safety record, were adaptive, while the key constructs at Sites A and B were largely administrative; adaptive being only 2 out of 7 and 3 out of 8 respectively.

Second, support for the proposition that the early detection of Potential Incidents requires adaptive processes (Weick, Sutcliffe and Obstfeld, 1999). Of the 3 constructs rated as key for Potential Incidents, only one was administrative ('Compliance') and two were adaptive (Hazard Detection' and 'Understanding of Risk') and neither of these two adaptive constructs figure as key for Actual Incidents or Near Misses. (It is understood that identifying Potential Incidents stops the system weaknesses shown up in them from incubating into Actual Incidents or Near Misses.)

Third, support for the negative influence on safety of 'Work Pressure' and 'Deference to Hierarchy' (Reason, 1997; Vaughan, 1997a). These two constructs were associated only with Actual Incidents and Near Misses, and not Potential Incidents, and also only with Sites A and B, and not Site C, the site with the best safety record and the only site for which 'Organizational Learning' was rated as key.

7.5 Paper 3: Leadership Practices and Process Safety (Thesis Chapter 5)

73 semi-structured interviews were conducted with people at the sharp end of organizations operating high hazard technology, exploring the leadership practices that they experienced and how these influenced administrative and adaptive working practices in relation to process safety. The interviews drew on Complexity Leadership Theory (CLT) and 'Leadership-As-Practice' (L-A-P).

This study makes six empirical and theoretical contributions:

First, supporting and extending Complexity Leadership Theory, the study found at Site C positive effects of both administrative and adaptive leadership practices, and specific practices of enabling leadership, on the successful entanglement of administrative and adaptive working practices in controlling hazards, in the form of a mechanism of collaborative competent improvisation, portrayed in **Fig 5-3** and described in detail in Chapter 5.

In the sphere of high hazard technology improvisation is a vexed issue. Widely accepted as a real and normal way of working, seen as 'work as done' vs 'work as imagined' (Hollnagel, 2014) without which simple compliance can be 'mispliance' that fails to account for unanticipated but important local conditions (Reason, Parker and Lawton, 1998), improvisation is also criticised if done by front line workers who may be unaware of overall system risks (Leveson et al., 2009) or even if done by experts may not capture useful learning (Amalberti and Vincent, 2019).

The observed mechanism of collaborative competent improvisation overcomes these criticisms, since it takes account of the actual work situation, deploys appropriate technical expertise with an understanding of the overall system and captures the improvement, formally embedding it in a modified practice. This also extends the 'framework of rule management' proposed by Hale and Borys (2013, p224) and the theory of entanglement proposed by Murphy et al. (2017). It also underlines the importance and practicality of improvisation as a necessary practice, as understood by Weick (2009, p267): 'Improvisation can be defined as reworking previously experienced material in relation to unanticipated ideas that are conceived, shaped, and transformed under the special conditions of a current performance'.

Second, further supporting and extending Complexity Leadership Theory, this study offers a response to the challenge from Tourish (2019) that CLT as currently described remains leader-centric and does not explain how leadership emerges, and that it therefore does not fully embrace organizations as complex adaptive systems. Both Site B and Site C provided evidence of leadership emerging, as leaderly influence both within peer groups and upwards within the hierarchy, through acceptance of specific expertise. The encouragement of this emergent leadership by formal leaders, is interpreted as a practice of adaptive leadership.

Third, further supporting Complexity Leadership Theory, the study offers a response to the second part of Tourish's challenge, that 'CLT has yet to become an actual theory of complex leader–follower interactions…implicit within wider complexity theories of organization' (Tourish, 2019, p233). This has been addressed by Rosenhead et al. (2019, p20) who point out that rather than being a complete analogue for organizations, 'complexity offers a potentially valuable metaphor for leadership practice and research'. This study found complexity to be indeed a useful metaphor, in the empirical evidence at Site C of the positive influence that enabling and adaptive leadership practices had on the successful entanglement of adaptive and administrative working practices, resulting in better process safety outcomes. This supports the CLT view of the organization as a combination of 'bureaucratic functions providing an orienting and coordinating structure… with complex adaptive systems, when functioning appropriately, providing an adaptive capability for the organization' (Uhl-Bien, Marion and McKelvey, 2007, p313-314)

Fourth, supporting and extending Leadership-As-Practice. The study found leadership primarily manifesting as practices, categorising them as administrative, adaptive and enabling, observed as focusing on 'realities of ordinary work' (Kempster and Gregory, 2017, p512).

Fifth, further supporting and extending Leadership-As-Practice, the study offers a response to a double challenge by Collinson (2018a, p363) that L-A-P focusses almost entirely on agency, and also that it has a 'lack of critical engagement, particularly in relation to its neglect of asymmetrical power relations and control practices'. This study found that viewing leadership in terms of practices allowed a useful distinction to be made between structurally embedded contextual conditions and the agentic enactment of leadership within those structures, with the influence of both context and leadership on working practices being observed as important, thus acknowledging structure as an equally important organizing concept as agency. The analysis of contextual conditions and practices into 'helping' and 'hindering' also made clear the hindering effect of such leadership practices as authoritarian over-directing as well as contextual conditions such as blame culture and production pressure. This provides evidence that Leadership-As-Practice is indeed a useful framework for critical analysis that can easily include aspects of power and control.

Sixth, supporting and extending theories of contextual ambidexterity and paradox, the study found that compliance and competent improvisation are mutually enabling and reconstitute one another. 'Structured flexibility' (Smith and Besharov, 2019) was observed in a norm of technical competence and mindful, questioning compliance, that led to improvements in risk management and also created the conditions for improvement, reinforcing both compliance and competence. Site C's open, trusting culture and flat organizational structure with accessible leaders provided the necessary 'supportive organizational context' (Gibson and Birkinshaw, 2004).

In contrast with Site A which had suffered several major actual incidents including some fatalities, and Site B which had also experienced a number of major incidents including some serious near misses, Site C had had no recent major incidents but had identified, reviewed and analysed many potential incidents, finding system weaknesses before they could develop into actual incidents. Site C's low threshold for raising issues and questioning ways of working provided a supportive environment in which such adaptive practices could flourish.

This supports the proposition that the valuable learning from potential incidents and near misses that identify system weaknesses requires 'a high degree of psychological safety, making it easier for people to identify, and own up to their involvement in making, mistakes'…and that…'leadership is key to fostering psychological safety through effective coaching, communicating, and minimize power and status differences' (Hallgren, Rouleau and de Rond, 2018, p123).

7.6 Paper 4: Process Safety Incident Analysis – a Critical Review (Thesis Chapter 6)

Current approaches to incident investigation and analysis were critically reviewed, including a review both of theories of causation and of organizational learning. To complement this review, an empirical study was conducted by analysing investigation reports and other documents relating to 117 incidents of three different types: actual incidents, near misses and potential incidents. The document analysis was done firstly by coding the documents in a combined grounded and theory-driven abductive process, and secondly, as a demonstration of the QCA method, by performing a QCA based on a list of factors consolidated from the document coding together with those derived from the two earlier interview-based studies (**Chapters 4** and **5**).

This study makes three empirical and theoretical contributions:

First, supporting the view that current incident investigations remain focused on proximate factors (Hulme et al., 2019), the incident document coding analysis found that documented causal factors and recommendations were predominantly administrative in nature. This aligns with the recognition that identifying underlying organizational factors is difficult (Braithwaite, 2010) and is also unsurprising given that current authoritative industry guidance from such bodies as the CCPS (2019) emphasises administrative factors.

Second, supporting HRO and Safety II theory, the document analysis showed that significantly more adaptive causal factors were identified for potential incidents than for actual incidents or near misses. In particular this supports HRO practices of 'strong response to weak signals' (Weick and Sutcliffe, 2001) and vigilant cross-checking to catch errors (Roberts, 1990). Further, the incident documents from Site C, with the best safety performance, identified many more adaptive causal factors and recommendations than the other two sites, especially recommendations concerning 'Organizational Learning', as well as more 'Compliance' and 'Planning & Resourcing', which are both administrative. These findings support Hollnagel's (2014) proposal that safety relies on administrative and adaptive processes acting together.

Third, supporting the theory of conjunctural causation, the study found QCA of potential great value to incident analysis by addressing causal complexity. However, to realise this value, realistic detailed knowledge of each case would be required.

7.7 Synthesis of the research

7.7.1 Consolidation of the contributions from the three studies

There is some overlap of the contributions made by the individual studies, providing some degree of triangulation. The critical realist approach taken, based on a stratified understanding of reality (Bhaskar, 2008) anticipates that observations of the same phenomena in different ways allows a closer approximation of reality to be taken from interpretation of empirical data. Thus the following consolidation adds weight to these contributions:

Both the repertory grid study and the incident documents study found evidence supporting the theories of HRO (Weick, Sutcliffe and Obstfeld, 1999) system safety (Leveson, 2004) and Safety II (Hollnagel, 2014) that both administrative and adaptive processes and practices are important for process safety

Both the repertory grid study and the incident documents study found evidence that adaptive practices are associated with potential incidents, supporting HRO and Safety II theory, in particular HRO practices of 'strong response to weak signals' (Weick and Sutcliffe, 2001) and vigilant cross-checking to catch errors (Roberts, 1990).

Both the repertory grid study and the semi-structured interview study found evidence of the hindering effect on process safety of such leadership practices as authoritarian over-directing and contextual conditions such as blame culture and production pressure.

7.7.2 Comparison of the findings from the three studies

Comparing the findings from the three studies provides further insight and contributions. These are now presented and discussed. **Table 7-1** shows a comparison of the summary results of the three studies, at each site. The top three rows show the topics rated as most important by the participants in the three studies: the constructs that emerged from repertory grid interviews, the factors from the semi-structured interviews and the factors from the analysis of the incident documents. These are divided into main columns headed Administrative, Adaptive, Enabling and Contextual Conditions. (The repertory grid constructs shown are all those rated as most important ('key') by participants from at least one site, except for those marked as 'H' which indicates they are 'Hygiene' constructs, which though not meeting the 'key construct' criteria, are still rated as important.) The rest of the table shows which of these topics occurred in the respective studies at each site, A, B and C. Thus within the table section for each site, the top row shows the important constructs that emerged from the repertory grid analysis; the second row shows the important factors that emerged from the analysis of the semi-structured interviews, and the bottom row those that emerged from analysing the incident documents.

This portrayal shows a mismatch between the topics that people think are important and those they are willing to share and document. Comparing the findings from the repertory grid study with those from the semi-structured interviews and document analysis reveals a form of cognitive dissonance (Festinger, 1957). The repertory grid study shows that participants regard a broad array of constructs as important; during the semi-structured interviews they discussed a narrower range of factors and the analysis of the incident documents found an even narrower range, predominantly administrative in nature. This indicates a perhaps institutionalised predisposition towards administrative practices and an apparent conflict between espoused theory and theory-in-use (Argyris and Schon, 1974).

The repertory grid technique is designed to elicit tacit knowledge. Using this technique helps both researchers and participants to become aware of the participants' theories in use (Argyris, 1980; Jankowicz, 2004). This study indicates that participants' theories-in-use included a number of adaptive constructs that did not emerge from the semi-structured interviews, nor the incident documents.

Table 7-1 Cross-case comparison of results – most important topics at each site

		ADMININSTRATIVE									CONTEXTUAL CONDITIONS			ENABLING			ADAPTIVE												
SITE	Rep Grid Constructs	Proc	Compl.	Risk Assess ment	Incident Investig & Analysis	Emerg. Resp	Superv.	Equipt (H)			Work Press.						Hazard Detect.	Vigila nce	Under standing Risk	Mitig ation	Org Learn	Compete nce (H)	Commu nication (H)						
	Semi-Structured Interviews	Proc	Compl.	Risk Mgt				Equipt	Planning & Resourc	Embed Improv		Cult.	Struct & Matur.	Sense making	Support Indivs & Netw.	Enabling Ambi-dext.						Compet ence		Encourg improv	Encourg team	Emergt Leadsh.	Reluct to Simplify	Sens. to Ops	Commit to Resil
	Incident Documents	Proc	Compl.	Risk Mgt				Equipt	Planning & Resourc												Org Learn								
A	Rep Grid Constructs	Y	Y	Y			Y	Y			Y						Y	Y				Y	Y						
	Semi-Structured Interviews								Y	Y				Y	Y									Y	Y				
	Incident Documents	Y	Y	Y				Y																					
B	Rep Grid Constructs	Y	Y		Y	Y					Y						Y		Y	Y									
	Semi-Structured Interviews								Y				Y	Y		Y								Y					
	Incident Documents	Y	Y	Y				Y	Y																				
C	Rep Grid Constructs					Y											Y	Y	Y	Y	Y								
	Semi-Structured Interviews	Y	Y	Y					Y			Y	Y	Y	Y	Y						Y		Y	Y	Y	Y	Y	Y
	Incident Documents	Y	Y	Y				Y	Y												Y								

The semi-structured interviews tend to indicate the factors that participants tend to use to convey their espoused theory (Argyris and Schon, 1974), that is, what they would like others to think they do, rather than what they actually do. Argyris and Schon (1974, pp6-7) make this explanation: 'when someone is asked how he would behave under certain circumstances, the answer he usually gives is his espoused theory of action for that situation. This is the theory of action to which he gives allegiance, and which, upon request, he communicates to others. However, the theory that actually governs his actions is this theory-in-use'.

This difference between participants' espoused theory and theory-in-use is emphasised by the small range of topics that emerged from the incident documents analysis. The topics were Procedures, Compliance, Risk Assessment, Equipment and Planning & Resourcing, all administrative in nature, with the sole exception of Organizational Learning which appeared only in documents from Site C.

This cross-study comparison suggests that responding to organizational expectations narrows the range of factors respondents choose to discuss. At Sites A and B the prevalence of the traditional 'administrative' paradigm appears to have created a gap between what people believe is important in terms of process safety and what they bring to the surface, share and document. This discrepancy may be inevitable (Argyris and Schon, 1974) however, if the gap is wide, as found in Sites A and B, this indicates that participants may be inhibited from applying in practice some of the adaptive ideas they recognise as important.

The oil & gas and chemical industry is generally highly procedural with a strong focus on conformity and compliance. High levels of institutionalization mean that people will frame discourses to align with established interests and values (Greenwood, Suddaby and Hinings, 2002; Suddaby and Greenwood, 2005) generating normative pressures and cognitive constraints on the practices that are regarded as appropriate or legitimate (Scott, 1994, p74).

So for example incident investigations often suffer from 'hindsight bias' (Dekker, 2011) and focus on finding and fixing problems 'rather than to challenge deep assumptions with rigorous and systemic thinking…' (Carroll, 2002, p124). This is particularly so since recommendations made in incident reports tend to be strongly influenced by current institutionalised industry guidance such as CCPS (2019). The absence of adaptive practices from incident reporting may sometimes even be deliberate, since 'organizational learning is a political process shaped by the interpretations and interests of competing stakeholders…'

who may seek to reinforce administrative practices to 'protect themselves from scapegoating by producing their own event narratives' (Buchanan and Denyer, 2013, p213). Since they are very often based on linear cause-and-effect models, incident reports also tend to make recommendations that only address these generally administrative 'root causes', a failing that has been called 'what you look for is what you find' (Lundberg, Rollenhagen and Hollnagel, 2009 p1298).

In situations such as emergencies and major incidents requiring rapid adaptation, existing systems and routines can unravel, disrupting the organization. Such events require flexibility and improvised behaviors (Cornelissen, Mantere and Vaara, 2014; Weick, 1988; Weick, Sutcliffe and Obstfeld, 1999; Weick and Sutcliffe, 2007) and more flexible approaches to collective action (Uhl-Bien, Marion and McKelvey, 2007). Experience of such situations could explain why the importance of adaptive practices was discussed by the repertory grid participants. However, the participants' general reluctance to share and document adaptive practices more explicitly may indicate an institutionalised belief that such practices may lead to an erosion of control, generating anxiety and producing defensive responses (Argyris and Schon, 1974).

Interviewees at Site C though, did apparently feel more able to discuss the value of adaptive practices such as expert improvisation, problem solving, change and learning. Here, there was a level of confidence, consistency and feeling of being in control, that apparently contributed to the creation of a climate of psychological safety in which adaptive practices of questioning and make suggestions for changing working practices could flourish.

There was also an established and effective administrative structure and well-developed procedures and working practices and it is suggested that these may have made up an important foundation upon which the more adaptive practices had been become established. Site C respondents reported a supportive environment and leaders with a strong learning orientation as key elements that stimulated reflection and productive dialogue, suggesting that the sound structures and processes created by an effective administrative bureaucracy are a pre-requisite for adaptive practices to develop and operate. This supports theories of paradox (Clegg, da Cunha and e Cunha, 2002; Lewis, 2000; Lewis and Smith, 2014; Milosevic, Bass and Combs, 2018; Smith and Lewis, 2012; Zhang et al., 2015)

In contrast, putting this description of what appeared as a climate of psychological safety at Site C together with the observation of a more evident traditional hierarchy at the other sites, appears to support the Schilling and Kluge (2009) proposition that 'restrictive and controlling management style' and 'status culture' are barriers to organizational learning. This proposition is supported by Pilbeam et al. (2016, p59) who found in their study that 'strongly hierarchical organizational context actively discouraged double-loop learning'

The repertory grid study indicated that 'Work Pressure' and 'Deference to Hierarchy' were both important constructs at both Sites A and B, but not Site C. Results of the semi-structured interviews provide further evidence of hindering contextual conditions: 'blame culture' at Site A, 'ineffective transition from project to operations' at both Sites A and B, 'inadequate resourcing' and 'unclear responsibilities' figuring as important factors at Site B; whereas at Site C, few people made mention of these issues.

The difference between Site C and the other two sites in the number of people mentioning factors categorised as 'adaptive leadership practices' and 'enabling leadership practices' is also striking: in the order of twice as many at Site C than either of the other sites. The category of 'administrative leadership practices' also provides a clear contrast: in particular Site A had many mentions of 'hindering' factors of 'authoritarian over-directing' and 'ineffective embedding of improvements'.

From these findings, a picture emerges at sites A and B of the hindering effects of hierarchy and asymmetric power making it difficult for the creation of a climate of psychological safety, and thus inhibiting organizational learning (Baumard and Starbuck, 2005; Bokeno, 2003; Buchanan and Denyer, 2013; Schilling and Kluge, 2009)

This picture contrasts strikingly with Site C, suggesting an underlying difference of leadership paradigm. At site C there were numerous indications of a norm of the 'shared goals, shared knowledge and mutual respect' that Carmeli and Gittell (2009, p724) suggest enhance the climate of psychological safety that is held by many writers to be so essential for effective organizational learning (Argote, 2011; Baer and Frese, 2003; Bergmann and Schaeppi, 2016; Edmondson, 1999; Edmondson and Lei, 2014; Hallgren, Rouleau and de Rond, 2018).

In summary, the findings from this cross-study comparison allow two overall empirical contributions:

First, supporting and empirically extending institutional theory, comparison of the findings of three studies showed that although the repertory grid technique revealed the participants' tacit understanding of the importance of adaptive practices, there was a reluctance to express this in the more explicit settings of semi-structured interviews and incident investigation reports, indicating a conflict between espoused theory and theory-in-use (Argyris and Schon, 1974) which can be explained as institutionalization within the highly procedural and compliance norms of the oil & gas and chemical industry, generating 'normative pressures and cognitive constraints on the practices that are regarded as appropriate or legitimate' (Scott, 1994, p74).

Second, supporting and empirically extending theories of organizational learning, the asymmetric power of strongly hierarchical organizations based on a leadership paradigm of command and control at Site A and to a lesser extent at Site B inhibited the creation of a climate of psychological safety and thus also organizational learning. This contrasted with Site C where a marked open culture and low threshold for questioning and suggesting improvements, coupled with more evident adaptive and enabling leadership practices, resulted in a much more supportive climate of psychological safety and consequent focus on organizational learning.

The main research question driving this research is:

'What is the role of leadership in managing the entanglement of rule-based, administrative practices and mindfulness-based, adaptive practices in avoiding, trapping and mitigating incidents in the operation of high hazard technologies?'

This question is answered in different ways by each of the contributions made by this research, and directly by the primary contribution, as follows:

The mechanism of collaborative competent improvisation at Site C, resulting in the effective entanglement of administrative and adaptive working practices was evidence of the practical manifestation of both CLT and L-A-P. This took the form of a combination of administrative leadership practices that included directing, prioritising, resourcing and embedding improvements, with adaptive leadership practices that included encouraging improvement, teamwork and emergent leadership, together with enabling leadership practices of challenging and sensemaking, encouraging questioning and listening. These practices are founded on an acceptance of the complexity both of organizations and the problems facing them in avoiding major process safety accidents.

Two quotes illustrate the practical value of these theories for creating a climate of psychological safety in which effective organizational learning can occur:

The first emphasises the importance of accepting a complexity view for enabling reflective learning: 'finding ways to help people to reflect on mindsets and overarching worldviews, and finding ways to critique some long-held beliefs about the 'way things are' is absolutely critical to their really coming to terms with the world and its complexity' (Boulton, Allen and Bowman, 2015, p123).

The second emphasises the importance of the adaptive leadership practice of humility: 'The leader who says "I don't know" essentially says that the group is facing a new ballgame where the old tools of logic may be its undoing rather than its salvation…To drop the heavy tools of rationality is to gain access to lightness in the form of intuitions, feelings, stories, experience, active listening, shared humanity, awareness in the moment, capability for fascination, awe, novel words, and empathy…And all these activities are made more legitimate when a leader says "I don't know". That admission forces the leader to drop pretense, drop omniscience, drop expert authority, drop macho posture, and drop monologues. The lightness of listening and exploring is the consequence.' (Weick, 2009, p268).

8 OVERALL CONCLUSIONS

The systematic literature review concluded that the prevalent paradigm of process safety based on rule-following within safety management systems, hierarchical organizational form and leader-centric command and control is insufficient to explain safety of high hazard technology; further, that these forms of leadership and organizing may in practice be inhibiting potentially valuable adaptive processes that enable organizational learning that could improve process safety, by failing to reconcile paradoxes of control and adaptation such as operational discipline vs sensemaking, clarity of structure vs flexible decision-making and leader vs leadership.

Theories of Complexity Leadership and Leadership-As-Practice appeared promising as better ways of understanding how these paradoxes can be reconciled by enabling contextual ambidexterity in the form of the entanglement of administrative and adaptive working practices. However, there was little empirical evidence supporting these theories, and some challenges had been made, principally by Collinson (2018) and by Tourish (2019).

The review also identified ambiguities in the understanding of accident causation and the dominance of 'root cause' analysis largely identifying administrative and few adaptive causal factors and recommendations, limiting organizational learning. Potential was identified for improving organizational learning from a more reflective double-loop approach, within a climate of psychological safety to overcome inhibitions arising from asymmetric power, and also from alternative methods of accident analysis such as conjunctural causation.

These issues have been addressed in a qualitative multiple case study research project, with data collected at three quite different operational oil & gas and chemicals sites, though all operated by the same international organization, so with similar basic management systems.

Three different but complementary methods of data collection and analysis were used, and a critical realist approach has been adopted for interpreting and comparing the results of these three studies. The findings have arisen from the expressed thoughts and views of a reasonably large and diverse sample of fairly experienced people working at the sharp end of operating high hazard plant capable of creating large scale industrial disasters, and from formal documents relating to the investigation of process safety incidents at these sites.

With the usual caveats of qualitative case study research, and acknowledging some specific limitations, the findings do nonetheless allow some clear conclusions to be drawn concerning the issues referred to above.

First, supporting theories of System Safety (Leveson, 2011), Safety II (Hollnagel, 2014) and HRO (Weick, Sutcliffe and Obstfeld, 1999) both administrative and adaptive working practices are important for process safety, for example both compliance with procedures and also mindful questioning and adaptation of working practices. This can be seen as paradoxical and so represents a leadership challenge, and this is discussed below. However, the research showed that compliance and competent improvisation are mutually enabling and reconstitute one another. ‘Structured flexibility’ (Smith and Besharov, 2019) was observed in a norm of technical competence and mindful, questioning compliance, that both led to improvements in risk management and also created the conditions for such improvement, reinforcing both compliance and competence. Site C’s open, trusting culture and flat organizational structure with accessible leaders provided the necessary ‘supportive organizational context’ (Gibson and Birkinshaw, 2004). This supports and extends empirically theories of contextual ambidexterity and paradox.

Second, adaptive practices are more closely associated with the identification of potential incidents than actual or near miss incidents. The early identification of system weaknesses in the form of potential incidents before they can incubate into actual or near miss incidents is an indicator of process safety. Such practices include hazard detection, communication, vigilance and understanding risk along as well as questioning and competent improvisation.

Third, the paradoxical need for both administrative and adaptive working practices can be met by successfully entangling them in a process of <u>collaborative competent improvisation</u> reliant both on technical expertise and specific leadership practices in a practical application of both Complexity Leadership Theory and Leadership-As-Practice. This process is described in detail in Chapter 5, and provides empirical evidence supporting the utility of both of these theories.

Fourth, leadership can and does emerge, as leaderly influence by individuals and acceptance of their specific expertise, both within peer groups and upwards within the hierarchy. This was evidenced in the semi-structured interviews study and provides at least a partial answer to the challenge from Tourish (2019) that CLT as currently described remains leader-centric and does not explain how leadership emerges, and that it therefore does not fully embrace organizations as complex adaptive systems. The emergence of leadership based on expertise also is a practical example of the HRO adaptive practice of 'deference to expertise'.

Fifth, complexity is a useful metaphor for leadership practice, even though complex adaptive systems may not represent a complete analogue for organizations. This is evidenced by the positive influence of 'enabling' leadership practices such as sensemaking and challenging as well as supporting individuals and networks, on the successful entanglement of adaptive and administrative working practices. These enabling leadership practices are employed instead of directing and controlling, recognising the reality of the organization as a complex system rather than as a mechanical system (Boulton, Allen and Bowman, 2015). This is proposed as an answer to the other part of the challenge from Tourish (2019) that CLT does not fully embrace organizations as complex adaptive systems.

Sixth, leadership is seen in practices and how these influence working practices. This supports Leadership-As-Practice, evidenced for example by the focus on the 'realities of ordinary work' (Kempster and Gregory, 2017) seen in the collaborative entanglement process described earlier.

Seventh, Leadership-As-Practice (L-A-P) acknowledges structure as an equally important organizing concept as agency. This is evidenced by the importance influence on working practices of structurally embedded contextual conditions, for example the supportive culture seen at Site C, as distinct from but alongside the influence of agentic leadership practices. This answers part of the challenge from (Collinson, 2018a, p363) that L-A-P is 'focussing almost entirely on agency'.

Eighth, L-A-P is a useful framework for critical analysis that can easily include aspects of power and control. This is evidenced by the analysis of contextual conditions and practices into 'helping' and 'hindering' in the semi-structured interviews study, that made clear the hindering effect of such leadership practices as authoritarian over-directing as well as contextual conditions such as blame culture and production pressure. This answers the other criticism from Collinson (2018a, p363) that L-A-P has a 'lack of critical engagement, particularly in relation to its neglect of asymmetrical power relations and control practices'.

Ninth, causal factors and recommendations in incident investigation reports tend to be administrative in nature. This was evidenced by the analysis of the incident documents, which were predominantly of an administrative nature. This current reality appears to be severely limiting the effectiveness of organizational learning.

Tenth, organizational learning is inhibited by institutionalization in the form of the highly procedural and compliance norms of the oil & gas and chemical industry. These norms tend to close down discussion and work against the creation of a climate of psychological safety necessary for people to speak up with concerns and question working practices. This was evidenced in the cross-study comparison of important factors that emerged from the three different data sources.

Eleventh, organizational learning is also inhibited by over-directive administrative leadership practices found in a strong hierarchy with highly asymmetric power. These factors reduce the people's inclination to speak up. Evidence of this was found particularly at Site A. In contrast, a climate of psychological safety was observed at Site C where the open culture and low threshold for speaking up was encouraged by leadership practices of maintaining accessibility and supporting both formal and informal networks, with a positive effect on the focus on organizational learning.

Twelfth, QCA is a potentially useful analytical method that could improve understanding of causation in complex systems.

8.1 Summary of contributions

The contributions made by this research are summarised in **Table 8-1**

Theoretical and Empirical Contributions				
Ch.	**Contribution (Evidence)**	**Theory empirically supported**	**Theory extended**	**Theory proposed**
4	Both administrative and adaptive practices are needed for process safety	HRO, System Safety, Safety II		
	Detection of Potential Incidents requires adaptive processes	HRO (Roberts)		
	Negative influence on process safety of Work Pressure and Hierarchy	Reason, Vaughan		
5	Collaborative competent improvisation, as process of entanglement of administrative and adaptive practices	CLT Murphy et al Hale & Borys	CLT Murphy et al Hale & Borys	Mechanism of collaborative competent improvisation
	Enabling leadership as Emergent	CLT	CLT (Tourish challenge)	
	Complexity as metaphor	CLT	CLT (Tourish challenge)	
	L-A-P influence on working practices	Kempster & Gregory		
	L-A-P acknowledges structure and accommodates asymmetric power	L-A-P	L-A-P (Collinson challenge)	
	Open culture/low threshold supports theories of Ambidexterity and Paradox	Heifetz & Laurie; Ghoshal & Bartlett Hallgren et al		
6	Investigation focus on proximate causes	Hulme; Carroll		
	Adaptive factors linked with pot. incids	HRO; Safety II		
	QCA value for incident analysis	Conjunctural causal complexity (Fiss)		
	Synthesis of the research			
	Institutionalization inhibits dialogue on adaptive practices and learning	Institutional theory Scott		
	Organizational learning supported by psychological safety and inhibited by asymmetric power	Org Learning: Argyris; Edmondson; Schilling and Kluge		
	Methodological Contributions			
	Use of Repertory Grid Technique to examine views of process safety			
	Use of Bow Tie to explain Actual Incident, Near Miss and Potential Incident			
	Adoption of Critical Realist ontology for analysis of process safety			

Table 8-1 Summary of contributions

8.2 Limitations of the research

A number of limitations are acknowledged.

Qualitative research cannot generally seek strict replicability, though it is claimed that the findings of this multiple case study are less idiosyncratic than a single case would be (Bryman, 2004) and that the cross-case comparisons do allow some cautious theoretical inferences to be made (Eisenhardt, 1989).

For this reason three sites were sought for the fieldwork rather than relying on a single site. Each study found that data saturation was achieved, so although more cases/sites would collect more data and so increase the potential value of the research, it is doubtful if without a large increase in the number of cases much more value would be obtained. Cost and time were inevitably limited. A similar argument could also be made for, and against, collecting more data by means of different methods such as surveys.

The choice of a three-case study qualitative research project also was a good fit with the chosen ontological stance of critical realism, which was taken on the grounds that it allows both a constructionist view but also for the existence of an objective reality. The subject matter being high hazard technology that seemed important, but an entirely positivist view was rejected as being strongly associated with the traditional hierarchy and command and control paradigm that was being challenged, and not very compatible with a complexity view of organizations.

Although it is considered that the characteristics of the three sites were described fairly, the descriptions are inevitably incomplete. Better information about process safety practices, outcomes and culture at the three sites would have been useful.

Although the access to interview people working directly with high hazard technology was much valued and appreciated by the researchers, inevitable restrictions on time and availability of people limited the scope and opportunities for data collection.

The findings inevitably represent only an indication of the views of the individual respondents. Although some confidence in data saturation is claimed for all three studies, the number and duration of the interviews was necessarily restricted by the availability of the respondents. The quality of the data is also inevitably limited by interview technique and the protocol used.

Specifically for the Repertory Grid study, it is acknowledged that limitations include some missing data points in some repertory grids, some doubtful distinction between the types of event by some interviewees, the small average number of constructs that were obtained per interview, and that the number of interviews at the three sites was not well-balanced.

For the leadership interviews study, the method used to analyse the interview data included a quantification of the codes, which some researchers may criticize as being neither an accepted quantitative method nor respecting the accepted qualitative approach of rich description and textual meaning. The quantification was done ‘in order to draw out the factors that are viewed as contributing to an outcome’ (Bryman, 2004, p758) and so facilitate the identification of differences between the three sites. Although no statistical significance or correlation is claimed for the differences so analysed, some clear associations have been suggested between the process safety outcomes of the sites and both the broad theoretical dimensions that emerged from the analysis and some of the first and second-order codes that were obtained from the interview data. Caution should of course be exercised in interpreting the generalizability of these associations.

The semi-quantification of the qualitative data obtained from the semi-structured interviews and the incident documents was done to facilitate the cross-case comparisons. It is recognised that such semi-quantification carries the risk of over-interpretation, that is reading too much into the data. Therefore the interpretation was done warily, with conclusions being drawn from only quite large differences, and corroboration was sought from the interview extracts as part of the interpretation process. The interpretation of the interview data and coding under the headings of working practices, leadership practices and contextual conditions is also accepted as open to researcher bias. For this reason check coding was performed by another researcher not otherwise involved with the research.

For the accident analysis study, the number of incident documents obtained at the three sites was not well-balanced. An attempt was made to compensate for this by the used of % unique frequencies of the codes used to analyse the documents, but this is inevitably less than ideal.

For the accident analysis study, the demonstration of QCA method used 'crisp set' QCA (csQCA). Although this is the simplest version, the use of csQCA demands that factors and outcomes must be dichotomized as either present (1) or absent (0). This presented some difficulty for this demonstration as the sources of data were not structured to facilitate a 'present' or 'absent' choice. Use of the fuzzy set method (fsQCA) would potentially overcome this limitation; using this method means assigning the value of outcomes and factors on a calibrated scale from 0 to 1, representing the extent to which a case falls within the set rather than being fully in or fully out of a set (Rihoux et al., 2009). This offers the advantage of a more accurate representation of reality when outcomes or factors are not naturally dichotomous. It also reduces the effect of researcher bias or measurement error; a bias or error in assigning a value for set membership being less than the gross effect of misclassifying it as 0 or 1. However, the process of calibration makes fsQCA significantly more complicated. Another version is multi-value QCA (mvQCA) that extends csQCA by adding a third allowable value. However its logic is debated and this version has not been much used (Roig-Tierno, Gonzalez-Cruz and Llopis-Martinez, 2017; Vink and van Vliet, 2009).

8.3 Implications for practitioners

This research has identified implications for practice in four areas:

Implications for process safety

The emphasis on compliance with effective procedures should be balanced with encouragement of continuous mindful sense-checking and questioning of existing processes and practices, emphasising the importance of adaptive practices such as hazard detection, vigilance, understanding of risk and mitigation for early identification of potential incidents, with their high value for organizational learning.

To operationalise this, a process of 'collaborative competent improvisation' should be developed that encourages workers to challenge existing working practices, and brings in appropriate technical expertise to develop, approve and embed improvements. This should be stimulated and supported by leadership practices at all organizational levels that encourage improvement and teamwork.

For this process to operate effectively a culture of trust is necessary, with a low threshold for reporting and discussing problems and ideas for improvement, and that recognises and avoids the negative influence on process safety of inappropriate priorities and work pressure and over-deference to hierarchy.

Implications for leadership in organizations

An understanding of leadership as formed of practices should be encouraged, along with the development of specific leadership practices that support adaptation within existing organizational structures.

An understanding of complexity as a useful metaphor for organizing and leadership practice should be encouraged. This also implies encouraging leadership to emerge both within peer groups and upwards within the hierarchy, as leaderly influence by individuals with specific expertise appropriate to the situation.

Implications for process safety incident investigation and analysis

Current approaches to incident investigation and analysis tend to focus on causal factors and recommendations that are administrative in nature, relating to issues such as procedures, compliance, planning and resourcing, limiting the value of such investigations to continuous improvement rather than more effective ‘double-loop’ organizational learning.

Investigations should be more reflective, looking beyond the mechanistic root cause approach to question underlying assumptions, take account of organizational and system complexity and seek causal factors and make recommendations of an adaptive nature.

Further, again recognising the causal complexity of socio-technical systems, the use of QCA to analyse for configurational causation from multiple factors should be considered.

The value of identifying, investigating and analysing potential incidents for learning about system weaknesses should be emphasised and encouraged, rather than relying on actual incidents and near misses.

Implications for organizational learning

The highly procedural and compliance norms of the oil & gas and chemical industry tend to inhibit organizational learning. These norms tend to close down discussion and work against the creation of a climate of psychological safety necessary for people to speak up with concerns and question working practices.

Similarly, organizational learning is also inhibited by over-directive administrative leadership practices found in a strong hierarchy with highly asymmetric power. These factors reduce the people’s inclination to speak up.

For effective organizational learning to occur, especially the high value low cost learning from potential incidents, a climate of psychological safety is necessary. This needs an open culture and low threshold for speaking up, which is encouraged by leadership practices of maintaining accessibility, supporting both formal and informal networks and encouraging improvement and teamwork. These conditions enable the process of ‘collaborative competent improvisation’ referred to above to operate effectively.

8.4 Implications for future research

Future research is indicated as needed in the following areas:

Studies to seek further examples of adaptive leadership practices in process safety, especially relating to the successful entanglement of adaptive and administrative practices. This field is in its infancy; the limited research within this project has demonstrated the potential value to process safety of further challenge to the existing leadership paradigm, and more empirical support is to be welcomed.

Studies to further the understanding of emergent leadership. This research project has provided some evidence that this concept is implicit in Complexity Leadership but this needs further empirical support.

This research has responded to the challenges made to Leadership-As-Practice that it ignores structure by focussing entirely on agency and that it is insufficiently critical by failing to account for asymmetric power in organizations; evidence was found that refutes these challenges, in both positive and negative influences on process safety and organizational learning of contextual factors as well as leadership practices. More research in these areas is also welcomed.

The limited data used in this demonstration of the method of QCA to accident analysis indicates that obtaining more accurate and realistic case-specific information would be likely to produce more useful results. A proposal is for an industry-wide collaboration to share incident data in the form of a standardised set of around 10 factors, as a practical number for QCA software to handle, that describe each case (incident) perhaps making use of artificial intelligence and machine learning to assist the analysis of large numbers of documents.

Such a research project could yield valuable insights into configurational causation, differentiating between configurations that lead to the successful early identification of system weaknesses especially in the form of potential incidents as well as near misses and those that lead to actual incidents. Using QCA in this way offers the opportunity for a significant improvement in the understanding of accident causation within the complex socio-technical systems in which process safety incidents occur, with consequent better organizational learning leading to improved safety of high hazard technology.

This research found that organizational learning was inhibited both by institutionalization in the form of the highly procedural and compliance norms of the oil & gas and chemical industry, which tend to close down discussion and work against the creation of a climate of psychological safety, and by the over-directive administrative leadership practices found in a strong hierarchy with highly asymmetric power necessary. Contrasting evidence was also found that where a climate of was observed, there was much more effective organizational learning.

In view of the importance of organizational learning to the safe operation of high hazard technology, more research in these areas is needed, both to improve understanding of underlying mechanisms of how hierarchical power and institutional norms affect psychological safety, and also to increase the visibility of these important issues.

REFERENCES

Abbott, A. (2001) *Time Matters: on Theory and Method.* Chicago: University of Chicago Press.

Alvesson, M. and Sveningsson, S. (2003) 'Managers doing leadership: The extra-ordinarization of the mundane', *Human Relations*, 56(12), pp. 1435–1459.

Amalberti, R. and Vincent, C. (2020) 'Managing risk in hazardous conditions: Improvisation is not enough', *BMJ Quality and Safety*, 29, pp. 60–63.

Antonakis, J., Day, D. V. and Schyns, B. (2012) 'Leadership and individual differences: At the cusp of a renaissance', *Leadership Quarterly*, 23(4) Elsevier Inc., pp. 643–650.

Archer, M.S. (2010) 'Morphogenesis versus structuration: On combining structure and action', *British Journal of Sociology*, 61(SUPPL. 1), pp. 225–252.

Argote, L. (2011) 'Organizational learning research: Past, present and future', *Management Learning*, 42(4), pp. 439–446.

Argyris, C. (1977) 'Double loop learning in organizations', *Harvard Business Review*, (Sept-Oct), pp. 115–125.

Argyris, C. (1980) *Inner contradictions of rigorous research*. San Diego, CA, USA: Academic Press.

Argyris, C. and Schön, D.. (1978) *Organizational Learning: a Theory of Action Perspective*. Reading, Mass.: Addison-Wesley.

Argyris, C. and Schon, D. (1974) *Theory in practice: Increasing professional effectiveness*. San Francisco: Jossey-Bass.

Ashby, W.R. (1958) 'Requisite Variety and Its Implications for the Control of Complex Systems', *Cybernetica*, 1(2), pp. 83–99.

Ashby, W.R. (1956) *Introduction to Cybernetics*. London: Chapman & Hall.

Avolio, B.J. and Gardner, W.L. (2005) 'Authentic leadership development: Getting to the root of positive forms of leadership', *Leadership Quarterly*, 16, pp. 315–338.

Avolio, B.J., Walumbwa, F.O. and Weber, T.J. (2009) 'Leadership: Current Theories, Research, and Future Directions.', *Annual Review of Psychology*, 60(1), pp. 421–449.

Baer, M. and Frese, M. (2003) 'Innovation is not enough: Climates for initiative and psychological safety, process innovations, and firm performance', *Journal of Organizational Behavior*, 24(1), pp. 45–68.

Barnard, C. (1938) *The Functions of the Executive*. Harvard University Press.

Barringer, S.N., Eliason, S.R. and Leahey, E. (2013) 'A History of Causal Analysis in the Social Sciences', in Morgan, S. L. (ed.) *Handbook of Causal Analysis for Social Research*. Dordrecht: Springer, pp. 301–328.

Bass, B.M. (1999) 'Ethics, character, and authentic transformational leadership behavior', *Leadership Quarterly*, 10(2), pp. 181–217.

Basten, D. and Haamann, T. (2018) 'Approaches for Organizational Learning: A Literature Review', *SAGE Open*, 8(3)

Baumard, P. and Starbuck, W.H. (2005) 'Learning from failures: Why it may not happen', *Long Range Planning*, 38(3 SPEC. ISS.), pp. 281–298.

Baumgartner, M. (2008) 'Regularity theories reassessed', *Philosophia*, 36(3), pp. 327–354.

Bea, R.G. (1998) 'Human and organization factors: Engineering operating safety into offshore structures', *Reliability Engineering and System Safety*, 61(1–2), pp. 109–126.

Bennett, N. and Lemoine, G.J. (2014) 'What a difference a word makes: Understanding threats to performance in a VUCA world', *Business Horizons*, 57(3), pp. 311–317.

Bennis, W. (2007) 'The Challenges of Leadership in the Modern World', *American Psychologist*, 62(1), pp. 2–5.

Bergmann, B. and Schaeppi, J. (2016) 'A data-driven approach to group creativity', *Harvard Business Review*, July

Bhaskar, R. (2016) *Enlightened Common Sense: The Philosophy of Critical Realism*.Hartwig, M. (ed.) Routledge.

Bhaskar, R. (2008) *A Realist Theory of Science*. London: Routledge.

Birkinshaw, J. and Gupta, K. (2013) 'Clarifying the Distinctive Contribution Oe', *Academy of Management perspectives*, 27(4), pp. 287–298.

Blake, R.R., Mouton, J.S., Barnes, L.B. and Greiner, L.E. (1964) 'Breakthrough in organization development', *Harvard Business Review*, 42, pp. 37–59.

Bokeno, R.M. (2003) 'The work of Chris Argyris as critical organization practice', *Journal of Organizational Change Management*, 16(6), pp. 633–649.

Bolden, R. (2011) 'Distributed Leadership in Organizations: A Review of Theory and Research', *International Journal of Management Reviews*, 13(3), pp. 251–269.

Boulton, J., Allen, P. and Bowman, C. (2015) *Embracing Complexity*. Oxford: Oxford University Press.

Bourrier, M. (2011) 'The Legacy of the High Reliability Organization Project', *Journal of Contingencies and Crisis Management*, 19(1), pp. 9–13.

Braithwaite, G.R. (2010) 'Twenty-First Century Reliability Accident investigation and the search for systemic failures', *Safety and Reliability*, 30(3), pp. 47–57.

Brewer, J.D. (2011) 'Abduction and retroduction', in Miller, R. and Brewer, J. (eds.) *The A-Z of Social Research*. SAGE Publications Ltd.

Bryman, A. (2004) 'Qualitative research on leadership: A critical but appreciative review', *Leadership Quarterly*, 15(6), pp. 729–769.

Buchanan, D. and Huczynski, A. (2010) *Organizational Behaviour*.7th Ed. Pearson Education Ltd.

Buchanan, D.A. and Denyer, D. (2013) 'Researching Tomorrow's Crisis: Methodological Innovations and Wider Implications', *International Journal of Management Reviews*, 15(2), pp. 205–224.

Burns, T., Stalker, G.M. (1961) *The Management of Innovation*. London: Tavistock.

Burns, J.M. (1978) *Leadership*. New York: Harper & Row.

Burrell, G. and Morgan, G. (1979) *Sociological Paradigms and Organisational Analysis*. London: Routledge.

Cannon, M.D. and Edmondson, A.C. (2005) 'Failing to learn and learning to fail (intelligently): How great organizations put failure to work to innovate and improve', *Long Range Planning*, 38(3 SPEC. ISS.), pp. 299–319.

Carmeli, A. and Gittell, J.H. (2009) 'High-quality relationships, psychological safety, and learning from failures in work organizations', *Journal of Organizational Behavior*, 30, pp. 709–729.

Carroll, B. (2016) 'Leadership as identity', in Raelin, J. A. (ed.) *Leadership-As-Practice - Theory and Application*. Abingdon, UK: Routledge, pp. 91–109.

Carroll, J.S. (2002) 'Learning from Experience in High Hazard Organizations', *Research in Organizational Behavior*, 24, pp. 87–137.

CCPS (2011) *Conduct of Operations and Operational Discipline*. Hoboken, NJ, USA: John Wiley & Sons, Inc.

CCPS (2019) *Guidelines for Investigating Process Safety Incidents*.3rd Ed. Hoboken, NJ, USA: Wiley.

CCPS (2001) *Layer of Protection Analysis: Simplified Process Risk Assessment*. Hoboken, NJ, USA: Wiley.

CCPS and Energy Institute (2018) *Bow Ties in Risk Management*. Hoboken, NJ, USA: Wiley.

Chen, Q., Wood, M. and Zhao, J. (2019) 'Case study of the Tianjin accident: Application of barrier and systems analysis to understand challenges to industry loss prevention in emerging economies', *Process Safety and Environmental Protection*, 131 Institution of Chemical Engineers, pp. 178–188.

Clay-Williams, R., Hounsgaard, J. and Hollnagel, E. (2015) 'Where the rubber meets the road: Using FRAM to align work-as-imagined with work-as-done when implementing clinical guidelines', *Implementation Science*, 10(1), pp. 1–8.

Clegg, S.R., da Cunha, J.V. and e Cunha, M.P. (2002) 'Management Paradoxes: A Relational View', *Human Relations*, 55(5), pp. 483–503.

Collinson, M. (2018a) 'What's new about Leadership-as-Practice?', *Leadership*, 14(3), pp. 363–370.

Collinson, M. (2018b) 'So what is new about leadership-as-practice?', *Leadership*, 14(3), pp. 384–390.

COMAH Strategic Forum (2017) *Managing Risk : The hazards that can destroy your business A guide to leadership in process safety*.

COMPASSS (2019) *COMPASSS (COMPArative Methods for Systematic cross-caSe analySis)* COMPASSS <https://compasss.org>,

Coopey, J. and Burgoyne, J. (2000) 'Politics and organizational learning', *Journal of Management Studies*, 37(6), pp. 869–886.

Cornelissen, J.P., Mantere, S. and Vaara, E. (2014) 'The contraction of meaning: The combined effect of communication, emotions, and materiality on sensemaking in the stockwell shooting', *Journal of Management Studies*, 51(5), pp. 699–736.

Cowley, W.H. (1928) 'Three distinctions in the study of leaders.', *The Journal of Abnormal and Social Psychology*, 23(2), pp. 144–157.

Crisp, R. (2015) *Social Psychology: A Very Short Introduction*. Oxford: Oxford University Press.

Cronqvist, L. (2019) *QCA Add-In* [Version 1.1]. University of Trier, https://www.qca-addin.net,

Crossan, M.M., Lane, H.W. and White, R.E. (1999) 'An Organizational Learning Framework: From Intuition to Institution', *The Academy of Management Review*, 24(3), p. 522.

CSB (2020) *Chemical Safety Board Completed Investigations*.

Cullen, L. (1990) The public inquiry into the Piper Alpha Disaster Vol.2 *Department of Energy*.

Currie, G., Lockett, A. and Suhomlinova, O. (2009) '*The institutionalization of distributed leadership: A "Catch-22" in English public services*', 62(11), pp. 1735–1761.

Dansereau, F., Graen, G. and Haga, W.J. (1975) 'A vertical dyad linkage approach to leadership within formal organizations. A longitudinal investigation of the role making process', *Organizational Behavior and Human Performance*, 13(1), pp. 46–78.

Dekker, S. (2007) *Just Culture*. Aldershot: Ashgate Publishing Limited.

Dekker, S. (2011) 'The criminalization of human error in aviation and healthcare: A review', *Safety Science*, 49(2) Elsevier Ltd, pp. 121–127.

Dekker, S. (2003) 'Failure to adapt or adaptations that fail: Contrasting models on procedures and safety', *Applied Ergonomics*, 34(3), pp. 233–238.

Dekker, S., Cilliers, P. and Hofmeyr, J.H. (2011) 'The complexity of failure: Implications of complexity theory for safety investigations', *Safety Science*, 49(6) Elsevier Ltd, pp. 939–945.

Dekker, S. and Pruchnicki, S. (2014) 'Drifting into failure: theorising the dynamics of disaster incubation', *Theoretical Issues in Ergonomics Science*, 15(6), pp. 534–544.

Dekker, S.W. a (2002) *The re-invention of human error*.

Deming, W.E. (1951) *Elementary principles of the statistical control of quality; a series of lectures*. Tokyo: Nippon Kagaku Gijutsu Remmei.

Denis, J., Langley, A. and Sergi, V. (2012) 'Leadership in the Plural', *The Academy of Management Annals*, 6(1), pp. 211–283.

Denyer, D. and Sibbick, G. (2015) 'Towards a High Reliability Organization at CSL', in Denyer, D. and Pilbeam, C. (eds.) *Managing Change in Extreme Contexts*. London: Routledge.

Denyer, D. and Tranfield, D. (2006) 'Using qualitative research synthesis to build an actionable knowledge base', *Management Decision*, 44(2), pp. 213–227.

Denyer, D. and Turnbull James, K. (2016) 'Doing Leadership-As-Practice Development', in *Leadership-as-Practice: Theory and Application*. New York: Routledge.

DeRue, D.S. (2011) 'Adaptive leadership theory: Leading and following as a complex adaptive process.', *Research in Organizational Behavior*, 31, pp. 125–150.

Det Norske Veritas / HSE (2000) *A Comparison of Accident Experience With Quantittive Risk Assessment (QRA) Methodology*. Norwich.

Dowe, P. (2000) *Physical Causation*. New York: Cambridge University Press.

Drath, W.H., Mccauley, C.D., Palus, C.J., Velsor, E. Van, Connor, P.M.G.O. and Mcguire, J.B. (2008) 'Direction , alignment , commitment : Toward a more integrative ontology of leadership', *The Leadership Quarterly*, 19(6) Elsevier Inc., pp. 635–653.

Easterby-Smith, M., Crossan, M. and Nicolini, D. (2000) 'Organizational learning: debates past, present and future', *Journal of Management Studies*, 37(September), pp. 783–796.

Edmondson, A. (1999) 'Psychological safety and learning behavior in work teams', *Administrative Science Quarterly*, 44(2), pp. 350–383.

Edmondson, A.C. and Lei, Z. (2014) 'Psychological Safety: The History, Renaissance, and Future of an Interpersonal Construct', *Annual Review of Organizational Psychology and Organizational Behavior*, 1(1), pp. 23–43.

Eisenhardt, K.M. (1989) 'Building Theories from Case Study Research', *Academy of Management Review*, 14(4) Academy of Management, pp. 532–550.

Elder-Vass, D. (2005) 'Emergence and the Realist Account of Cause', *Journal of Critical Realism*, 4(2), pp. 315–338.

Endsley, M.R. (1999) 'Situation Awareness and Human Error : Designing to Support Human Performance', *High Consequence Systems Surety Conference*.

Endsley, M.R. (1995) 'Toward a Theory of Situation Awareness in Dynamic Systems.pdf', *Human Factors*, 37(1) Human Factors and Ergonomics Society, pp. 32–64.

Endsley, M.R. and Jones, D. (2012) *Designing for Situation Awareness*.2nd Ed. Boca Raton, FL, USA: CRC Press.

Energy Institute (2015) *Tripod beta : guidance on using Tripod beta in the investigation and analysis of incidents, accidents and business losses*. London.

English, D. and Branaghan, R.J. (2012) 'An empirically derived taxonomy of pilot violation behavior', *Safety Science*, 50(2) Elsevier Ltd, pp. 199–209.

Ensley, M.D., Hmieleski, K.M. and Pearce, C.L. (2006) 'The importance of vertical and shared leadership within new venture top management teams: Implications for the performance of startups', *Leadership Quarterly*, 17(3), pp. 217–231.

Ethiopia Aircraft Accident Investigation Bureau (2019) '*Aircraft Accident Investigation Bureau Preliminary Report March, 2019*'

European Commission (2012) Seveso-III *European Commission*.

European Commission JRC Major Accident Hazard Bureau (2020) *eMARS database*.

European Union (2012) 'Seveso III Directive: Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC', *Official Journal of the European Union*, , pp. 1–37.

Fairhurst, G.T. (2009) 'Considering context in discursive leadership research', *Human Relations*, 62(11), pp. 1607–1633.

Fairhurst, G.T. and Connaughton, S.L. (2014) 'Leadership: A communicative perspective', *Leadership*, 10(1), pp. 7–35.

Fairhurst, G.T. and Uhl-Bien, M. (2012) 'Organizational discourse analysis (ODA): Examining leadership as a relational process', *Leadership Quarterly*, 23(6) Elsevier Inc., pp. 1043–1062.

Farjoun, M. (2010) 'Beyond dualism: Stability and change as a duality', *Academy of Management Review*, 35(2), pp. 202–225.

Fayol (1916) *General and industrial administration*. Paris: École Breguet.

Festinger, L. (1957) *A Theory of Cognitive Dissonance*. Stanford: Stanford University Press.

Fiol, M. and Lyles, M. (1985) 'Organizational Learning', *Academy of Management Review*, 10(4), pp. 803–813.

Fischer, T., Dietz, J. and Antonakis, J. (2017) 'Leadership Process Models: A Review and Synthesis', *Journal of Management*, 43(6), pp. 1726–1753.

Fiss, P., Marx, A. and Cambré, B. (2013) 'Chapter 1 - Configurational Theory and Methods in Organizational Research: Introduction', in Fiss, P., Marx, A. and Cambré, B. (eds.) *Configurational Theory and Methods in Organizational Research*. Bingley: Emerald Group Publishing Limited, pp. 1–22.

Fiss, P.C. (2011) 'Building better causal theories: A fuzzy set approach to typologies in organization research', *Academy of Management Journal*, 54(2), pp. 393–420.

Flin, R. (2003) '"Danger-men at work": Management influence on safety', *Human Factors and Ergonomics In Manufacturing*, 13(4), pp. 261–268.

Flin, R. (2007) 'Measuring safety culture in healthcare: A case for accurate diagnosis', *Safety Science*, 45(6), pp. 653–667.

Flin, R., Mearns, K., O'Connor, P. and Bryden, R. (2000) 'Measuring safety climate: Identifying the common features', *Safety Science*, 34(1–3), pp. 177–192.

Flin, R., O'Connor, P. and Crichton, M. (2008) *Safety at the Sharp End*. Aldershot: Ashgate Publishing Limited.

Flin, R., Wilkinson, J. and Agnew, C. (2014) *Crew Resource Management for Well Operations teams - Report No. 501*.

Foster, C.J., Plant, K.L. and Stanton, N.A. (2019) 'Adaptation as a source of safety in complex socio-technical systems: A literature review and model development', *Safety Science*, 118, pp. 617–631.

Frese, M. and Keith, N. (2015) 'Action Errors, Error Management, and Learning in Organizations', *Annual Review of Psychology*, 66(1), pp. 661–687.

Fruhen, L.S.S., Flin, R.. H. and McLeod, R. (2013) 'Chronic unease for safety in managers: a conceptualisation', *Journal of Risk Research*, 17(May 2015), pp. 1–11.

Garvin, M.J. (1993) 'Building a Learning Organization', *Harvard business review*, July-Augus

Ghoshal, S. and Bartlett, C.A. (1994) 'Linking Organizational Context and Managerial Action : the Dimensions of Quality of Management', *Strategic Management Journal*, 15, pp. 91–112.

Gibb, C. a (1947) 'The principles and traits of leadership.', *Journal of abnormal psychology*, 42(3), pp. 267–284.

Gibson, C.B. and Birkinshaw, J. (2004) 'The antecedents, consequences, and mediating role of organizational ambidexterity', *Academy of Management Journal*, 47(2), pp. 209–226.

Giddens, A. (1984) *The Constitution of Society*. Cambridge: Polity Press.

Gittell, J.H. (2003) *The Southwest Airlines Way*. New York: McGraw Hill,.

Gittell, J.H. and Uhl-bien, M. (2016) *Relational Coordination and Complexity Leadership* Academy of Management Annual Meeting,

Godwyn, M. and Gittell, J.H. (2012) *Sociology of Organizations*. Thousand Oaks: Pine Forge Press; Sage.

Goffin, K. (2002) 'Repertory Grid Technique', in Partington, D. (ed.) *Essential Skills for Management Research*. Sage Publications.

Goffin, K. and Koners, U. (2011) 'Tacit knowledge, lessons learnt, and new product development', *Journal of Product Innovation Management*, 28(2), pp. 300–318.

Goffin, K., Lemke, F. and Szwejczewski, M. (2006) 'An exploratory study of "close" supplier-manufacturer relationships', *Journal of Operations Management*, 24(2), pp. 189–209.

Goffin, K., Raja, J.Z., Claes, B., Szwejczewski, M. and Martinez, V. (2012) 'Rigor in qualitative supply chain management research', *International Journal of Physical Distribution & Logistics Management*, 42(8/9), pp. 804–827.

Goffman, E. (1959) *The Presentation of Self in Everyday Life*. New York: Anchor Books.

Goleman, D. (2004) 'What makes a leader?', *Harvard business review*, 76(6), pp. 93–102.

Goleman, D. (1998) 'The Emotional Intelligence of Leaders', *Leader to Leader*, Fall, pp. 20–27.

Goodman, P.S., Ramanujam, R., Carroll, J.S., Edmondson, A.C., Hofmann, D.A. and Sutcliffe, K.M. (2011) 'Organizational errors: Directions for future research', *Research in Organizational Behavior*, 31, pp. 151–176.

Gordon, P. (1994) 'Robert Owen', *Prospects*, 24(1–2), pp. 279–296.

Gowland, R. (2006) 'The accidental risk assessment methodology for industries (ARAMIS)/layer of protection analysis (LOPA) methodology: A step forward towards convergent practices in risk assessment?', *Journal of Hazardous Materials*, 130(3 SPEC. ISS.), pp. 307–310.

Graeff, C.L. (1983) 'The Situational Leadership Theory: A Critical View', *The Academy of Management Review*, 8(2), p. 285.

Graen, G.B. and Uhl-Bien, M. (1995) 'Relationship-based approach to leadership: Development of leader-member exchange (LMX) theory of leadership over 25 years: Applying a multi-level multi-domain perspective', *The Leadership Quarterly*, 6(Lmx), pp. 219–247.

Green et al (1996) *Human Factors for Pilots*. Aldershot: Ashgate Publishing Limited.

Greenwood, R., Suddaby, R. and Hinings, C.R. (2002) 'Theorizing change: The role of professional associations in the transformation of institutionalized fields', *Academy of Management Journal*, 45(1), pp. 58–80.

Grice, J.W. (2002) 'Idiogrid: Software for the management and analysis of repertory grids', *Behavior Research Methods, Instruments, and Computers*, 34(3), pp. 338–341.

Grint, K. (2010) *Leadership - A Very Short Introduction*. Oxford, UK: Oxford University Press.

Grint, K. (2005) 'Problems, problems, problems: The social construction of "leadership"', *Human Relations*, 58(11), pp. 1467–1494.

Gronn, P. (2000) 'A New Architecture for Leadership', *Educational Management & Administration*, 28(200007), pp. 171–174.

Guldenmund, F.W. (2010) *Understanding and Exploring Safety Culture*. TU Delft.

Guldenmund, F.W. (2000) 'The nature of safety culture: a review of theory and research', *Safety Science*, 34, pp. 215–257.

Hackitt, J. (2012) 'Why Corporate Governance and Why Now?', *UK HSE Chair speech at OECD Corporate Governance for Process Safety conference, 14-15 June 2012*. UK HSE.

Hailwood, M. (2016) 'Learning from accidents - reporting is not enough', *Chemical Engineering Transactions*, 48, pp. 709–714.

Hale, A. and Borys, D. (2013) 'Working to rule, or working safely? Part 1: A state of the art review', *Safety Science*, 55, pp. 207–221.

Hale, A.R., Heming, B.H.J., Carthey, J. and Kirwan, B. (1997) 'Modelling of safety management systems', *Safety Science*, 26(1–2), pp. 121–140.

Hallgren, M.H., Rouleau, L. and de Rond, M. (2018) 'A Matter of Life or Death: How Extreme Context Research Matters for Management and Organization Studies', *Academy of Management Annals*, 12(1), pp. 111–153.

Handy, C. (1999) *Understanding Organizations*.4th Ed (ed.) London: Penguin.

Hannah, S.T., Uhl-Bien, M., Avolio, B.J. and Cavarretta, F.L. (2009) 'A framework for examining leadership in extreme contexts', *The Leadership Quarterly*, 20(6) Elsevier B.V., pp. 897–919.

Harris, D. and Li, W.-C.C. (2011) 'An extension of the Human Factors Analysis and Classification System for use in open systems', *Theoretical Issues in Ergonomics Science*, 12(2), pp. 108–128.

Hart, C. (1998) *Doing a Literature Review*. London: Sage Publications Ltd.

Hatch, M. and Cunliffe, A. (2006) *Organization Theory*.2nd Ed. Oxford: Oxford University Press.

Heifetz and Laurie (1997) 'The Work of Leaders', *Harvard Business Review*, (December)

Heifetz, R. a and Laurie, D.L. (2003) 'Learning to lead: Real leaders say, "I don't have the answer."', *Ivey Business Journal*, 67(3), p. 1.

Heifetz, R., Grashow, A. and Linsky, M. (2009) 'Leadership in a (permanent) crisis.', *Harvard business review*, 87, pp. 4–9.

Heinrich, H.W. (1936) *Industrial Accident Prevention*. New York: McGraw Hill,.

Helmreich, R.L. (2000) 'On error management: lessons from aviation.', *BMJ (Clinical research ed.)*, 320(7237), pp. 781–5.

Helmreich, R.L., Merritt, a C. and Wilhelm, J. a (1999) 'The evolution of Crew Resource Management training in commercial aviation.', *The International journal of aviation psychology*, 9(1), pp. 19–32.

Hernandez, M., Eberly, M.B., Avolio, B.J. and Johnson, M.D. (2011) 'The loci and mechanisms of leadership: Exploring a more comprehensive view of leadership theory', *Leadership Quarterly*, 22(6) Elsevier B.V., pp. 1165–1185.

Herzberg, F. (1959) *Motivation to Work*. John Wiley & Sons, Inc.

Herzberg, F. (1964) 'The motivation-hygiene concept and problems of manpower', *Personnel Administration*, 27(1)

Hofmann, D.A. and Frese, M. (2011) *Errors in Organizations*. New York: Routledge/Taylor & Francis Group.

Hofstede, G. (1980) *Culture's Consequences: International Differences in Work-Related Values*. Beverly Hills, CA: Sage Publications.

Holland, J.H. (2006) 'Studying complex adaptive systems', *Journal of Systems Science and Complexity*, 19(1), pp. 1–8.

Hollnagel, E. (2014) *Safety-I and Safety-II*. Aldershot: Ashgate Publishing Limited.

Hollnagel, E. (2004) *Barriers and Accident Prevention*. Aldershot: Ashgate.

Hollnagel, E. and Goteman, Ö. (2004) 'The Functional Resonance Accident Model', *Proceedings of cognitive system engineering in process plant*, (February), pp. 155–161.

Hollnagel, E., Woods, D.D. and Leveson, N. (2006) *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate Publishing Limited.

Hopkins, A. (2010) *Failure to Learn*. Sydney: CCH Australis Ltd.

Hopkins, A. (2006a) 'Studying organisational cultures and their effects on safety', *Safety Science*, 44(10), pp. 875–889.

Hopkins, A. (2006b) 'What are we to make of safe behaviour programs?', *Safety Science*, 44(7), pp. 583–597.

Hopkins, A. (2005) 'Safety, Culture and Risk: The Organisational Causes of Disasters', *CCH Australia Publishing*

Hopkins, A. (2000) *The Lessons From Longford*. Sydney: CCH Australia.

Hopkins, A. (2012) *Disastrous Decisions*. Sydney: CCH Australia.

Hopkins, A. (2009) *Learning from High Reliability Organisations*. CCH Australia.

Hopkins, A. (2007) *The Problem of Defining High Reliability Organisations*. The National Research Centre for Occupational Health and Safety Regulation, Australian National University.

House, R.J. (1971) 'A path goal theory of leader effectiveness', *Administrative science quarterly*, 16(3), pp. 321–339.

House, R.J. (1977) *A Theory of Charismatic Leadership. Working Paper Series 76-06*. Southern Illinois University Fourth Biennial Leadership Conference.

HSE (2001) *Reducing risks, protecting people*. London.

HSE (2013) *Managing for health and safety. 3rd edition.*

HSE (2007) *Leadership for the major hazard industries.*

HSE (2004) *Investigating accidents and incidents.*

HSE (n.d.) *Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable.*, *https://www.hse.gov.uk/risk/theory/alarp1.htm*

Hudson, P. (1999) 'Safety Culture-Theory and Practice', *RTO HEM Workshop on "The Human Factor in System Reliability - Is Human Performance Predictable? "*

Hudson, P. (2014) 'Accident causation models, management and the law', *Journal of Risk Research*, 17(6) Routledge, pp. 749–764.

Hudson, P.T.W. and Hudson, T. (2015) 'Integrating Cultural and Regulatory Factors in the Bowtie: Moving from Hand-Waving to Rigor', in Ibrahamapour, V. and Yacout, S. (eds.) *Ontology Modeling in Physical Asset Integrity Management.* Springer, pp. 1–264.

Huettermann, H., Doering, S. and Boerner, S. (2014) 'Leadership and team identification: Exploring the followers' perspective', *Leadership Quarterly*, 25(3) Elsevier Inc., pp. 413–432.

Hulme, A., Stanton, N.A., Walker, G.H., Waterson, P. and Salmon, P.M. (2019) 'What do applications of systems thinking accident analysis methods tell us about accident causation? A systematic review of applications between 1990 and 2018', *Safety Science*, 117(March) Elsevier, pp. 164–183.

Hume, D. (1777) *An Enquiry concerning Human Understanding - Edited with an Introduction and Notes by P Millican.* Oxford University Press.

IAEA (2013) *Managing Human Performance to Improve Nuclear Facility Operation.*

ICI (1979) *Hazard Analysis Course Notes - University of Queensland.*

IEC (2015) *Functional Safety* International Electrotechnical Commission, Geneva

ILO (1991) *Prevention of Major Industrial Accidents.* Geneva.

ILO (2001) *Guidelines on Occupational Safety and Health Management Systems.* Geneva.

IOGP (2013) *Shaping safety culture through safety leadership Report No 452.*

IPIECA and OGP (2014) '*Operating Management System Framework*', (OGP Report No. 510), p. 44.

ISO (2018) *ISO 45000:2018 Occupational health and safety management systems — Requirements with guidance for use* ISO, Geneva

Jackson, B. and Parry, K. (2011) *A Very Short, Fairly Interesting and Reasonably Cheap Book About Studying Leadership.*2nd Ed. London: SAGE Publications Ltd.

Jackson, K. and Bazely, P. (2019) *Qualitative Data Analysis with NVivo.* 3rd edn. London: Sage Publications.

Jackson, Thomas and Millet (eds.) (2007) *Software for Dependable Systems.* Washington DC: National Academies Press.

Jankowicz, D. (2004) *The Easy Guide to Repertory Grids.* Chichester: Wiley.

Jansen, J.J.P., Vera, D. and Crossan, M. (2009) 'Strategic leadership for exploration and exploitation: The moderating role of environmental dynamism', *The Leadership Quarterly*, 20(1) Elsevier Inc., pp. 5–18.

Johnson, P., Buehring, A., Cassell, C. and Symon, G. (2006) 'Evaluating qualitative management research: Towards a contingent criteriology', *International Journal of Management Reviews*, 8(3), pp. 131–156.

Jordan, E., Gross, M.E., Javernick-Will, A.N. and Garvin, M.J. (2011) 'Use and misuse of qualitative comparative analysis', *Construction Management and Economics*, 29(11), pp. 1159–1173.

Jules, C. and Good, D. (2014) 'Introduction to Special Issue on Paradox in Context: Advances in Theory and Practice', *Journal of Applied Behavioral Science*, 50(2), pp. 123–126.

Kahn, W.A. (1990) 'Psychological conditions of personal engagement and disengagement at work', *Academy of Management Journal*, 33(4), pp. 692–724.

Kanki, B., Helmreich, R. and Anca, J. (2010) *Crew Resource Management*.2nd Editio. San Diego, CA, USA: Academic Press.

Katz, B.R.L. (1960) 'Toward a More Effective Enterprise', *Harvard Business Review*

Kelly, G. (1955) *The psychology of personal constructs. Vol. 1. A theory of personality. Vol. 2. Clinical diagnosis and psychotherapy*. Oxford: Norton.

Kelly, G. (1963) *A Theory of Personality - The Psychology of Personal Constructs*. New York: Norton.

Kempster, S. and Gregory, S.H. (2017) '"Should I Stay or Should I go?" Exploring Leadership-as-Practice in the Middle Management Role', *Leadership*, 13(4), pp. 496–515.

Kempster, S. and Parry, K.W. (2011) 'Grounded theory and leadership research: A critical realist perspective', *Leadership Quarterly*, 22(1) Elsevier B.V., pp. 106–120.

Khan, F.I. and Abbasi, S. a. (1999) 'Major accidents in process industries and an analysis of causes and consequences', *Journal of Loss Prevention in the Process Industries*, 12(5), pp. 361–378.

Kirkpatrick, S. a. and Locke, E. a. (1991) 'Leadership: do traits matter?', *Executive*, 5(2), pp. 48–60.

Kletz, T.A. (1993) *Lessons from disaster - How organisations have no memory and accidents recur*. London: Institution of Chemical Engineers.

Krause, T. (1990) *The Behaviour-Based Safety Process*. New York: Van Nostrand Reinhold.

Krook, M.L. (2010) 'Women's Representation in Parliament: A Qualitative Comparative Analysis', *Political Studies*, 58(5), pp. 886–908.

Ladkin, D. (2010) *Rethinking Leadership*. Cheltenham, UK: Edward Elgar.

Ladkin, P.B. (2005) *Why-Because Analysis of the Glenbrook, NSW Rail Accident and Comparison with Hopkins' Accimap*. University of Bielefeld.

Ladkin, P.B. and Loer, K. (2001) *Explaining Accidents Causally Using Why-Because Analysis (WBA)*. University of Bielefeld.

Larouzée, J. and Guarnieri, F. (2015) 'From theory to practice: Itinerary of Reason's Swiss cheese Model', *Safety and Reliability of Complex Engineered Systems - Proceedings of the 25th European Safety and Reliability Conference, ESREL 2015*, (January 2018), pp. 817–824.

Lawrence, P.R. and Lorsch, J.W. (1967) 'Differentiation and Integration in Complex Organizations', *Administrative Science Quarterly*, 12, pp. 1–47.

Lawton, R. and Parker, D. (2002) 'Barriers to incident reporting', *Quality and Safety in Health Care*, 11(1), p. 7.

Lei, Z., Naveh, E. and Novikov, Z. (2016) 'Errors in Organizations: An Integrative Review via Level of Analysis, Temporal Dynamism, and Priority Lenses', *Journal of Management*, 42(5), pp. 1315–1343.

Lekka, C. (2011) 'High reliability organisations High reliability organisations A review of the literature', *Health and Safety Executive*

Lemke, F., Clark, M. and Wilson, H. (2011) 'Customer Experience Quality: An exploration in business and consumer contexts using repertory grid technique', *Journal of the Academy of Marketing Science*, 39, pp. 846–869.

Leveson, N. (2011) *Engineering a Safer World - Systems Thinking Applied to Safety*. Cambridge, Massachusetts: The MIT Press.

Leveson, N. (2004) 'A new accident model for engineering safer systems', *Safety Science*, 42(4), pp. 237–270.

Leveson, N., Dulac, N., Marais, K. and Carroll, J. (2009) 'Moving Beyond Normal Accidents and High Reliability Organizations: A Systems Approach to Safety in Complex Systems', *Organization Studies*, 30(2–3), pp. 227–249.

Levitt, B. and March, J.G. (1988) 'Organizational Learning', *Annual Review of Sociology*, 14, pp. 319–337.

Levy, M., Pliskin, N. and Ravid, G. (2010) 'Studying decision processes via a knowledge management lens: The Columbia space shuttle case', *Decision Support Systems*, 48(4) Elsevier B.V., pp. 559–567.

Lewin, Kurt, Lippit, R., White, R.K. (1939) 'Patterns of aggressive behavior in experimentally created social climates', *The Journal of Social Psychology*, 10, pp. 271–299.

Lewis, D. (1973) 'Causation', *The Journal of Philosophy*, 70(17), pp. 556–567.

Lewis, M. (2000) 'Exploring Paradox: Toward a More Comprehensive Guide', *Academy of Management Review*, 25(41)

Lewis, M.W., Andriopoulos, C. and Smith, W.K. (2014) 'Paradoxical leadership to enable strategic agility', *California Management Review*, 56(3), pp. 58–77.

Lewis, M.W. and Smith, W.K. (2014) 'Paradox as a Metatheoretical Perspective: Sharpening the Focus and Widening the Scope', *The Journal of Applied Behavioral Science*, 50(2), pp. 127–149.

Li, Y. and Guldenmund, F.W. (2018) 'Safety management systems: A broad overview of the literature', *Safety Science*, 103(November 2017) Elsevier, pp. 94–123.

Lichtenstein, B.B. (2000) 'Self-organized transitions: A pattern amid the chaos of transformative change.', *Academy of Management Perspectives*, 14(4), pp. 128–141.

Lichtenstein, B.B. and Plowman, D.A. (2009) 'The leadership of emergence: A complex systems leadership theory of emergence at successive organizational levels', *Leadership Quarterly*, 20(4) Elsevier Inc., pp. 617–630.

Lindberg, A.K., Hansson, S.O. and Rollenhagen, C. (2010) 'Learning from accidents - What more do we need to know?', *Safety Science*, 48(6) Elsevier Ltd, pp. 714–721.

Lundberg, J., Rollenhagen, C. and Hollnagel, E. (2009) 'What-You-Look-For-Is-What-You-Find - The consequences of underlying accident models in eight accident investigation manuals', *Safety Science*, 47(10) Elsevier Ltd, pp. 1297–1311.

Lupher, T. (2009) 'A physical critique of physical causation', *Synthese*, 167(1), pp. 67–80.

Mackie, J. (1974) *The Cement of the Universe: A Study of Causation*. Clarendon Press: Oxford University Press.

Mahoney, J. and Goertz, G. (2012) 'Scope in Case Study Research', in Byrne, D. and Ragin, C. C. (eds.) *The SAGE Handbook of Case-Based Methods*. SAGE Publications Ltd, pp. 307–317.

Marais, K., Dulac, N. and Leveson, N. (2004) 'Beyond Normal Accidents and High Reliability Organizations : The Need for an Alternative Approach to Safety in Complex', *Engineering Systems Division Symposium, MIT, Cambridge,.*, pp. 1–16.

March, J.G. (1991) 'Exploration and Exploitation in Organizational Learning', *Organization Science*, 2(1) JSTOR, pp. 71–87.

Marion, R. and Uhl-Bien, M. (2007) 'Introduction to the Special Issue on Leadership and Complexity', *Leadership Quarterly*, 18(4), pp. 293–296.

Marion, R. and Uhl-Bien, M. (2001) 'Leadership in complex organizations', *The Leadership Quarterly*, 12(4), pp. 389–418.

Maslow, a. H. (1943) 'A theory of human motivation.', *Psychological Review*, 50(4), pp. 370–396.

Mastaglio, T., Wilkinson, J.J., Jones, P.N., Bliss, J.P. and Barnett, J.S. (2011) *Current Practice and Theoretical Foundations of the After Action Review* United States Army Research Institute for the Behavioral and Social Sciences,

McGregor, D. (1960) *The Human Side of the Enterprise*. McGraw-Hill Books.

McLeod, R.W. (2015) *Designing for Human Reliability*. Kidlington, Oxon UK: Gulf Professional Publishing.

McLeod, R.W. and Bowie, P. (2018) 'Bowtie Analysis as a prospective risk assessment technique in primary healthcare', *Policy and Practice in Health and Safety*, 16(2) Informa UK Ltd., pp. 177–193.

Meshkati, N. (1991) 'Human factors in large-scale technological systems' accidents: Three Mile Island, Bhopal, Chernobyl', *Organization & Environment*

Micheli, P., Jaina, J., Goffin, K., Lemke, F. and Verganti, R. (2012) 'Perceptions of industrial design: The "means" and the "ends"', *Journal of Product Innovation Management*, 29(5), pp. 687–704.

Middlemas, S.G., Croft, H.G. and Watson, F. (2018) 'Behind closed doors: The role of debriefing and feedback in a professional rugby team', *International Journal of Sports Science and Coaching*, 13(2), pp. 201–212.

Miles and Huberman (1994) *Qualitative Data Analysis*.2nd Editio. Thousand Oaks, CA: Sage Publications.

Mill, J.S. (1882) *A system of logic, ratiocinative and inductive : being a connected view of the principles of evidence, and methods of scientific investigation by John Stuart Mill.*8th Editio. New York: Harper & Brothers.

Milosevic, I., Bass, A.E. and Combs, G.M. (2018) 'The Paradox of Knowledge Creation in a High-Reliability Organization: A Case Study', *Journal of Management*, 44(3), pp. 1174–1201.

Mintzberg, H. (1980) 'Structure in 5'S: a Synthesis of the Research on Organization Design.', *Management Science*, 26(3), pp. 322–341.

Mitchell, T.R., Biglan, a., Oncken, G.R. and Fiedler, F.E. (1970) 'The Contingency Model: Criticism and Suggestions.', *Academy of Management Journal*, 13, pp. 253–267.

Moure-Eraso, R. (2015) 'On Tenth Anniversary of Tragic Explosion and Fire at BP Texas City Refinery, CSB Chairman Releases Safety Message Calling Attention to the Continued Need for Safety Improvements', *US Chemical Safety Board*

Mullerbeck, E. (2015) *After Action Review - Continuous improvement of ongoing projects or initiatives*. UNICEF Knowledge Exchange Toolbox.

Mumford, S. and Anjum, R.L. (2013) *Causation A Very Short Introduction*. Oxford: Oxford University Press.

Murphy, J., Rhodes, M.L., Meek, J.W. and Denyer, D. (2017) 'Managing the Entanglement: Complexity Leadership in Public Sector Systems', *Public Administration Review*, 77(5), pp. 692–704.

Newman, A., Donohue, R. and Eva, N. (2017) 'Psychological safety: A systematic review of the literature', *Human Resource Management Review*, 27(3) Elsevier Inc., pp. 521–535.

O'Reilly, C.A. and Tushman, M.L. (2008) 'Ambidexterity as a dynamic capability: Resolving the innovator's dilemma', *Research in Organizational Behavior*, 28, pp. 185–206.

O'Reilly, C.I. and Tushman, M.L. (2013) 'Organizational Ambidexterity: Past, Present, and Future.', *The Academy of Management Perspectives*, 27(4), pp. 324–338.

OECD (2012) *Corporate Governance for Process Safety*.

Oliver, N., Calvard, T. and Potočnik, K. (2017) 'Cognition, Technology, and Organizational Limits: Lessons from the Air France 447 Disaster', *Organization Science*, 28(4), pp. 729–743.

Örtenblad, A. (2001) 'On differences between organizational learning and learning organization', *The Learning Organization*, 8(3), pp. 125–133.

Osborn, R.N. and Hunt, J.G. (J) (2007) 'Leadership and the choice of order: Complexity and hierarchical perspectives near the edge of chaos', *Leadership Quarterly*, 18(4), pp. 319–340.

Osborn, R.N., Hunt, J.G. and Jauch, L.R. (2002) 'Toward a contextual theory of leadership', *Leadership Quarterly*, 13, pp. 797–837.

Osborn, R.N. and Marion, R. (2009) 'Contextual leadership, transformational leadership and the performance of international innovation seeking alliances', *Leadership Quarterly*, 20(2) Elsevier Inc., pp. 191–206.

OSHA (n.d.) *Process Safety Management of Highly Hazardous Chemicals standard (29 CFR 1910.119)* OSHA, Washington DC

OSHA (2016) *The Importance of Root Cause Analysis During Incident Investigation*.

OSHA (2015) 'Incident (Accident) Investigations: A Guide for Employers', *United States Department of Labor - Occupational Safety and Health Administration*, , pp. 1–14.

Outhwaite, W. (2019) 'Book review: Enlightened Common Sense: The Philosophy of Critical Realism', *European Journal of Social Theory*, 22(1), pp. 127–130.

Owen, R. (1857) *The Life of Robert Owen , written by himself*

Parker, D., Lawrie, M. and Hudson, P. (2006) 'A framework for understanding the development of organisational safety culture', *Safety Science*, 44(6), pp. 551–562.

Pedler, M. and Burgoyne, J. (2011) 'Action Learning', in Reason, P. and Bradbury, H. (eds.) *The Sage Handbook of Action Research*. Sage Publications Ltd, pp. 319–332.

Pendleton and Furnham (2011) *Leadership: All You Need To Know*. Basingstoke: Palgrave Macmillan.

Perneger, T. V. (2005) 'The Swiss cheese model of safety incidents: Are there holes in the metaphor?', *BMC Health Services Research*, 5, pp. 1–7.

Perrow, C. (1984) *Normal Accidents: Living with High-Risk Technologies*. Basic Books.

Petzinger, T; Mintzberg, H; Prusack, L; Senge, P. (1999) 'The Gurus Speak: Complexity and Organizations', *Emergence: Complexity & Organization*, 28(1), pp. 109–119.

Phimister, J.R., Oktem, U., Kleindorfer, P.R. and Kunreuther, H. (2003) 'Near-miss incident management in the chemical process industry', *Risk Analysis*, 23(3), pp. 445–459.

Phipps, D.L. and Parker, D. (2014) 'A naturalistic decision-making perspective on anaesthetists' rule-related behaviour', *Cognition, Technology & Work*, 16(4), pp. 519–529.

Pidcock, L. (2016) *Corporate Heritage Brands and Characteristics that Affect Potential Applicants ' Perceptions of Organisational Attractiveness Submitted by*. Cranfield.

Pilbeam, C., Davidson, R., Doherty, N. and Denyer, D. (2016) 'What learning happens? Using audio diaries to capture learning in response to safety-related events within retail and logistics organizations', *Safety Science*, 81 Elsevier Ltd, pp. 59–67.

Pillay, M. (2015) 'Accident Causation, Prevention and Safety Management: A Review of the State-of-the-art', *Procedia Manufacturing*, 3, pp. 1838–1845.

Pindur, W., Rogers, S.E. and Kim, P.S. (1995) 'The history of management: a global perspective', *Journal of Management History*, 1(1), pp. 59–77.

Pitblado, R., Potts, T., Fisher, M. and Greenfield, S. (2015) 'A Method for Barrier-Based Incident Investigation', *Process Safety Progress*, 34(4), pp. 326–330.

La Porte, T.R. (1996) 'High Reliability Organizations: Unlikely, Demanding and At Risk.', *Journal of Contingencies & Crisis Management*, 4(2), pp. 60–71.

Process Safety Leadership Group (2008) *Principles of Process Safety Leadership*. London.

Qureshi, Z. (2008) *A review of accident modelling approaches for complex socio-technical systems* Australian Government Department of Defence,

Raelin, J. (2011) 'From leadership-as-practice to leaderful practice', *Leadership*, 7(2), pp. 195–211.

Raelin, J.A. (2016a) 'Introduction', in *Leadership-As-Practice - Theory and Application*.

Raelin, J.A. (2016b) *Leadership-As-Practice - Theory and Application.*Raelin, J. (ed.) New York: Routledge.

Raelin, J.A. (2018) 'What are you afraid of: Collective leadership and its learning implications', *Management Learning*, 49(1), pp. 59–66.

Ragin, C.C. (1987) *The Comparative Method.* Oakland California: UCAL Press.

Ragin, C.C. (2007) 'Qualitative Comparative Analysis Using Fuzzy Sets (fsQCA)', in Rihoux, B. and Ragin, C. (eds.) *Configurational Comparative Analysis*. Sage Publications, pp. 87–121.

Ragin, C.C. (2017) *User's Guide to Fuzzy-Set Qualitative Comparative Analysis 3.0*. Irvine, California.

Ragin, C.C. and Sonnett, J. (2004) 'Between Complexity and Parsimony: Limited Diversity, Counterfactual Cases, and Comparative Analysis', *e-Scholarship*, , pp. 1–19.

Raisch, S., Birkinshaw, J., Probst, G. and Tushman, M.L. (2009) 'Organizational Ambidexterity: Balancing Exploitation and Exploration for Sustained Performance', *Organization Science*, 20(4), pp. 685–695.

Raja, J.Z., Bourne, D., Goffin, K., Çakkol, M. and Martinez, V. (2013) 'Achieving customer satisfaction through integrated products and services: An exploratory study', *Journal of Product Innovation Management*, 30(6), pp. 1128–1144.

Rasmussen, J. (1997) 'Risk management in a dynamic society - A modelling problem', *Safety Science*, 27(2–3), pp. 183–213.

Rasmussen, J. and Lind, M. (1982) *A Model of Human Decison Making in Complex Systems and its use for Design of System Control Strategies*. Riso National Laboratory, Denmark.

Reason, J. (1990a) 'The Contribution of Latent Human Failures', *Philosophical Transactions of the Royal Society of London*, 327, pp. 475–484.

Reason, J. (1990b) *Human Error*. Cambridge: Cambridge University Press.

Reason, J. (2008) *The Human Contribution*. Farnham: Ashgate Publishing Limited.

Reason, J. (2016) *Organizational Accidents Revisited.* Farnham: Ashgate Publishing Limited.

Reason, J. (1998) 'Achieving a safe culture: Theory and practice', *Work and Stress*, 12(3), pp. 293–306.

Reason, J., Hollnagel, E. and Paries, J. (2006) 'Revisiting the "Swiss Cheese" Model of Accidents', *European Organisation for the Safety os Air Navigation*, 12(13), pp. 93–129.

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), pp. 289–304.

Reason, J.T. (1997) *Managing the risks of organizational accidents*. Farnham: Ashgate.

Rego, L. and Garau, R. (2007) '*Stepping into the Void*', Center for Creative Leadership.

Reiter-Palmon, R., Kennel, V., Allen, J.A., Jones, K.J. and Skinner, A.M. (2015) 'Naturalistic decision making in after-action review meetings: The implementation of and learning from post-fall huddles', *Journal of Occupational and Organizational Psychology*, 88(2), pp. 322–340.

Revans, R. (1982) *The Origins and Growth of Action Learning*. Bromley: Chartwell Bratt.

Rhodes, C. (1998) 'Book Review: Chris Argyris and Donald Schon (1996) Organizational Learning II: Theory, method and practice', *Asia Pacific Journal of Human Resources*, 36(1), pp. 107–109.

Rihoux, B. and De Meur, G. (2009) 'Crisp-Set Qualitative Comparative Analysis', in Rihoux, B. and Ragin, C. C. (eds.) *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques*. Thousand Oaks: Sage Publications, Inc.

Rihoux, B., Ragin, C., Berg-Schlosser, D., Meur, G. De, Rihoux, B. and Ragin, C.C. (2009) 'Qualitative Comparative Analysis (QCA) as an Approach', in Rihoux, B. and Ragin, C. C. (eds.) *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques*. Thousand Oaks: SAGE Publications, Inc, pp. 1–18.

Roberts, K.H. (1990) 'Some Characteristics of One Type of High Reliability Organization', *Organization Science*, 1(2), pp. 160–176.

Roberts, K.H. (2009) 'Book Review Essay Managing the Unexpected : Six Years of HRO-Literature Reviewed', *Journal of Contingencies and Crisis Management*, 17(1)

Roberts, K.H., Rousseau, D.M. and La Porte, T.R. (1994) 'The culture of high reliability: quantitative and qualitative assessment aboard nuclear-powered aircraft carriers', *The Journal of High Technology Management Research*, 5(1), pp. 141–161.

Rochlin, G., La Porte, T. and Roberts, K. (1987) 'The self-designing high-reliability organization: Aircraft carrier flight operations at sea', *Naval War College Review*, 40(4), p. 97.

Rochlin, G.I. (2011) 'How to Hunt a Very Reliable Organization', *Journal of Contingencies and Crisis Management*, 19(1), pp. 14–20.

Roig-Tierno, N., Gonzalez-Cruz, T.F. and Llopis-Martinez, J. (2017) 'An overview of qualitative comparative analysis: A bibliometric analysis', *Journal of Innovation and Knowledge*, 2(1) Journal of Innovation & Knowledge, pp. 15–23.

Rosenhead, J., Franco, L.A., Grint, K. and Friedland, B. (2019) 'Complexity theory and leadership practice: A review, a critique, and some recommendations', *Leadership Quarterly*, 30(5) Elsevier, p. 101304.

Rost, J. (1995) 'Leadership: A Discussion About Ethics', *Business Ethics Quarterly*, 5(1), pp. 129–143.

Rubinson, C. (2019) *Avoiding Common Errors in QCA: A Short Guide for New Practitioners.*, *COMPASSS website <www.compasss.org>*

de Ruijter, A. and Guldenmund, F. (2016) 'The bowtie method: A review', *Safety Science*, 88 Elsevier Ltd, pp. 211–218.

Sagan, S.D. (1995) *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. Princeton University Press.

Sagan, S.D. (2004) 'The problem of redundancy problem: why more nuclear security forces may produce less nuclear security.', *Risk analysis : an official publication of the Society for Risk Analysis*, 24(4), pp. 935–46.

Sandberg, J. and Alvesson, M. (2020) 'Meanings of Theory: Clarifying Theory through Typification', *Journal of Management Studies*

Van Der Schaaf, T. and Kanse, L. (2004) 'Biases in incident reporting databases: An empirical study in the chemical process industry', *Safety Science*, 42(1), pp. 57–67.

Schein, E. (2004) *Organizational Culture and Leadership*.3rd Ed. San Francisco: Jossey-Bass.

Schilling, J. and Kluge, A. (2009) 'Barriers to organizational learning: An integration of theory and research', *International Journal of Management Reviews*, 11(3), pp. 337–360.

Schneider, C.Q. and Grofman, B. (2006) 'It might look like a regression ... but it's not! An intuitive approach to the presentation of QCA and fs/QCA results', *Conference on "Comparative Politics: Empirical Applications of Methodological Innovations", Sophia University, Tokyo (Japan), 15 - 17. July 2006*., pp. 15–17.

Schneider, C.Q. and Wagemann, C. (2012) *Set-Theoretic Methods for the Social Sciences: A Guide to Qualitative Comparative Analysis*. Cambridge: Cambridge University Press.

Schneider, M. and Somers, M. (2006) 'Organizations as complex adaptive systems: Implications of Complexity Theory for leadership research', *Leadership Quarterly*, 17, pp. 351–365.

Scott, R.W. (1994) 'Institutions and Organizations: toward a Theoretical Synthesis', in Scott, W. R. and Meyer, J. W. (eds.) *Institutional Environments and Organizations: Structural Complexity and Individualism*. Thousand Oaks, CA: Sage Publications.

Senge, P. (2002) 'Introduction', in Darling, M. and Parry, C. (eds.) *From Post-Mortem to Living Practice - As in-depth study of the evolution of the After Action Review*. Signet Consulting Group.

Senge, P.M. (1990) *The Fifth Discipline*. New York: Doubleday.

Seshia, S.S., Bryan Young, G., Makhinson, M., Smith, P.A., Stobart, K. and Croskerry, P. (2018) 'Gating the holes in the Swiss cheese (part I): Expanding professor Reason's model for patient safety', *Journal of Evaluation in Clinical Practice*, 24(1), pp. 187–197.

Shappell, S.A. and Wiegmann, D.A. (2000) *The Human Factors Analysis and Classification System - HFACS* US DOT Office of Aviation Medicine,

Shrivastava, P. (1985) The Lessons of Bhopal, *Business and Society Review*,

Smith, W., Erez, M., Jarvenpaa, S., Lewis, M.W. and Tracey, P. (2017) 'Adding Complexity to Theories of Paradox, Tensions, and Dualities of Innovation and Change: Introduction to Organization Studies Special Issue on Paradox, Tensions, and Dualities of Innovation and Change', *Organization Studies*, 38(3–4), pp. 303–317.

Smith, W.K. and Besharov, M.L. (2019) 'Bowing before Dual Gods: How Structured Flexibility Sustains Organizational Hybridity', *Administrative Science Quarterly*, 64(1), pp. 1–44.

Smith, W.K. and Lewis, M.W. (2011) 'Toward a theory of paradox: A dynamic equilibrium model of organizing', *Academy of Management Review*, 36(2), pp. 381–403.

Smith, W.K. and Lewis, M.W. (2012) 'Leadership Skills for Managing Paradoxes', *Industrial and Organizational Psychology*, 5(2), pp. 227–231.

Snowden, D.J. and Boone, M.E. (2007) 'A Leader ' s Framework for Decision Making A Leader ' s Framework for Decision Making', *Harvard Business Review*, November, pp. 68–76.

Spector, H. (2011) 'The MMTS Analysis of Causation', in Goldberg, R. (ed.) *Perspectives on Causation*. Oxford and Portland, Oregon: Hart Publishing.

Spurgin, A. (2010) *Human Reliability Assessment*. Boca Raton, FL, USA: CRC Press.

Stogdill, R.M. (1948) 'Personal factors associated with leadership; a survey of the literature', *The Journal of Psychology*, 25, pp. 35–71.

Stoop, J. and Benner, L. (2015) 'What do STAMP-based Analysts Expect from Safety Investigations?', *Procedia Engineering*, 128, pp. 93–102.

Strauch, B. (2015) 'Can we examine safety culture in accident investigations, or should we?', *Safety Science*, 77, pp. 102–111.

Strevens, M. (2003) 'Against Lewis's new theory of causation: A story with three morals', *Pacific Philosophical Quarterly*, 84(4), pp. 398–412.

Suddaby, R. and Greenwood, R. (2005) 'Rhetorical Strategies of Legitimacy', *Administrative Science Quarterly*, 50(March)

Summers, A., Vogtmann, W. and Smolen, S. (2011) 'Improving PHA/LOPA by consistent consequence severity estimation', *Journal of Loss Prevention in the Process Industries*, 24(6) Elsevier Ltd, pp. 879–885.

Suppes, P. (1970) *A probabilistic theory of causality*. Amsterdam: North-Holland.

Sutcliffe, K.M. (2011) 'High reliability organizations (HROs)', *Best Practice and Research: Clinical Anaesthesiology*, 25(2) Elsevier Ltd, pp. 133–144.

Svedung, I. and Rasmussen, J. (2002) 'Graphic representation of accident scenarios: Mapping system structure and the causation of accidents', *Safety Science*, 40(5), pp. 397–417.

Swart, J., Turner, N., van Rossenberg, Y. and Kinnie, N. (2016) 'Who does what in enabling ambidexterity? Individual Actions and HRM practices', *International Journal of Human Resource Management*, 30(4) Routledge, pp. 508–535.

Taleb, N.N. (2007) 'Black Swans and the domains of statistics', *American Statistician*, 61(3), pp. 198–200.

Tan, F.B. and Hunter, M.G. (2002) 'The Repertory Grid Technique: A Method for the Study of Cognition in Information Systems', *MIS Quarterly*, 26(1), pp. 39–57.

Taylor, F. (1911) *The principles of scientific management*. New York: Harper & Brothers.

Thiem, A. and Dusa, A. (2013) 'QCA : A Package for Qualitative Comparative Analysis', *The R Journal*, 5(1), pp. 87–97.

Thomas, M. (2008) '*Confidence in System Safety*', 3rd IET International Conference on System Safety.

Tourish, D. (2019) 'Is Complexity Leadership Theory Complex Enough? A critical appraisal, some modifications and suggestions for further research', *Organization Studies*, 40(2), pp. 219–238.

Tourish, D. (2014) 'Leadership, more or less? A processual, communication perspective on the role of agency in leadership theory', *Leadership*, 10(1), pp. 79–98.

Tranfield, D., Denyer, D. and Smart, P. (2003) 'Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review', *British Journal of Management*, 14(3) Blackwell Publishing Ltd., pp. 207–222.

Tsoukas, H. and Dooley, K.J. (2011) 'Introduction to the Special Issue: Towards the Ecological Style: Embracing Complexity in Organizational Research', *Organization Studies*, 32(6), pp. 729–735.

Turner, B.A. and Pidgeon, N.F. (1997) *Man-Made Disasters*.2nd Editio. Oxford: Butterworth/ Heinemann.

Turner, N. and Lee-Kelley, L. (2013) 'Unpacking the theory on ambidexterity: An illustrative case on the managerial architectures, mechanisms and dynamics', *Management Learning*, 44(2), pp. 179–196.

Turner, N., Swart, J. and Maylor, H. (2013) 'Mechanisms for managing ambidexterity: A review and research agenda', *International Journal of Management Reviews*, 15(3), pp. 317–332.

Tyler, T.R. and Blader, S.L. (2005) 'Can businesses effectively regulate employee conduct? The antecedents of rule following in work settings', *Academy of Management Journal*, 48(6), pp. 1143–1158.

Uhl-Bien, M. (2006) 'Relational Leadership Theory: Exploring the social processes of leadership and organizing', *The Leadership Quarterly*, 17(6), pp. 654–676.

Uhl-Bien, M. and Arena, M. (2018) 'Leadership for organizational adaptability: A theoretical synthesis and integrative framework', *Leadership Quarterly*, 29(1) Elsevier, pp. 89–104.

Uhl-Bien, M. and Arena, M. (2017) 'Complexity leadership: Enabling people and organizations for adaptability', *Organizational Dynamics*, 46(1) Elsevier Inc., pp. 9–20.

Uhl-Bien, M. and Marion, R. (2008) *Complexity Leadership Part 1: Conceptual Foundations*. Charlotte, NC: Information Age Publishing, Inc.

Uhl-Bien, M. and Marion, R. (2009) 'Complexity leadership in bureaucratic forms of organizing: A meso model', *Leadership Quarterly*, 20(4) Elsevier Inc., pp. 631–650.

Uhl-Bien, M., Marion, R. and McKelvey, B. (2007) 'Complexity Leadership Theory: Shifting leadership from the industrial age to the knowledge era', *The Leadership Quarterly*, 18, pp. 298–318.

Uhl-Bien, M., Riggio, R.E., Lowe, K.B. and Carsten, M.K. (2014) 'Followership theory: A review and research agenda', *The Leadership Quarterly*, 25(1) Elsevier Inc., pp. 83–104.

UKHSE (2005) '*Offshore Installations (Safety Case) Regulations 2005 (SCR05)*'

Underwood, P. and Waterson, P. (2014) 'Systems thinking, the Swiss Cheese Model and accident analysis: A comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models', *Accident Analysis and Prevention*, 68 Elsevier Ltd, pp. 75–94.

Underwood, P. and Waterson, P. (2013) 'Systemic accident analysis: Examining the gap between research and practice', *Accident Analysis and Prevention*, 55 Elsevier Ltd, pp. 154–164.

Underwood, P. and Waterson, P. (2012) 'A critical review of the STAMP, FRAM and Accimap systemic accident analysis models', in Stanton, N. (ed.) *Advances in Human Aspects of Road and Rail Transportation*. London: CRC Press.

United States Department of Defense (1949) *Procedures for performing a failure mode effect and critical analysis - MIL-P-1629 -*.

Vaughan, D. (1997a) *The Challenger Launch Decision*. Chicago: University of Chicago Press.

Vaughan, D. (1997b) 'The Trickle-Down Effect: Policy Decisions, Risky Work, and the Challenger Tragedy', *California Management Review*, 39(2)

Vince, R. (2018) 'The learning organization as paradox: Being for the learning organization also means being against it', *Learning Organization*, 25(4), pp. 273–280.

Vink, M.P. and van Vliet, O. (2009) 'Not quite crisp, not yet fuzzy? assessing the potentials and pitfalls of multi-value QCA', *Field Methods*, 21(3), pp. 265–289.

Visscher, G. (2008) 'Some observations about major chemical accidents from recent CSB investigations', *Institution of Chemical Engineers Symposium Series*, 7412(154), pp. 34–48.

Vogus, T.J. and Sutcliffe, K.M. (2007) 'The Safety Organizing Scale', *Medical Care*, 45(1), pp. 46–54.

Vogus, T.J. and Sutcliffe, K.M. (2012) 'Organizational mindfulness and mindful organizing: A reconciliation and path forward', *Academy of Management Learning and Education*, 11(4), pp. 722–735.

Vroom, V.H. (1964) *Work and Motivation*. Oxford, England: Wiley.

Wagenaar, W.A. and Van Der Schrier, J. (1997) 'Accident analysis. The goal, and how to get there', *Safety Science*, 26(1–2), pp. 25–33.

Walsh, I.J. and Bartunek, J.M. (2011) 'Cheating the fates: Organizational foundings in the wake of demise', *Academy of Management Journal*, 54(5), pp. 1017–1044.

Walsh, J.P. and Ungson, G.R. (1991) 'Organizational memory', *The Academy of Management Review*, 16(1), pp. 57–91.

Walter, F., Cole, M.S., der Vegt, G.S. Van, Rubin, R.S. and Bommer, W.H. (2012) 'Emotion recognition and emergent leadership: Unraveling mediating mechanisms and boundary conditions', *Leadership Quarterly*, 23(5) Elsevier Inc., pp. 977–991.

Wang, C.L. and Ahmed, P.K. (2003) 'Organisational learning: A critical review', *The Learning Organization*, 10(1), pp. 8–17.

Watson, H.A. (1961) *Launch Control Safety Study*. Murray Hill, NJ.

Weick, E. (1988) 'Enacted Sensemaking in Crisis Situations', *Journal of Management Studies*, 25(4)

Weick, K.E. (1979) *The Social Psychology of Organizing*. McGraw-Hill Books.

Weick, K.E. (2009) *Making sense of the organization: The impermanent organization, Vol 2*. Chichester: Wiley.

Weick, K.E. (1987) 'Organizational Culture as a Source of High Reliability', *California Management Review*, 29(2), pp. 112–127.

Weick, K.E. and Sutcliffe, K.M. (2006) 'Mindfulness and the Quality of Organizational Attention', *Organization Science*, 17(4), pp. 514–524.

Weick, K.E. and Sutcliffe, K.M. (2015) *Managing the unexpected: assuring high performance in an age of complexity*.3rd Ed. Hoboken, NJ, USA: Wiley.

Weick, K.E. and Sutcliffe, K.M. (2001) *Managing the unexpected: assuring high performance in an age of complexity*. Jossey-Bass.

Weick, K.E. and Sutcliffe, K.M. (2007) *Managing the unexpected: assuring high performance in an age of complexity*. 2nd edn. San Francisco: Jossey-Bass.

Weick, K.E., Sutcliffe, K.M. and Obstfeld, D. (2005) 'Organizing and the Process of Sensemaking', *Organization Science*, 16(4), pp. 409–421.

Weick, K.E., Sutcliffe, K.M. and Obstfeld, D. (1999) 'Organizing for High Reliability: Processes of Collective Mindfulness', in *Research in Organizational Behavior, Volume 21*. Stanford Jai Press, pp. 81–123.

Weinzimmer, L.G. and Esken, C.A. (2017) 'Learning From Mistakes: How Mistake Tolerance Positively Affects Organizational Learning and Performance', *Journal of Applied Behavioral Science*, 53(3), pp. 322–348.

Westrum, R , Adamski, A. (1999) 'Organizational factors associated with safety and mission success in aviation', in Garland, D., Wise, J. and Hopkin, V. (eds.) *Human factors in transportation. Handbook of aviation human factors*. Lawrence Erlbaum Associates, pp. 67–104.

Wiegmann, D.A. and Shappell, S.A. (2001) 'Human error analysis of commercial aviation accidents: Application of the human factors analysis and classification system (HFACS)', *Aviation Space and Environmental Medicine*, 72(11), pp. 1006–1016.

Wienen, H.C.A., Bukhsh, F.A., Vriezekolk, E. and Wieringa, R.J. (2017) '*Accident analysis methods and models – a systematic review. (Technical Report No. TR-CTIT-17-04)*', , p. 57.

Wood, M.H. (2018) 'Analysing accidents and lessons learned: You can't improve what you don't measure', *Chemical Engineering Transactions*, 67, pp. 391–396.

Wood, M.H. and Fabbri, L. (2019) 'Challenges and opportunities for assessing global progress in reducing chemical accident risks', *Progress in Disaster Science*, 4, p. 100044.

Woods, D. (2003) *Creating Foresight : How Resilience Engineering Can Transform NASA's Approach to Risky Decision Making. Testimony on The Future of NASA* Committee on Commerce, Science and Transportation, John McCain, Chair October 29, 2003,

Woods, D. (2006) 'Engineering Organizational Resilience to Enhance Safety: A Progress Report on the Emerging Field of Resilience Engineering', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 50(19), pp. 2237–2241.

Woods, D.D. and Shattuck, L.G. (2000) 'Distant Supervision–Local Action Given the Potential for Surprise', *Cognition, Technology & Work*, 2(4), pp. 242–245.

Woods, P. (2016) 'Democratic Roots - Feeding the multiple dimensions of leadership-as-practice', in Raelin, J. (ed.) *Leadership-As-Practice - Theory and Application*. Routledge, pp. 70–87.

Wynn, D. and Williams, C. (2012) 'Principles for conducting Critical Realist case study research in Information Systems', *MIS Quarterly*, 36(3), pp. 787–810.

Yammarino, F.J. and Bass, B.M. (1991) 'Person and situation views of leadership: A multiple levels of analysis approach', *The Leadership Quarterly*, 2(2), pp. 121–139.

Yukl, G. (2008) 'How leaders influence organizational effectiveness', *Leadership Quarterly*, 19(6), pp. 708–722.

Yukl, G. and Lepsinger, R. (2006) 'Leading change: Adapting and innovating in an uncertain world', *Leadership in Action*, 26(2), pp. 3–7.

Yun, S., Faraj, S. and Sims, H.P. (2005) 'Contingent leadership and effectiveness of trauma resuscitation teams.', *The Journal of applied psychology*, 90(6), pp. 1288–1296.

Zhang, Y., Waldman, D.A., Lan Han, Y. and Bei Li, X. (2015) 'Paradoxical Leader Behavior in People Management: Antecedents and Consequences', *Academy of Management Journal*, 58(2), pp. 538–566.

Zhou, L., Fu, G. and Xue, Y. (2018) 'Human and organizational factors in Chinese hazardous chemical accidents: a case study of the "8.12" Tianjin Port fire and explosion using the HFACS-HC', *International Journal of Occupational Safety and Ergonomics*, 24(3), pp. 329–340.

APPENDICES

Appendix A Interview Protocols

A-1 Repertory Grid Interview Protocol

My name is Charles Cowley. I am doing research at Cranfield University, UK. The purpose of this research is to examine what operational and technical people see as the important factors that influence process safety, including the influence of leadership. This research is funded by the Energy Institute. In a moment I will take you through the structured interview process. First I would like to remind you that you are here as a volunteer and are free to leave this interview at any time. In addition, the contents of this interview will remain confidential and anonymous. With your permission, the interview will be recorded.

We are going to use a particular approach that involves you comparing and contrasting a number of actual, near-miss and potential **process safety incidents** (basically explosions, fires and toxic releases) that you are familiar with. This will help us identify the factors that helped **identify** and **trap** potential incidents and **avoid** them developing into actual incidents, the factors that **allowed** the near-miss and actual incidents to happen, and the factors that helped **mitigate** near-miss and actual incidents. First we need you to choose the incidents that you will compare and contrast in this interview.

*(Hand two cards, labelled **a and b**, to the participant)* Please think of two **actual incidents** you are familiar with. On the cards, please write down a short description of the incident, just to identify it. We do not need you to provide full details of the incident, just enough details for you to remember which incident is which.

*(Hand two cards, labelled **c and d**, to the participant)* Now please think of two **near-miss incidents**, Again, on each card, please write down a short description to identify it.

*(Finally, hand two cards, labelled **e and f**, to the participant)* Now please think of two **potential incidents** and write down on each card a short description to identify it.

(*Now get some basic familiarity with each incident by discussion)* Please tell me briefly how each of these incidents unfolded… just a quick summary of the main aspects

Compare and Contrast I will now select groups of three from the six incidents that you have chosen and ask you to compare and contrast them. The first group of three is a, c and e.

(Pull out the three cards (a, c and e) and lay them in front of the participant KEY QUESTION: **"Considering these three incidents, please think about how two of these were similar, and thereby different from the third one, in regard to how people *identified and responded* to them?"**

Move the cards around while asking for the interviewee to think about similarities and differences. "in what sense are they similar and different?"

(It is important to prompt the participant until they have clearly explained the contrast that they have used to compare the three incidents. Participants might find this difficult in the first instance.

In what way is [Construct] important to you in regard to describing these incidents?"

Write the construct on the protocol sheet and confirm with the participant that this is correct.)

Pick out one word (xxx) that the interviewee uses…. " how would you define the two extremes of the idea of xxx ?"

(e.g. if the participant has said 'unusual situation' they might suggest 'normal procedure' and 'never been done before' as the two extremes)

Rating each incident in relation to the constructs Now, please rate these three cards in relation to [name of construct]. Please arrange them in order of how they rate according to [the construct]. You should allocate each incident with a rating of between **1 and 4** with **1** meaning [one extreme] and **4** meaning [other extreme]. You can have two incidents on the same rating if necessary.

(Remind the respondent what 1 and 4 means. Allow the participant time to order the three cards and to state which number each has been allocated)

Now please rate the other three cards on the same scale. You can change the ratings of the first three cards if need be at this point.

(Allow the participant time to order the remaining three cards and to state which rating each has been allocated. Write down the rating of all six cards and any comments that he makes throughout the process).

Please explain why you have given each incident this rating. *(LISTEN to their answer…. The recording will capture…)*

(Confirm that they are using the construct scale consistently… pick two extremes as a check)

Now I want to clarify: why did you put [this card] under 1 and [this other card] under 4?

(This process should then be repeated with different triads up to 10 triads. In order to standardize the process the following triads will be used…. See REPERTORY GRID FORM

Repertory Grid Form

ELEMENTS: 6 occurrences:

2 Actual Incidents (a, b) 2 Near Miss Incidents (c, d) 2 Potential Incidents (e, f)

CONSTRUCT RATINGS: 4-point scale (4 on L; 1 on R)

		Elements							
Construct (score 4)		**a**	**b**	**c**	**d**	**e**	**f**	**Construct POLE (score 1)**	
	1	*		*		*		1	
	2	*		*			*	2	
	3	*			*	*		3	
	4	*			*		*	4	
	5		*	*		*		5	
	6		*	*			*	6	
	7		*		*	*		7	
	8		*		*		*	8	
	9	*	*			*		9	
	10			*	*		*	10	
		a	**b**	**c**	**d**	**e**	**f**		

Email to be sent to each interviewee ahead of the interview

Dear (INSERT NAME)

Thank you very much for agreeing to be interviewed about process safety incidents and leadership. My name is Charles Cowley. I am doing research at Cranfield University, UK. The purpose of this research is to examine what operational and technical people see as the important factors that influence process safety, including the influence of leadership. This research is funded by the Energy Institute. I would like to emphasise that this is voluntary you are free to leave the interview at any time. In addition, the contents of the interview will remain confidential and anonymous. With your permission, the interview will be recorded.

I would emphasise that the subject of this research is **process safety** - meaning basically avoiding explosions, fires and toxic releases - the sort of incidents that can result from the nature of the plant and the materials it contains. These incidents can lead to multiple fatalities and serious injuries as well as major environmental impact and asset damage. They usually start with a 'loss of primary containment' or 'LOPC'.

In the interview I would like to ask you about a number of process safety-related occurrences that you know about, to get your personal interpretation of the circumstances and factors affecting them. Before the interview**, please choose two examples** of each of the following types of occurrence:

- Actual incident: real incident that happened (energy or hazardous material was released) and had significant actual consequences (RAM 3 to 5)
- Near-miss incident: real incident that happened (energy or hazardous material was released) without significant consequences - but could have had RAM 3 to 5 consequences
- Potential incident – unsafe act or condition that could have led to an incident (RAM 3 to 5) but was stopped from developing into a real incident, without release of energy or hazardous material.

Please come to the interview ready to talk about each of them, i.e. a total of six occurrences. **Please also bring with you basic documentation about each one: incident report, DATABASE reference etc.**

The objective is to get your personal views about each one: What happened, how it occurred, and the things that were happening during and in the lead-up to the incident that may have influenced the people involved to act as they did. During the interview I will ask you about how they compare and contrast, following a straightforward process. The interview should take 1 to 1½ hours maximum.

The phone call and the interview are completely confidential. All information you provide will be completely disidentified. You can be completely frank in whatever you say; nothing will be traceable to you afterwards.

With your permission, the interview will be recorded to make sure of a complete and accurate description of your views. At any time you may stop the interview and all notes and records will be deleted immediately on your request. This research is being conducted in accordance with the Cranfield University Ethical Policy which guarantees complete confidentiality and anonymity.

Thank you once again for your help with this research. I look forward very much to meeting and working with you.

Best wishes

Charles

A-2 Semi-Structured Interview Protocol

Hello

…and thank you for making time for this. My name is Charles Cowley. I am doing research at Cranfield University in the UK. The purpose of this research is to examine what operational and technical people see as the important factors that influence process safety, including the influence of leadership. This research is funded by the Energy Institute. In a moment I will ask you a number of questions about how things are done at your worksite, but first I would like to remind you that this conversation is voluntary; you are free to stop it at any time and the content will remain confidential and anonymous. With your permission, the call will be recorded.

Now I would like to get your views about how things are organised and ***how things are done*** *at the site.*

a. How would you describe the leadership you see at your work site? … what words or phrases spring to mind?

b. Who would you regard as **engaging in leadership** at your work site [PLEASE NOTE THAT NAMES WILL NOT BE DISCLOSED]? ……what are the key actions and interactions that these people engage in (i.e. what do they do)?

c. When an urgent problem or safety issue occurs – an urgent operational or technical issue …who decides what to do? ….how do they get the authority to take action?

d. How **effective** is leadership at your workplace? …What are the signs of effective/ineffective leadership? ... How does this affect the way people work? ….How does leadership affect safety outcomes?

e. What is the role of leadership in directing, planning and resourcing work?

f. How clear are lines of authority, roles and responsibilities?

g. How are new ideas, practices and work methods **encouraged and stimulated**?

h. How do people **challenge established thinking** and practices or adapt and bring improvements?

i How do people manage the tension between **rule-following** and **adapting sensibly to local conditions and problems?**
… how does leadership influence this?

j How do people create **shared awareness of the situation** regarding current operational or technical issues?
… how does leadership influence this?

k How **wary or uneasy** are people about what could go wrong? … how does leadership influence this?

l How does the organisation **detect, contain and recover from** unsafe acts and conditions (i.e. potential incidents) before they can develop into real incidents?
… how does leadership influence this?

m How do people react when an incident occurs? … how does leadership influence this?

n How do people learn and actively change after an incident? … how does leadership influence this?

Thank you.

Appendix B Method of determining factor values for QCA

The Incident Documents' study identified the 'Causal Factors' and 'Recommendations' shown in **Tables 6-6 and 6-7.** For the QCA only Causal Factors (**Table 6-6**) were used. Using a NVivo coding query report as the basis, a spreadsheet was prepared containing the Causal Factors codes referenced in each incident document. The spreadsheet was simplified to a matrix with the incident number and type on one axis and the codes on the other. The codes were then re-sorted into the consolidated factors in **Table 6-7** and if any of the constituent codes of a consolidated factor had a value of 1 (indicating that the documents relating to an incident contained at least one such coded reference) then the consolidated factor was given the value 1; otherwise it was given the value 0. An extract from the spreadsheet used for this is shown in **Table B-1**

Table B-1 Spreadsheet used for determining values for the Consolidated Factors

TYPE		AI	AI	AI	AI	AI	NM	PI	AI	NM	AI	AI	AI	AI	NM	AI	AI	AI
		A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	A12	A13	A14	A15	A16	A17
1 : CAd1 Lack of empowerment													1					
10 : CAm1 Blame culture											1		1					
11 : CAm2 Production pressure										1	1		1					
	OVDIRLD	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0
12 : CAm3 Distractions or other error-enforcing conditions																	1	
13 : CAm4 Inadequate supervision, checking or monitoring						1				1	1	1	1					
14 : CAm5 Operation outside design envelope															1			
15 : CAm6 Reckless non-compliance											1							
16 : CAm7 Unclear responsibilities																		
17 : CAm8 Well-meaning improvisation without full risk awarenes																		
28 : CAm19 Inadequate job planning											1		1					
29 : CAm20 Inadequate resourcing																		
30 : CAm21 Inadequate technical competence & training													1					
31 : CAm22 Inadequate procedures			1			1		1				1	1					
	INADMINPRAC	0	1	0	0	1	0	1	0	1	1	1	1	0	1	0	1	0
21 : CAm12 Inadequate communication of risk information												1						
22 : CAm13 Inadequate hazard identification						1					1	1		1				
23 : CAm14 Inadequate Management of Change																		
24 : CAm15 Inadequate risk awareness or assessment						1												
25 : CAm16 Inadequate risk management controls											1	1					1	
	INHAZRISKMAN	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0
3 : CAd3 Inadequate mindfulness and vigilance										1		1					1	
4 : CAd4 Ineffective communication										1			1					
5 : CAd5 Lack or loss of Situation Awareness																		
6 : CAd6 Risk normalization										1								
	INNONTECH	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0
8 : CAd8 Inadequate checking for wider implications																		
9 : CAd9 Lack of implementation of LFI actions						1												
	INORGLEARN	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20 : CAm11 Inadequate equipment or system design														1	1			
26 : CAm17 Inadequate construction QC								1										
27 : CAm18 Inadequate maintenance, inspection or testing		1						1	1									
	INASSETINTEG	1	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0
2 : CAd2 ++ Effective vigilance																		
7 : CAd7 ++ Potential Incident investigation								1										
19 : CAm10 ++ Effective system design detecting potential incident																		
	SUPCULT	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
18 : CAm9 Inadequate emergency response	REJECTED																	

This process determined the 0 and 1 values for the 7 consolidated factors for which the incident document codes had a correspondence; this can be seen in **Table 6-7** and the correspondence was used in the spreadsheet (see **Table B-1**). However, two other factors, Adaptive Leadership Practices ('ADAPTLDPR') and Enabling Leadership Practices ('ENABLDPR') appear in **Table 6-7**, that emerged from the semi-structured interviews study (**Chapter 5**). These factors did not form part of the incident document coding.

The results of the semi-structured interviews study in **Table 5-4** did provide some evidence that Adaptive Leadership Practices were significantly more present at Site C than the other sites, while Enabling Leadership Practices were more present at Site B than the other sites. Lacking any more refined data, the simple approach was followed to set ADAPTLDPR = 1 for all Site C incidents, and to set ENABLDPR = 1 for all Site B incidents, and all other incidents were set to 0 for these two factors.

This can be seen in **Table 6-8** 'Final Values of Consolidated Factors'

Appendix C Research Ethics Policy

Research Ethics Policy

CU-RIO-POL-2.0 – V6

Cranfield takes its obligation to all its stakeholders to observe and maintain the highest ethical standards very seriously. These standards are embraced by the University and enacted by all its members. They include the Seven Principles of Public Life (the Nolan Principles) of selflessness, integrity, objectivity, accountability, openness, honesty and leadership. These principles inform every aspect of University operations by staff, students and lay governors, and create the culture of academic freedom necessary for first-class research and education in line with the University's objectives which are to:

(i) advance, disseminate and apply learning, knowledge and understanding with particular emphasis on the disciplines of the Sciences, Technology, Engineering and Management; and

(ii) promote and encourage the transformation and application of that wisdom, knowledge and learning for the benefit of industry, the public services, and individuals and for the wider public benefit.

Helping students to acquire a sense of professional and personal ethics in their work is an important part of the educational process the University offers.

The Cranfield University Ethics Policy supports all members of the University in meeting these standards. Practices relevant to particular areas of activity (for instance teaching or research) and particular members of the University (for instance students or staff) will vary in specific application, however the core principles will always apply.

Professional Conduct

All members of the University shall seek to conduct their work in a professional manner to the benefit of all the communities that the University seeks to serve. More specifically, they will not claim knowledge, competence or qualifications they do not possess. In their work members will (i) avoid harm to anyone, and (ii) where conflicts between professional positions arise, members will seek to resolve these with integrity. Integrity implies not merely honesty but fair dealing and truthfulness.

Teaching

In its teaching the university will:

- Seek to bring all its knowledge to the design, delivery and assessment of all its teaching programmes;
- Describe clearly and appropriately the level and content of all courses;
- Recruit and admit only such students who are believed, by those admitting them, to be appropriately qualified, willing to study diligently, and able to satisfactorily complete, the course;

- Not discriminate on the basis of the student's source of funding, or race, colour, nationality, ethnicity, religious views, sexuality, disability, marital status or other academically irrelevant factors;
- Adhere to the provisions of legislation set out in The Equality Act 2010.
- Assess fairly and honestly all students and maintain honest feedback to students concerning their progress;
- On completion of the course describe honestly and fairly the student's performance on the course.

Research & Consultancy

The University has a Research Integrity Policy Statement and has adopted Universities UK's "The Concordat to Support Research Integrity" and upholds its principles. There is a University Ethics Committee (CUREC) which will oversee ethical research practices and review proposals for all research and consultancy in order to safeguard direct and indirect participants (including researchers) in all the University's research including, but not limited to, safety, physical, psychological, emotional, spiritual, reputational, mental well –being or financial harm.

In their research all staff and students will:

- Maintain professional standards including honesty and integrity;
- Properly document results;
- Evaluate critically results;
- Attribute honestly the contributions of others;
- Wherever possible report all results openly, though bearing in mind the University's commercial considerations, sponsors' needs for confidentiality or other good reasons;
- Ensure all research studies gain ethical approval through the Cranfield University Research Ethics System (CURES) prior to commencement of data collection;
- Adhere to The Equality Act 2010

In addition all staff will:

- Educate and develop themselves, colleagues and students to an understanding of good research practice;
- Secure and store relevant primary data in accordance with the General Data Protection Regulation 2018. (dates should be included in paper copy files).

Administration

In its administration the University will:

- promptly, honestly and fairly with all stakeholders;
- Ensure that just, equitable, timely and open discussions are made and communicated.

Consultancy

In its consultancy the University will:

- Only offer consultancy and advice within the area of the consultant's knowledge and expertise;
- Maintain the highest professional standards including honesty and openness;
- At all times respect client confidentiality, unless expressly permitted by the client to divulge details.

Students

Students will:

- Abide by the Student Charter which represents a shared understanding of the role, rights and responsibilities of an individual student;
- Observe the University's Codes of Practice and Policy Statements including that on Free Speech;
- Conduct themselves in a positive manner which neither brings discredit on the University nor harm to its members.

Implementation of the Policy

These principles should govern the conduct of each member of the University. Whilst the Principles apply to all activities, there are in addition a number of areas where more detailed ethical principles and practices have been set out; these include *inter alia* the University's Senate Handbooks, Financial Manual and the General Student Handbook.

Additional Information

These are useful sources of additional information about ethics. This list will be updated from time to time. The University is not responsible for the content of these websites.

Bew P (2014) Ethics in Practice: Promoting Ethical Conduct in Public Life, Committee on Standards in Public Life (July 2014)

British Psychological Society - a primary source of advice on ethical research practice providing guidelines and protocols.

The Data Protection Act 2018 - controls how your personal information is used by organisations, businesses or the government.

Ethics in Research and Publication - collaboration of an independent panel of experts in research and publishing ethics and Elsevier.

The Research Ethics GuidebookThe Research Ethics Guidebook - this is designed as a resource for social science researchers - those early in their careers, as well as more experienced colleagues.

Institute of Business Ethics - encourages high standards of business behaviour based on ethical values.