MANAGING DEMAND VARIABILITY IN COMPLEX
SOCIOTECHNICAL SYSTEMS

A CASE FOR RESILIENCE IN AIRLINE OPERATIONS CONTROL

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ABSTRACT

This thesis is designed to provide evidence as to why resilience thinking should be taken seriously in the studies and practices of airline operations control (AOC). It examines how frontline controllers dynamically respond to variability in demands and the challenges they encounter when rescheduling resources on-the-fly across multiple, autonomous centres of control. The empirical observations and interview protocols were tailored to shed light on the socio-cognitive strategies deployed by frontline controllers at four airline integrated operations control centres. The AOC system, as the unit of analysis, proved to be a befitting laboratory for re-examining propositions developed in the studies of the resilience engineering and the naturalistic decision-making research streams.

The overarching finding of this study is that anticipatory adjustments are required to make up for gaps in assessments relative to both foreseen and unforeseen threats. The results elucidate how responsive and adaptive architectures evolve during dynamic renegotiation of decision authority in order to circumvent catastrophic loss of control. The findings further lend support to the argument that responsiveness not only applies to the planned contingencies, but also to the processes by which the escalating situation is managed. By mapping various styles of renegotiation against the demands that elicited them, the results begin to clarify how demand severity and scope continue to shape the way controllers perceive and interpret rule prescriptions, and the way they go about matching a changing and ambiguous set of contingent rules to a changing and ambiguous set of situations.

Furthermore, this thesis introduces the notion of socio-cognitive variability control (SCVC) as a concept for determining the ‘goodness’ of an airline scheduling and recovery protocols. The SCVC idea is poised on a decision-space framework, where the goodness of a protocol is contingent on the variety and range of responses it can afford. This representation contrasts a criterion-space framework, where the goodness of a response is based on a set of predetermined objectives. The thesis stance is that an operative framework that offers more variety to address variability should be considered a more befitting framework for measuring resilience in work settings where goals tend to shift quickly. It is hoped that the reformulations presented in this thesis will inspire a new set of methods and practices that are grounded on resilience thinking and on exploration of decision-space frameworks.
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The endeavour of this PhD thesis was made possible only because of the extraordinary help and encouragement I have received from my advisors, mentors, colleagues, family and friends.

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I am highly indebted to the leadership of Resilience Engineering Association, for sponsoring me to participate in the 2013 Young Talents Congress at Soesterberg, the Netherlands. This experience marked a turning point in my PhD journey and provided a much broader view of issues to investigate in this thesis. I am particularly grateful to the Giants, Professors Erik Hollnagel, David Woods, Sidney Dekker, and Jan Maarten Schraagen, for their constructive comments and feedback on the day.

I am also greatly indebted to the controllers that provided immense wealth of insight into the challenges they face daily and to the airlines that welcomed us to conduct field research in their busy operations control centres. This thesis would not have been possible if not for their generosity.

Finally, I am eternally indebted to my family and friends for their sacrifice and prayers. They provided endless moral and practical support throughout my doctoral journey. I am especially in awe of their selfless contributions that made my plans to undertake a doctoral study possible.
DECLARATION

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

_______________________
EJIKEME KENNETH IGBO

08 July 2015
To those extraordinary men and women who inspired me, taught me and then SET me on a journey of intellectual enlightenment…

To those selfless men and women who GAVE ME A CHANCE and helped clear up many obstacles that littered my quest for intellectual development…

And to my ever devoted family who GAVE THEIR ALL to get me to this point in my intellectual journey…

I DEDICATE THIS THESIS TO YOU ALL!
HE IS NO FOOL, WHO GIVES WHAT HE CANNOT KEEP
TO GAIN WHAT HE CANNOT LOOSE

Jim Elliot
# CHAPTER 3: RESILIENCE IN SOCIOTECHNICAL SYSTEMS. A RESILIENCE ENGINEERING PERSPECTIVE

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# CHAPTER 4: RESEARCH DESIGN AND METHODOLOGICAL CONSIDERATIONS

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Even mistaken hypotheses and theories are of use in leading to discoveries... The alchemists founded chemistry by pursuing chimerical problems and theories which are false.

Claude Bernard (1813–1878), *on the Path to Discovery*

…they be not the highest instances that give the securest information; as may well be expressed in the tale... of the philosopher, that while he gazed upwards to the stars fell into the water: for if he had looked down he might have seen the stars in the water, but looking aloft he could not see the water in the stars. So it cometh often to pass, that mean and small things discover great, better than great can discover the small.

Francis Bacon (1561–1626), *on the Advancement of Learning*

1.1 Motivation

Inherent in the design of most systems of operation is the capability to absorb predictable fluctuations in demand. In the course of developing an airline’s operational plan, the designers often employ buffers, barriers and defences in the form of extra resources, operating rules and escalation protocols so as to minimise a plan’s susceptibility to failure. Interestingly, plans still fail, demand predictions prove inaccurate, crews get sick, aircraft break down, catering services get delivered late, weather forecasts change drastically, the prescribed rules prove untenable in the face of changing circumstances, and the list goes on. Although many of these events are hardly surprising and often have established procedures for activating responses, the exact temporal and dynamic characteristics that govern their evolution are not always predictable. Particularly in a system that has highly interdependent resources controlled by functions that are separated geographically and sometimes differ culturally, it is almost impossible to identify precisely all the vulnerabilities in the system; a natural consequence of which is that some emergent risks remain unknowable prior to a failure event. Consequentially, the reality in practice is often a far cry from the optimism that underpins how planners and schedulers think about the feasibility of most flight resource schedules.
Understanding how controllers manage to produce successful performance in defiance of such ferocious challenges is the prime subject of interest in this thesis. It is, however, important to note that the focus of investigation in this research evolved substantially throughout the life of the project. The evolution of this study was largely fuelled by the iterative manner by which knowledge of substantive practices in airline operations control (AOC) evolved throughout the course of study. The evolution was also shaped by the many interceptions to the pre-defined direction of study, as new theoretical frameworks and empirical observations call into question the underpinning assumptions regarding how the observed practices and theories relate. New insights provided impetus for clarification of assumptions, reformulation of thinking, extension of knowledge and, in a few instances, complete abandonment of some conceptual frameworks in lieu of those that proffered more comprehensive explanation to the empirical observations. However, the path to discovery was largely moderated and, oftentimes, squelched by pragmatic considerations relating to gaining access to the form and quality of data that can provide insight into the phenomenon of interest. Access to real-world control centres promoted a more ethnographic exploration into the processes and forces that shape how controllers address the vagaries of demands in a highly unpredictable environment, and how breakdown can occur in those processes. This thesis, therefore, encapsulates a four-year journey that was undertaken to illuminate how frontline controllers manage relentless fluctuations in demand, in the context of a work environment where excellence in safety and service delivery are not only critical for success and survival, but can easily create operational dilemmas and inextricable conflicts-of-priority.

1.2 Reframing the airline operations control problem

Commercial aviation is a ruthlessly competitive environment that requires high operating costs in order to maintain basic services and resources needed for daily operations. A consequence of this perennial economic challenge is that airline companies, more often than not, operate precariously at the limits of their resources leaving only very limited back-up resources to address unforeseen contingencies. As a result, frontline controllers are constantly placed in a dilemma whether to engage all available resources to address immediate threats, or to increase the residual capacity of resources—by way of flight retiming and cancellations—to be better positioned to cope with the next surprise.
Understandably, it makes sense that studies in airline operations, both past and present, have focused largely on developing a variety of computational algorithms with a view to providing substantial cost savings by cutting down the high operating costs incurred by airlines (Kimes, 1989; Mathaisel, 1996; Petersen, Sölveling, Clarke, Johnson & Shebalov, 2012; Pita, Barnhart & Antunes, 2013; Zuidberg, 2014). Given the complex nature of the airline problem, it has become customary to decompose the overall problem into a set of sub-problems (Barnhart, Belobaba & Odoni, 2003, p. 69). But, issues often arise in the process of decomposition, whereby some vital elements are intentionally left out in order to ensure the problem remains mathematically tractable (Petersen et al., 2012). Even highly acclaimed and influential models tend to ignore critical aspects of the operations that influence how frontline controllers appraise and respond to variations to planned operations, such as mixed fleet types, maintenance considerations, concurrent disruptions, and negotiation practices (e.g., Ahuja, Magnanti & Orlin, 1993; Barnhart, Boland, Clarke, Johnson, Nemhauser & Shenoi, 1998; Talluri, 1998). As a result, in spite of their promising cost-saving estimations, they appear inadequate for handling complex real-world problems, and their performance under atypical situations has been found to be quite poor (Clausen, Larsen, Larsen & Rezanova, 2010; Kohl, Larsen, Larsen, Ross & Tiourine, 2007; Lettovsky, Johnson & Nemhauser, 2000).

Despite advances in technological systems, it is the case to date that decision-making in many airlines’ operations control centres—including the four centres that were investigated in this study—are still very much undertaken by humans with very basic support from technology. This observation points to the need to retool current investigation toward understanding the broader dynamics of the AOC system that support positive adaption to both expected and surprising variations. From a high-level design perspective, this knowledge may significantly improve the way designers configure technology to support cognitive interactions in complex work systems, and further elucidate more appropriate design-for-implementation solutions and approaches for integrating “smart” technologies into complex, human adaptive systems.

Moreover, the often undeclared assumption that underpins most optimisation-based formulations in airline operations control appears to be that resources are limited. The acknowledgement of constraints in resources then evokes an impression that simply throwing in more resources would lead to higher efficiency. But, this view often fails to
capture the ways other forms of demands, such as cognitive and social demands, could hobble the performance of the AOC system. In particular, it is often missed that there are costs associated with coordination, that priorities are never static but rather evolving, and that the goals of external organisations that participate in schedule execution are not necessarily in congruence with the airline goals. The extension of the AOC demand variability analysis to include a socio-cognitive dimension, therefore, takes the AOC dynamic rescheduling problem from a purely computational space to a more organisational space, where goals are adapted on-the-fly as priorities change.

In view of the foregoing discussions, it becomes apparent that the important contributions of the human agent may be missed when investigations of the AOC system are centred only on optimising computational models. This thesis, therefore, takes a view that computational models alone will hardly (if ever possible) capture comprehensively the realities of a real-world practice. A befitting complement to prior research in airline operations control is to explore the human-machine side of the story: how humans, wielding computational tools, address the erratic nature of demands in airline operations. This approach further underscores the importance of re-focusing current investigations toward identifying the factors that support individuals, subgroups and organisations to perform as situations demand without precariously violating operational, regulatory and safety constraints. This integrated human-machine view of the AOC system is, therefore, posited as a more appropriate formalism for examining not only the temporal and physical factors that affect airline operational processes, but also the dynamic and organisational factors that will influence—and be reshaped by—the way technological artefacts are deployed in practice. This research represents a leap toward a more holistic view of airline operations control.

Further, this study adopts the principles of ‘joint cognitive system’ (JCS) to expound and elaborate its sociotechnical viewpoint. The philosophy behind taking a JCS perspective reiterates the maxim that a system is more than just the sum of its parts. In this sense, the resultant dynamics in an AOC system cannot be simply understood by studying any of its cognitive components in isolation. Therefore, it is important to understand how relationships between different components of the system—in this case, the human agents at the individual, subgroup and organisational levels, and the technological artefacts and software solutions—are affected by variability in the system dynamics. Of particular
interest is to elucidate the forces that shape how controllers vary their performance in order to adapt successfully to constant fluctuations in the system and the consequential changes in the operational plan. It is also important to understand how lax rules or strict enforcement of formal procedures could alter these relationships or lead to a whole new set of relations. Ultimately, this thesis seeks to shed light on not only pertinent organisational forces that shape how frontline controllers go about their daily work, but also on the role of the human agent in adapting formalised guidance extemporaneously in efforts to cope with the broad range of challenges that controllers confront in the AOC domain of practice.

1.3 The airline operations control system

This study is delimited to focus only on tactical control operations, which in this thesis are referred to as the airline operations control (AOC) system. This system encompasses the core processes—including decision-making, negotiation, and coordination processes—which are geared toward execution of flight schedules, and schedule recovery protocols that are deployed in the wake of a disruptive event.

The chief actors involved in the day-to-day control of airline operations include the operations controllers (controllers), crewing controllers, flight dispatchers, maintenance controllers, customer-service officers and shift managers. Collectively, these personnel are referred to as frontline controllers in this study. Controllers refer only to operations controllers; but frontline controllers encompass all the different actors involved in tactical operations control at the airline operations control centre. The operations controllers and shift managers occupy the central position in this research. Hence, the core of the research process is centred on the interrelationships and cognitive transactions that occur between the controllers/shift managers and other actors within, and across, the system boundary during negotiation, decision-making and coordination processes. Although air traffic controllers (ATCs), airport authorities, station managers, and ground controllers (such as ramp, gates, passenger and baggage handling, and load control) are only considered as agents within the broader air transportation environment, the interactions between these agents and the frontline controllers at the operations control centres are considered part of the operational system under analysis.
Equally important, this system is defined from a functional sense. As depicted in Figure 1.1, the system under investigation is defined relative to the interrelationships and activities that support core control functions in accordance to the principles of cognitive systems engineering (Hollnagel & Woods, 2005). This is in contrast to a structure-focused characterisation of systems. Overall, this thesis advances a view that a functional viewpoint provides a better platform for capturing how changes in demand propagate across functions and how variability in one part resonates across the entire system (Hollnagel, 2012).

Figure 1.1: A simplified model of functional interrelationships in an AOC system
1.4 Thesis Objectives

The central goal of study was broadly defined at first to allow the research direction to be driven by themes that emerged in the course of study. Consequently, the first objective was defined to guide, as well as delimit, the scope of exploration at the early stages of research. The other objectives emerged in the course of the literature review and field studies, and were adopted as objectives to guide the flow of discussions in this thesis.

1. To observe and describe a perspective of the AOC practice from a social and cognitive perspective

This shift in focus—from the traditional techno-centric, computational investigation to a socio-cognitive inquiry—provides a fresh pedestal for questioning assumptions that we often take for granted regarding how practitioners navigate through inherent uncertainty and complexity in the AOC domain of practice. It also enables the researcher to seek alternative explanations and appropriate formalisms for identifying influential factors that shape adaptive behaviours in the AOC domain. An important motivation for this shift in focus is that, despite significant advances in the computational study of airline operations, human controllers still execute the majority of control tasks in the AOC domain while being supported by technological artefacts. This thesis takes a stance that AOC inquiry should build on this joint-cognitive dynamics. It is expected that such shift in focus will have profound implications for the way in which researchers and designers conceptualise work rules in AOC—that is, conceptualising rules as actually applied in practice as opposed to conceptualising rules as specified in the guidelines.

2. To share insights on the pragmatic steps taken to overcome limits to authenticity relative to observing work in context.

From a cognitive systems’ viewpoint, Woods and Hollnagel (2006) have argued that work is best observed in its natural setting so as to preserve the authenticity of cognitive systems’ observations. Authenticity has been lauded as a core value for cognitive systems’ observations, in the sense that researchers need to be clear about the connection between claims they make regarding the dynamics at play in a particular work setting and concrete evidence grounded on the practitioners’ understanding of how work is performed in that specific field of practice (Woods & Hollnagel, 2006). With regards to the AOC inquiry, Bruce (2008) has raised concerns regarding the suitability of commonly used protocols—
including observation, interview, and think-aloud protocols—for accessing and gathering authentic evidence about ‘work in context’ in AOC practice, given the complex and fast-paced nature of the AOC business environment. Bruce (2008) drew from the works of Yin (1994) and Zikmund (2000) to argue that each of these protocols is limited, in one way or another, by a lack of accuracy in recalling events; confusion of details particularly in the event of simultaneous disruptions; interference with work processes; observer subjectivity; and inability to accurately interpret attitudes, opinions, and body language, particularly when observation is used as the sole tool for collecting evidence of work in context (Bruce, 2008, p. 93). A thorny question then arises as to how one can elicit authentic samples of AOC work in context, given that AOC practice is heavily characterised by “…endless variety and uniqueness of problems” (Bruce, 2008, p. 44). In response to this question, this objective sets up a challenge to ascertain more appropriate ways to shape the conditions of observation (Woods & Hollnagel, 2006) so as to facilitate access to authentic samples of evidence grounded on the practitioners’ understanding of work dynamics in their domain of practice.

3. To delineate how the various parties involved in the AOC processes adapt their behaviours in response to the wide ranging variety and uniqueness of demand situations.

With this objective, the researcher wishes to provide insight into the routines that practitioners employ and how they adapt authority, responsibility and functional boundaries when rescheduling interdependent resources in a resource-constrained and highly fluid business environment. Efforts to uncover the dynamics of ‘work-in-context’ in AOC practice also extends to how practitioners appropriate pre-specified guidance when addressing new forms of demands and opportunities in the face of dwindling resource pressures; more prosaically, what they do, how they do it, and the rationale that underpins their strategies. One assumption that is expressed with this objective is that an AOC system is prone to a continuing “faster, cheaper, better” pressure, as is the case in many other complex work domains, including healthcare systems (Cook, 2006) and NASA space shuttle explorations (Vaughan, 1996, 2004; Woods, 2003, 2009). This thesis further presupposes that there exists a high potentiality for incongruent views relating to goals, interests or motives across individuals, subgroups, and echelons, given the conflicting nature of a standing order that requires one to be both thorough and efficient (Hollnagel, 2009; Rasmussen, 1997). To paint a more vivid picture of this conflict: achieving a cheaper
or better result would often entail a controller taking time to consider and renegotiate a vast number of variables with colleagues before committing to a particular solution trajectory. By contrast, achieving a faster result would often warrant the controller circumventing certain procedures put in place to ensure a thorough negotiation (Hollnagel, 2009) in order to deliver ‘good enough’ results; however, within a reasonable timeframe. Therefore, the agenda here is to first understand how these dynamics play out in the context of an AOC system, and then take it further to abstract generalizable patterns across different AOC configurations.

4. To construct explanations grounded on observations made in this study, and further identify links between findings in this study and findings in comparable domains.

Woods and Hollnagel (2006) postulated that one can abstract generalizable patterns and produce candidate explanations for the basic patterns by comparing and contrasting findings across geographic and temporal settings. In this light, the agenda for this objective is to conduct a comparative analysis of findings made in this study against other views that have been expressed in the literature. It would be interesting to identify situations and contexts where the thesis findings agree with previous studies conducted in AOC and other joint-cognitive work domains. However, a more interesting outcome would be to identify specific concepts and frameworks that have proved useful for interpreting and explaining the observations, along with particular contexts that require explanations that are unique or different from popular views that have been expressed in the literature. It is expected that this objective will set up a path toward discovery and yield significant contributions in the form of a set of extrapolative patterns and hypotheses that will guide future investigations in the AOC domain and perhaps in a new domain of practice.

5. To reflect on the significance and implications of study.

The agenda is to reflect on the learning gained in the process of identifying gaps, addressing limitations, confirming and refuting hypotheses, and in applying theoretical frameworks across contexts. It is expected that these exercises will produce significant contributions to knowledge and practice, along with promising lessons for further research.
1.5 Thesis Overview

Chapter 1 provides an overview of the research problem, the scope of study and the objectives pursued in this research. It also provides a justification for taking a sociotechnical viewpoint and a ‘joint cognitive systems’ perspective for this inquiry, along with a reflection on the limitations of current approaches for studying ‘work in context’ specific to the airline operations domain. It goes further to argue for a need to adopt a more systemic approach to investigating the AOC practice. The chapter concludes with an outline of the thesis.

Chapter 2 reflects on the perspectives that have been proposed in the literature regarding the antecedent conditions for performance in sociotechnical systems, especially in those so-called safety-critical or high-risk systems. The discussions open with a review of accident models and then on to a reflection on models of performance, in acknowledgement that many psychological and sociological perspectives on performance evolved in the same direction. The latter sections describe the dynamics of demands in airline operations and, further, present a review of extant literature on the strategies in use in the AOC practice.

In chapter 3, a review of resilience studies across six perspectives is presented. It shows the comparative study that was conducted with a view to constructing new lessons across both natural and engineered systems. The chapter also examines descriptions and representations of resilience were to find a gap and a potential theoretical lens to guide the investigative process, in addition to serving as an explanatory base for making sense of the field results. Findings from the review, amongst other things, highlight pertinent constructs and themes that have emerged in the study of resilience across various contexts and fields of study. The constructs and themes, in conjunction with some representations and metaphors adopted from studies in ‘human factors’ and ‘resilience engineering’, are used as the underpinning premises for the discussions on the various depictions of resilience.

Chapter 4 presents a reflection on the research design, with particular focus on the key methodological considerations that underpin the research process. It further articulates the complex links between key methodological considerations in the research design and the position of the researcher in relation to myriad theoretical perspectives and philosophical worldviews. The research design not only draws from ethnography and the grounded
theory methods, but also adopts insights from deductive qualitative approaches. The research position to philosophical debates, along with the implications for taking such stance, is also presented. The chapter concludes with an argument that science is progressive; the more we research, the more we know about our world. New evidence is bound to either strengthen or invalidate long held beliefs.

Chapter 5 captures the research process: that is, the field studies and the analytical procedure applied. It further presents some descriptive representations of the operations control centres visited along with the profiles of both the airline companies and the individual participants. Analyses of the findings follow afterwards, with a view to showing the aspects of the theoretical constructs that emerged from the data and those that were sourced from the literature. The discussion also appropriates myriad interpretive lenses as a way to invite diverse perspectives and alternative explanations to the interpretation of the observed phenomena. Findings in this study are compared to findings in other high-risk domains with a view to capturing dynamics that are transferable across domains and the ones that are context specific. The comparative study further serves as a test of generality for the observations in this research. Lastly, abstractions from the discussions are used to construct an integrated framework that delineates the relationships between the different attributes captured in the observations.

Chapter 6 opens with a summary of the key findings, arguments and assumptions made in this thesis. Thereafter, a more detailed reflection on their theoretical, methodological, and practical implications is presented. The chapter reappraises the relevance of a resilience approach to studies of tactical control in airline operations given its emphasis on core functional activities and the need to maintain a dynamic balance in work systems that are inherently unstable. Limitations of study as well as challenges faced in the course of executing this research are discussed. The chapter concludes with a proposition of possible directions that could be taken in order to further explore some of the observations captured and the arguments raised in this research.
CHAPTER 2

BUILDING A CONTEXTUAL FRAMEWORK

There are known-knowns; there are things we know we know. We also know there are known-unknowns; that is to say that there are things we now know that we don’t know. But there are also unknown-unknowns; the ones we don’t know we don’t know.

Donald Rumsfeld (2002), on Levels of Uncertainty

The dogmas of the quiet past are inadequate to the stormy present. The occasion is piled high with difficulty, and we must rise with the occasion. As our case is new, so we must think anew and act anew. We must disenthrall ourselves, and then we shall save our country.

Abraham Lincoln (1809-1865), on Adapting to Situations

OVERVIEW: Efforts to identify, explain, or address the dynamics that exacerbate a system's susceptibility to failure—and conversely, to find ways to configure a system that is not disposed to failure—have divided opinions and, further, fuelled fierce debates amongst scholars who have investigated the evolution of performance in organisations operating large-scale technological systems. This chapter addresses part of the first objective—to describe a perspective of the airline operations control (AOC) practice from a social and cognitive standpoint—by setting up a socio-cognitive framework of an AOC system grounded on the interactions at the interface of both cognitive and social processes. The discussion opens with a reflection on some widely debated and (arguably) influential perspectives on whether organisations—especially the so-called safety-critical or high-risk organisations—are capable of devising organisational cultures and processes that can attenuate their susceptibility to large-scale system failures. The discussion then goes on to reviews of accident models and theories of performance, with the aim to uncover their psychological and sociological underpinnings. This chapter further addresses the implications of complexity thinking and how variability in demand impacts and shapes the AOC practice. Overall, the main significance of this chapter lies in the insight it provides relative to the strategic and tactical responses airlines employ to deal with incessant economic pressures and an overwhelming uncertainty that characterise their current business landscape. Perhaps such dynamically tailored responses can inform collegiate understanding on how safety-critical organisations—that are overburdened with relentless economic pressures—can organise for evolvability and exaptation. The chapter ends with a reflection on the implications of the models, perspectives and theories for a study of resilience in the context of AOC domain.
2.1 Introduction

Regardless of the route taken to study performance in high-risk systems, safety inevitably crops up as one of the core considerations on whether a successful outcome has been achieved in the production process. For example, a long-standing record of cost-effective operations marred by minor safety lapses, near-miss incidents and perhaps some near-catastrophes will hardly sustain an airline’s competitiveness in the face of current economic landscape. It makes sense, therefore, to understand how safety considerations impact on production decisions and how frontline controllers adapt their behaviours in the face of both routine and novel demand challenges. The discussions in this chapter are designed to shed light on sociological and psychological issues around performance by making a detour through a number of perspectives: from accident and disaster theories to theories on failure and reliability. The goal is to understand the link between safety and production, and how interactions between safety and production requirements shape the arena for successful outcomes in safety-critical operations.

This chapter is broadly segmented into three parts. The first part (Section 2.2) explores various perspectives on performance in safety-critical, sociotechnical systems. The discussions cover key accident theories, as well as theories on cultures that enable high-risk organisations to successfully balance their safety and production requirements. The second part (Sections 2.3 to 2.6) conceptualises a socio-cognitive view of demand variability in an AOC context, including a characterisation of demand typology and how variations develop in airline operations. The third part (Section 2.7) reflects on current state-of-the-practice in airline planning and scheduling. From an empirical standpoint, the goal is to identify both tactical and strategic responses that airlines currently employ to deal with the vagaries of demands in their domain. But, from a more abstract perspective, the agenda is to understand how the functional resonances created by fluctuations in environmental, organisational, and contextual demands reverberate across an airline network, with particular interest on how such forces enable and/or hobble an AOC’s functioning.

It is worth mentioning that the terms ‘high-risk’ and ‘safety-critical’ are often used interchangeably to denote systems, operations and organisations that either have a core mission to regulate safety (such as Air Traffic Control), or run highly essential operations that pose high risk to the society when accidents happen (such as nuclear power plants).
2.2 Perspectives on performance in sociotechnical systems

The discussion in this section centres on four perspectives that are grounded on safety, accident and disaster research. The primary focus here is on their respective stances, the criticisms that are vital to the way we apply or interpret them in the context of airline operations control and, most importantly, their insights into the patterns of behaviours that help sustain or hamper successful performance in high-risk operations. It is important to clarify, though, that the motivation to understand what each perspective says about the antecedent conditions for success or failure have far less to do with a search for causation or ‘broken parts’. On the contrary, it has more to do with illuminating the complex processes that encapsulate how success or failure is constructed. But, in the process, the researcher hopes to gain some understanding as to why the discourse on ‘safety vis-à-vis production’ performance has generated such immense diversity of theories and opinions amongst renowned scholars.

2.2.1 Man-Made Disasters

As at the time of its formulation, Barry Turner’s Man-Made Disasters theory (Turner, 1978; Turner & Pidgeon, 1997) represents a unique insight on the dynamics and antecedent conditions for failure in sociotechnical systems and their governing institutions. Turner’s ‘man-made disaster’ (MMD) theory provided a sociological perspective that view failure as stemming from some familiar organisational, managerial and administrative processes that subvert the safe operations of technological systems (Pidgeon, 1997; Turner, 1976). As such, the MMD school-of-thought proposes that disasters should be regarded as ‘sociotechnical’ problems that arise from interactions between social, organisational and technical processes (Gherardi, Turner, Pidgeon & Ratzan, 1999).

2.2.1.1 Key observations and contributions of the Man-Made Disasters theory

The Man-Made Disasters theory pioneered several observations in the fields of disaster and safety research, as well as in the broader research on risks and vulnerability in safety-critical organisations. A prominent observation relates to the claim that disasters are not chance events or “bolts from the blue” (Gherardi et al., 1999, p. 234). Rather, disasters are incubated long before they are eventually released by a precipitating event. According to the MMD perspective, incubation of disaster is nurtured when an organisation holds onto an
illusion of control by advancing dogmatically entrenched, but erroneous, assumptions about the appropriateness of their practices. Such illusions create a subtle divergence between an organisation’s beliefs about risks and vulnerability in their operations and the ways risks and vulnerability actually develop in the real world; thus, exacerbating the build-up of disasters (Turner & Pidgeon, 1997, p. 72). However, a precipitating event exposes such discrepancies forcing organisations to question their current models and operational practices (Turner, 1978).

While explaining the notion of incubation, Turner argues that failure originates from a lapse in foresight and a subsequent lapse in detection of the erroneous assumptions. Failure of foresight, Turner claims, feeds a false sense of control while the conditions that precipitate a failure event are accumulating unnoticed (Turner, 1976, pp. 379-381). Turner’s perspective upholds that failure is essentially a natural consequence of a breakdown in the norms and practices that, in the past, had been culturally accepted as adequate (Turner & Pidgeon, 1997, p. 70). A critical aspect of the incubation stage is that the build-up of latent errors and lapses—what Turner dubbed *anti-tasks*—typically goes unrecognised because the signals of impending danger are often faint; and even when they are visible, tend to be at odds with current organisational beliefs about risks and vulnerability. Correspondingly, as Pidgeon & O’Leary (2000, p. 17) explained, discrete lapses and failures are inadvertently compounded due to “a collective failure of organisational cognition and ‘intelligence’, as the developing system vulnerability to failure remains concealed by social processes that attenuate evaluations of risk”. Eventually, in the aftermath of a catastrophic failure, the appropriateness of such organisational norms and beliefs are called into question, triggering a need to address the gap between what is known after-the-fact and what was assumed to be the case before the precipitating event.

The MMD theory also proposed the idea that increases in “negentropic” (i.e., negative entropy or order-producing) processes increases not only the reliability of production, but also the likelihood of compounding disparate, unrelated problems. MMD theorists argue that unintended consequences of errors will most likely be amplified and diffused more broadly through the same channels that are employed for organised production (Turner, 1978, p. 180; Pidgeon & O’Leary, 2000, p. 17). As energy from the production cycles are transferred or combined, so is the anti-tasks that are produced. In this light, a hierarchically-based, order-seeking system with multiple echelons has a greater potential
to compound and diffuse anti-tasks than a system with more decentralised form of control (Turner, 1978, p. 180). A corollary of this argument is that too much order in a system actually enhances the path to failure, an idea that has since been comprehensively developed in the discussions of how complex adaptive systems stabilise dynamically on the edge of chaos (Kauffman, 1991, 1993; Kauffman & Johnsen, 1991; Lewin, 1992, 1999; Marion, 1999).

Table 2.1: Antecedent patterns to a disaster (Abstracted from Turner 1976, pp. 388-391)

<table>
<thead>
<tr>
<th>Common Patterns</th>
<th>Explanations</th>
</tr>
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<tbody>
<tr>
<td>Rigidities in perception and belief in organisational</td>
<td>A situation where organisation’s frame-of-references and beliefs are fixated on certain assumptions, which invariably fail to capture other risks that fall outside the boundary of what is counted as hazards and threats to the system.</td>
</tr>
<tr>
<td>settings</td>
<td></td>
</tr>
<tr>
<td>The decoy problem</td>
<td>A situation where an organisation is misled to believe a situation has been resolved by shifting attention to a related event which might well be just a symptom or a decoy event.</td>
</tr>
<tr>
<td>Organisational exclusivity: disregard of non-members</td>
<td>A situation where organisations discount suggestions and ideas that do not agree with their norms and practices, particularly if those were offered by one who is considered an outsider.</td>
</tr>
<tr>
<td>Information difficulties: Variable Disjunction of</td>
<td>A situation whereby individuals or parties handling a problem are unable to fully grasp the complexity of the problem nor obtain precisely the same information about the problem due to the “variable disjunctive” nature of the problem/information, which often lead to differing interpretations and perceptions of the problem.</td>
</tr>
<tr>
<td>Information</td>
<td></td>
</tr>
<tr>
<td>Failure to comply with existing regulations</td>
<td>Violations could occur because regulations are ambiguous, in conflict with production goals, or thought to be out-of-step with technological advances.</td>
</tr>
<tr>
<td>Minimising emergent danger</td>
<td>Failure to see or fully appreciate the magnitude of an emergent danger, which often lead people with the power to act to underestimate the risks posed by the observed signals and, consequently, to delay in taking preventative actions.</td>
</tr>
</tbody>
</table>
In summary, an interesting abstraction from the MMD theory is that failure originates from the same processes that produce success (Turner & Pidgeon, 1997). In other words, failure is produced due to a breakdown in the very processes that produce success, an argument that has been reinforced by the ‘resilience engineering’ perspective (Hollnagel, Woods & Leveson, 2006). Again, Turner’s MMD theory provides common patterns and antecedent conditions that preceded the 84 cases he studied (Turner, 1976, pp. 388-391). The observed patterns/preconditions are summarised in Table 2.1. In general, the thesis of the MMD theory could be summed up in this statement: “despite the best intentions of all involved, the objective of safely operating technological systems could be subverted by some familiar and ‘normal’ processes of organisational life” (Pidgeon, 1997, p. 2; Pidgeon & O’Leary, 2000, p. 16). As a way to cope with the inevitable subversion of good intentions, the MMD theory proposes the following: “senior management commitment to safety; shared care and concern for hazards and solicitude over their impacts upon people; realistic and flexible norms and rules about hazards; and continual reflection upon practice through monitoring, analysis and feedback systems” (Pidgeon & O’Leary, 1994; 2000, p. 18).

2.2.1.2 Elaborations and criticisms of the Man-Made Disasters theory

Sidney Dekker elaborated on the dynamics of the disaster incubation process with his discussions of the drift metaphor. Dekker concurs that the path to failure is often virtually unnoticed in foresight, as organisational norms and values regarding what is considered acceptable creep imperceptibly towards a tipping point (Dekker, 2011). Dekker’s idea of a gradual migration toward failure was further buttressed with Vaughan’s depiction of how organisations normalise deviances (Dekker, 2011, pp. 103-107). In agreement to Vaughan’s conclusions on the Challenger space-shuttle accident, Dekker explains that organisational behaviour migrates toward failure when risky behaviours that contributed to successful outcome in the past are incorporated into daily work routines and are then repeated, setting the stage for small incremental ‘drifts’ in the direction of failure (Dekker, 2011, p. 105; Vaughan, 1996). Dekker also points out that unrelenting production pressures and resource limitation can gradually become institutionalised as a normal aspect of decisional constraints, necessitating a continuous construction and renegotiation of the idea of ‘risk’ across the technical and the social dimensions of work. Both Dekker and Vaughan agree
that this dynamic was at the heart of the incubation period for the Challenger space-shuttle accident (Dekker, 2011, p. 105).

On order-producing processes, Karl Weick reflected on the implications of negentropic processes in light of the core cultures of high-reliability organisations (HROs). Weick (1998) considers thoughtfully that the very routineness, order and reliability that HROs cultivate might as well encourage small errors to spread and be seeded in numerous places (Weick, 1998, p. 73). Weick then goes further to infer that even effective organisations are vulnerable to failure if their success derives from tight coupling, integration or other practices that make it easier for error to propagate (Weick, 1998, p. 73).

But, despite the conspicuous similarities between Turner’s incubation of disasters and Dekker’s drift to failure metaphor, Dekker picked up on MMD’s commitment to mechanistic, Newtonian epistemologies and further argues that the MMD theory focuses largely on “broken parts” (or failed processes). More significantly, Dekker protests MMD’s view of risk as energy to be contained rather than as a dynamic, adaptive energy that can evolve over time. Dekker argues that such Newtonian conceptualisation of risk as energy-to-be-contained “…is not necessarily well-suited to explain the organisational and sociotechnical factors behind system breakdown, nor equipped with a language that can meaningfully handle processes of gradual adaptation, or the social processes of risk management and human decision-making” (Dekker, 2011, p. 90).

Further, Gephart (1984) decries the original MMD model’s inability to capture more explicitly how political processes and power relations shape interpretation of outcomes. To resolve this limitation, Nick Pidgeon—in Turner & Pidgeon (1997), Pidgeon (1997), and Pidgeon & O’Leary (2000)—draws on the work of Rijpma (1997), among others, to highlight several political processes that often undermine learning from disasters. Pidgeon then went on to propose some influences that stand as barriers to learning in sociotechnical systems such as, “faulty reporting of incidents, secrecy and institutional cover-ups, normalisation of errors in the face of external accountability, and the reinterpretation of failure as success” (Pidgeon, 1997; Pidgeon & O’Leary, 2000, p. 20).
2.2.2 Normal Accident Theory

In the 1984 and 1999 editions of his book, *Normal Accidents: living with high-risk technologies*, Charles Perrow argues and illustrates that system accidents (or system failures in general) are inevitable in complex, tightly coupled systems and should, therefore, be considered “normal events” (Perrow, 1984). The central thesis of his theory—what is now referred to as the Normal Accident Theory (NAT)—is that system accidents typically result from multiple, unexpected, and often incomprehensible, interactions of failures emanating from highly interconnected components (Perrow, 1999, p. 23). As such, accidents can be considered an inherent property of complex systems; hence, the proposition that they be viewed as inevitable or “normal” to complex systems (Perrow, 1984, p. 70). Perrow explains that modern high-risk systems, such as nuclear reactors, are becoming increasingly complex, and that their increasing complexity will inadvertently mask how failure in one part of a system collides or interacts with failure in other parts of the system (Perrow, 1999, p. 35). He also emphasises that such combinations can and do produce unanticipated—nonetheless, inevitable—consequences.

2.2.2.1 Complex Interactions and Tight Coupling

Perrow proposes a framework (Figure 2.1) for characterising complex systems according to their riskiness (Perrow, 1984, p. 78). In his framework, Perrow identified two variables for conceptualising riskiness in highly interconnected systems—complex interaction and tight coupling. Interaction encompasses the reciprocal action-response mechanism that characterises the relationships among elements in a system. Perrow argues that interactions can be linear or complex (Perrow, 1984, p. 78). Linear interactions are, more often than not, thoughtfully designed into the system; largely envisaged as a potentiality of what could happen; or at the very least comprehensible as at the time of their occurrence. By contrast, complex interactions can rapidly generate sequences that are not only unexpected but can also be either incomprehensible or not immediately visible to those responsible for the safe operation of the system (Hollnagel, 2009, p. 88). Interactive complexity, thus, arises when there are multitudes of ways that parts and relationships between parts can interact within a system (Dekker, 2011, p. 128).
The notion of “incomprehensibility” of complex, non-linear sequences appears particularly relevant when a system is highly compartmentalised leading to operators relying on inferential information sources (Perrow, 1999, p. 23). Often, the knowledge and skill-set required to accomplish set tasks are highly specialised leading to limited understanding of interdependencies across functions and the processes or ways in which changes occur. Both Perrow and Hollnagel also suggest that systems that exhibit interactive complexity tend to have multiple control parameters that may interact in uncertain ways, multiple common-mode connections linking components that are spatially distributed and out-of-sequence, and delayed signals along with unfamiliar or unintended feedback loops (Perrow, 1984; Hollnagel, 2009, p. 88). In such systems, it is more likely that nonlinear sequences can evade foresights and simulated trainings, and can only be captured or made visible with the benefit of hindsight.

Perrow also identified coupling as a degree of interconnectedness or interdependency between components. A system is said to be loosely coupled when there is low
interdependency between its components. By contrast, a system is tightly coupled when there is a high level of interdependency between its components; especially when they are linked in a time-dependent manner (Perrow, 1984, pp. 78-80). Tightly coupled processes tend to have limited slack and heavily constrained sequences of action. Such restrictions place “hard limits” on the solution space that operators can apply in order to manoeuvre unanticipated surprises (Hoffman & Woods, 2011; Woods & Branlat, 2011). Again, tight coupling allows for only little margin for changes and/or delays. Due to the high level of dependency in the sequences of actions, a delay in one part of the system tends to cascade rapidly through the entire system in far shorter time than would have been expected if the system were loosely coupled. In some tightly coupled operations, like a nuclear chain reaction, delays in processing are simply not an option. Further, tightly coupled processes necessitate that interventions required to control operational processes must be correct, with very little tolerance for variability in precision. Moreover, there is a potentiality that the nature of the problem may well not be understood correctly; thereby raising the odds that intervention could complicate rather than resolve the problem (Hollnagel, 2009, pp. 86-88).

By contrast, loosely coupled processes have more variability in the sequences of actions that can be deployed to achieve a production goal. They are more forgiving of delays as there may be opportunities to intervene at some stage in the process. Loosely coupled processes may allow for standby modes to be activated and for intermediate stages of output to be stored readily for variable periods. In addition, they can allow a production cycle to continue even when some processes or components are compromised; nonetheless, at a reduced capacity (Dorner, 2014; Hollnagel, 2009, p. 87; Perrow, 1984).

2.2.2.2 Implications, Criticisms and Elaborations of Normal Accident Theory

One of the central arguments of NAT is that organisations are not capable of devising governance structures that can eradicate the risk of accidents in complex, tightly coupled systems. Perrow contends that on one hand, interactive complexity requires that decentralised agencies proximal to the production processes be empowered to improvise in the face of a developing problem. But, on the other hand, tight coupling necessitates that a centralised agency be given oversight of the entire operations to maintain congruence across subsystem goals and processes (Perrow, 1984). Perrow’s stance is clear and simple:
organisations cannot be both at the same time (Perrow, 1999, pp. 303-305). The crux of Perrow’s propositions is his advocacy against efforts at re-designing such high-risk systems, as he believes that system accidents are hardly avoidable and cannot be designed around. As a solution, Perrow suggests abandoning systems he considers non-essential high-risk systems (e.g., nuclear weapons programs and nuclear power stations at the top-right quadrant in Figure 2.1) and strict regulations for those risky-but-essential systems (such as air and rail transports in top-left quadrant). His conclusion appears to be that there is very little hope at making systems like nuclear reactors and nuclear weapon programs any safer (Perrow, 1984, p. 305).

Not surprisingly, Perrow’s pessimistic view of high-risk operations drew several exchanges among systems and organisational theorists, who propose that such high-risk systems can learn to operate reliably (e.g., La Porte & Rochlin, 1994; Weick, 2004). Of particular interest is Andrew Hopkins’s analysis of NAT in view of its limited applicability in explaining many of the best-known disasters and accidents, such as the Bhopal chemical leak, the Chernobyl nuclear catastrophe, the catastrophic failure of the Challenger space shuttle, and five Australian coal mine explosions between 1972 and 1999 (Hopkins, 1999). In his discussions, Perrow (1999, pp. 355-383) discounts such notable accidents as not fitting into the archetype of normal accidents because (based on his framework) the systems are not considered complex and tightly coupled enough. This conclusion led Hopkins to question the criteria for measuring complexity and coupling, joining the ranks of other organisational theorists who have echoed that the clear absence of criteria for interaction and coupling renders Perrow’s categorisation “anecdotal, inconsistent and subjective” (e.g., La Porte & Rochlin, 1994; Kates, 1986 quoted in Hopkins, 1999, p. 96).

Moreover, in his 1999 book, Perrow acknowledges Scott Sagan’s (1993) comparative discussions of NAT and the so-called high-reliability theory as spot on and, further, draws on Sagan’s findings to protest against safety researchers, who he believes are gradually detoxing NAT’s emphasis on power relations and group interests. In view of power relations and parochial interests, Perrow forcefully argues that financial considerations and pressures from the elite would inevitably subvert efforts at tweaking organisational processes to cope with the catastrophic potentials of high-risk systems (Perrow, 1994, 1999). Hopkins, however, provided a counter argument that Perrow’s later attempts to reformulate NAT in Perrow (1999) so as to incorporate organisational sociological ideas
along with the concept of group interest and power relations, in effect, replaces rather than substantiates NAT as a theory of accident (Hopkins, 1999, p. 101).

In addition, Hollnagel (2009) points out that it is actually the consequence of complexity rather than complexity itself that matters in high-risk work environments (p. 88). Hollnagel’s position is that the main challenge with interactively complex systems is less about their *interactiveness* as Perrow’s framework suggests, but more about their *manageability* (or *controllability*). Accordingly, Hollnagel proposes a re-conceptualisation of Perrow’s model of riskiness by replacing the ‘interaction’ dimension with ‘manageability’. Hollnagel, further, grounded the concept of manageability on how easy or difficult it is for operators to understand what is going on in the work environment (Table 2.2)—a phenomenon he explained as the *tractability or intractability* of the work environment (Hollnagel, 2009, pp. 42-43).

*Table 2.2: Tractable and Intractable Systems (Hollnagel, 2009, p. 57)*

<table>
<thead>
<tr>
<th></th>
<th>Tractable system</th>
<th>Intractable system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of details</strong></td>
<td>Descriptions are simple with few details</td>
<td>Descriptions are elaborate with many details</td>
</tr>
<tr>
<td><strong>Comprehensibility</strong></td>
<td>Principles of functioning are known</td>
<td>Principles of functioning are partly unknown</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>System does not change while being described</td>
<td>System changes before description is completed</td>
</tr>
<tr>
<td><strong>Relation to other systems</strong></td>
<td>Independence</td>
<td>Interdependence</td>
</tr>
<tr>
<td><strong>Controllability</strong></td>
<td>High, easy to control</td>
<td>Low, difficult to control</td>
</tr>
<tr>
<td><strong>Metaphor</strong></td>
<td>Clockwork</td>
<td>Teamwork</td>
</tr>
</tbody>
</table>

In spite of the myriad controversies generated by his perspective and the flaws echoed by scholars who critiqued the normal accidents theory, Perrow’s formulation of NAT at the very least lends insight into how successful performance can be sustained in interactively
complex and tightly coupled systems—although his advocacies are, by far, more pessimistic. The key abstractions from NAT discussions include the consequence of interactive complexity and tight coupling, the challenges of simultaneously operating centralised and decentralised governance, and the problem of undermining safety goals through acts aimed at relieving financial and stakeholder pressures. Perrow further suggests that the challenge with error-avoiding systems is not so much that their risks are difficult to decipher from operational data, but that they often result from information that is undiscoverable in foresight and can only seem apparent in hindsight (Perrow, 1994, p. 218). In view of Perrow’s arguments, the surprise reflects not only that which is cognitively missed but more so that which is cognitively absent. It is, therefore, of interest to this research to explore further the implications of interactive complexity and tight couplings in complex, adaptive sociotechnical systems and, more specifically, in the context of airline operations control.

2.2.3 High Reliability Theory

As at the time the Normal Accident Theory was making waves in the field of safety and accident research, a cross-disciplinary team of researchers at the University of California Berkeley and the University of Michigan became enamoured with a subset of organisations operating high-risk technologies, the so-called high-reliability organisations (HROs). Their research focused primarily on such HROs, including naval aircraft carriers (e.g., Rochlin, La Porte & Roberts, 1987), air traffic control systems (e.g., La Porte, 1988) and nuclear-power generation plants (e.g., Bourrier, 1996; Marcus, 1995). As the researchers claim, HROs provide a natural laboratory for studying how organisations can organise for high reliability, given the extraordinary steps they take in pursuit of error-free performance (La Porte, 1988; Roberts, 1990; Rochlin, 1993; Schulman, 1993; Weick, 1987). HROs, according to these researchers, are widely acclaimed for their canny responsiveness in the face of unforgiving social and political landscapes. Moreover, whilst they operate in environments prone to catastrophic failure, they somehow manage to go for considerable periods without experiencing such failures (La Porte & Rochlin, 1994; Rochlin, 1993). HROs also seem to have mastered the craft of prioritising safety, recognising the changing shape of vulnerability, and creating strong cultures that afford vigilance and responsiveness (e.g., La Porte & Consolini, 1991; Weick, Sutcliffe & Obstfeld, 1999). So strong was the conviction from their observations that the high-reliability theorists would stake their
reputations on the premise that HROs can operate failure-free for a considerable period by deliberately creating requisite cultures and processes for high reliability (La Porte 1988; Rochlin, La Porte & Roberts, 1987; Weick et al., 1999). The high-reliability theorists thus became the lead advocates on the idea that organisations operating high-risk technologies can indeed evade catastrophic accidents, despite the challenges of interactive complexity and tight coupling, as well as relentless political and social pressures.

To sustain long periods of failure-free operations, however, high-reliability theory (HRT) argues that organisations must develop cognizance in recognising subtle differences and variations in their processes of production (Weick & Sutcliffe, 2001). In this light, the high-reliability theorists argue that reliability does not come from reproducibility of actions or patterns of activity, as evident in the classical engineering notion of reliability. Rather, reliability is achieved through the management of variations in performance and in cross-departmental collaborations (Schulman, 1993; Weick et al., 1999). Grounded on these claims, the high-reliability theorists propose five organisational behaviours that underpin organisations that have developed a requisite culture of high reliability.

2.2.3.1 Practices that underpin high-reliability organisations

The high-reliability theorists, in particular Karl Weick and colleagues, have proposed that high reliability can be cultivated and maintained through a culture of mindfulness (Weick, 1987; Weick & Sutcliffe, 2001; Weick, Sutcliffe & Obstfeld, 1999). Weick explains that mindfulness involves deliberate differentiation and reframing of perceived signals in order to abstract an enlarged set of possibilities about what was noticed (Weick, 1987). Weick and colleagues further claim that mindfulness also allows for identification of unexpected deviation as well as new sources of ignorance; these will in turn act as an imperative for noticing subtle shifts in vulnerability (Weick et al., 1999). In general, the high-reliability theorists suggest that it is the processes of mindfulness that enables HROs to perform reliably despite a continuous stream of surprises and non-routine events (e.g., Weick, 1987).

Correspondingly, the HRT school-of-thought propose several practices as indicators of organisations that demonstrate mindfulness (e.g., Weick et al., 1999; Weick & Sutcliffe, 2011). First is a preoccupation with failure, a cognitive process that involves maintaining a suspicious and sceptical outlook even when it seems all aspects of the operation are well under control. The second is a reluctance to simplify interpretations, which suggests one should
endeavour to critically follow up on perceived signals by seeking alternative explanations rather than simply explaining new signals on the basis of some narrow expectations of what is currently the norm. The third is sensitivity to operations, an ongoing process whereby one is constantly heedful of the developments within and around the system. This practice include being sensitive to the ways by which signals are sought and data evaluated, as well as how disparate problems might collide and produce new vulnerability. The fourth is a commitment to resilience. This practice is operationalized by having a broad range of resources, capabilities, and sufficient diversity in skill-set so as to be ready to respond to both anticipated and unforeseen problems. The fifth is deference to expertise by devolving authority to make decisions to levels where expertise resides.

For some reason, some propositions (e.g., Weick, Sutcliffe & Obstfeld, 1999) have the fifth principle as underspecified structuring, although both practices appear to focus on the challenges of centralised/decentralised decision-making architecture as highlighted by Perrow (1984, 1999). Along this direction, both Weick (1987) and Schulman (1993) argue that organisations can and do cope with conflicting requirements by delegating decision authority considerably to units that are closer to the point of action. HRT maintains that by under-specifying governance structure, an organisation can allow for migration of authority to the level where action is required, while at the same time enacting protocols that will ensure high-level goals and priorities are promptly considered at those levels (Weick et al., 1999). In view of Weick’s (1987) and Schulman’s (1993) arguments, Shrivastava and colleagues infer that encouraging authority to migrate may perhaps be the vital mechanism that enables organisations to cope with the conflicting requirements to be simultaneously centralised and decentralised (Shrivastava, Sonpar & Pazzaglia, 2009, p. 1364).

Furthermore, drawing on Sagan’s (1993) propositions and the works of the HRT school of thought, Dekker (2011, pp. 94-95) outlines what he considers the four ingredients that enhance cultures of high reliability in safety-critical organisations. The first concerns a culture of safety that is entrenched from the highest echelon of governance. The rationale is that workers in an organisation will not take safety talks seriously if there is no strong commitment to safety from the leadership of the organisation. This proposition, in essence, echoes the propositions made by the MMD theorists (cf., Pidgeon & O'Leary, 1994; 2000, p. 18). The second relates to the need for redundancy, which can be applied as an overlap of roles and authority or as duplication of responsibilities, hierarchies, supplies,
technological systems, etc. The third concerns considerable delegation of decision authority to units and individuals that possess expertise to address relevant operational issues. Schulman have also argued elsewhere that delegation of authority to frontline operators and lower level governance could lead to a workforce that is involved in vigorously debating alternative viewpoints and engaging in complex negotiations to arrive to an acceptable solution (Schulman, 1993). The fourth ingredient relates to organisational learning, in which high reliability grows out of incremental learning through trials and errors.

2.2.3.2 Criticisms of the high reliability theory

It is hardly surprising that the first set of critiques to highlight the limitations of HRT as a theory of accidents in high-risk systems came from the Normal Accident Theorists (NATs)—particularly Scott Sagan (1993) and Charles Perrow (1994). Sagan in his book, *The Limits of Safety: Organisations, Accidents and Nuclear Weapons*, concluded that his empirical analysis of accidents and almost-catastrophic near misses during the cold war era lends more support for NAT than for HRT (Sagan, 1993). The findings, Sagan claims, evince that safety was not placed first in some of the incidents studied; that there were not many instances of sophisticated trials-and-errors learning as posited by HRT, instead there were significant cover ups and mis-learning following notable cases of accidents and near-misses; moreover, that decentralisation was not very helpful as HRT would have us believe (Sagan, 1993). Sagan grounded his claims on the analysis of dozens of incidents, some of which became Perrow’s (1994) anchors for rebutting core HRT premises.

For his part, Perrow scoffs at the idea of processes for averting catastrophes as “rosy prospects” (Perrow, 1994, p. 213). In regards to systems that were identified by Morone & Woodhouse (1986) as being successful at averting catastrophic accidents (e.g., recombinant DNA research programs and toxic waste management systems), Perrow contends that such systems are more or less new frontiers of risky systems that have not yet disclosed their danger (Perrow, 1994, pp. 212-213). Perrow went further to point out that, although HRT acknowledges the vast cognitive limitations of human beings, they seem to believe that organisations can compensate for those limitations. But even more optimistic, Perrow argues, is the supposition that such organisational compensations are unproblematic in themselves and do not involve more complex or new irrationalities (Perrow, 1994, p. 213).
Both Sagan (1993) and Perrow (1994) also decry HRT’s view of systems as closed and pursuing clearly defined safety goals. Perrow suggests that an open system’s view of the Diablo Canyon nuclear power plant case study—one of the systems investigated by the HRT scholars—would have called the HRT researchers’ attention to the fact that the plant is sitting on an earthquake fault line, which insidiously aggravates the catastrophic potentials of that nuclear plant (Perrow, 1994, p. 216). From this research standpoint, the open system’s view and Perrow’s example hold particular significance given the contributions of proximity to earthquake fault lines in the breach of Fukushima nuclear power plant’s safety defences in the Japan triple disaster of 2011.

Other reviewers, who have also weighed in on the debate, have pointed out that the HRTs’ work appears to focus solely on the so-called HROs—most of which happen to have links with the military and the navy—and has not been extended to mainstream organisations (Scott, 1994). Shrivastava, Sonpar & Pazzaglia (2009) also highlighted that the HROs which served as a test-bed for most HRT premises put a high premium on reliability because their operating environments seldom offer them a second chance (Shrivastava et al., 2009, p. 1363). In defence of HRTs’ selective focus on the set of HROs they studied, Weick, Sutcliffe & Obstfeld (1999) argue that organisations that perform against the backdrop of potential catastrophe largely have requisite mechanisms that support high reliability performance. Such mechanisms, the researchers claim, are often under-developed in organisations whose core objectives are focused more on efficiency rather than on reliability (Weick et al., 1999, p. 81). Although Weick and colleagues appear to have a solid case, Perrow (1994, p. 214) quickly points to its limitation. Perrow contends that by selectively paying attention to only cases where HROs succeeded, HRT researchers have failed to grasp why such organisations sometime fail. This new understanding, according to Perrow, can only come by examining other organisations with the same characteristics and cultures that failed, despite having the acclaimed requisite cultures—as evident in many of the cases Sagan (1993) reviewed.

Moreover, many articles (including those that are not directly related to this debate) have argued or illustrated that redundancy—in spite of its usefulness—does not always contribute to failure-free performance (e.g., Dekker, 2011; Leveson, 2004; Perrow, 1994; Sagan, 1993). Overlap or even duplication of roles and decision-making hierarchies, for instance, can lead to individuals and subgroups shirking responsibilities (Hollnagel, 2009,
p. 115) and can also lead to power tussles and conflicts-of-interest between mainstream units and their shadow units (Dekker, 2011, p. 123; Perrow, 1994, p. 217). Again, redundancy adds more and not less complexity to the system; thereby, simultaneously obscuring visibility to symptoms of malfunctioning and increasing the number of ways components of the system can fail alone or in combination (Dekker, 2011, p. 123; Perrow, 1999, p. 368). Based on Sagan’s findings on the Thule B-52 bomber accident, Perrow draws attention to how the B-52 bomber jet was used as a redundant alarm system. The idea was that the loss of the bomber jet to an enemy fire will alert the US Strategic Air Command of a possible nuclear attack. However, it seems the US Strategic Air Command failed to anticipate a scenario where the B-52 bomber jet would crash without being shot down by an enemy fire (Perrow, 1994, p. 215). Thus, the crash of B-52 bomber jet almost triggered a nuclear retaliation by the US Strategic Air Command because the designers failed to consider the possibility of a false alarm scenario due to an accidental crash.

### 2.2.3.3 Significant shifts in thinking in HRT research

In expounding the fourth ingredient, Dekker (2011) highlights a significant shift in thinking with the later versions of HRT, in that HROs flirt with smaller dangers in order to understand and forestall larger ones (Weick, 1987; Weick, Sutcliffe & Obstfeld, 1999). In his earlier formulations, Weick (1987) proposed that HROs have zero tolerance for errors and complete absence of trial-and-error learning. However, Weick’s later formulations (e.g., Weick & Sutcliffe, 2001; Weick et al., 1999) acknowledge contrary propositions from La Porte and Consolini (1991) that, although errors are rare, they are altogether inevitable in HROs. Weick also acknowledges a shift in thinking regarding the notion that HROs can learn through sophisticated trial-and-error programs (Weick et al., 1999). Nevertheless, on the idea of learning through trials-and-errors, the HRT school-of-thought maintain that there are limits to trial-and-error learning in high-risk operations. They emphasise that HROs engage more with simulated exercises when the cost of failure in a real-world system is too great for learning by trials and errors (La Porte & Consolini, 1991). This new thinking resonates with David Snowden’s notion of ‘safe-fail’ experimentation, as opposed to the more traditional, engineering-based ‘fail-safe’ experimentation (Snowden, 2010).

Again, it turns out both Sagan’s (1993) and Perrow’s (1994) rebuttal of the closed system view of HRT contributed to a more open system’s view in the later conceptualisations of HROs. This shift has been reflected in HRTs’ acceptance that public perceptions and other
exogenous forces can indeed shape priorities within an organisation (La Porte & Rochlin, 1994). Furthermore, there is now a wider acceptance among HRT scholars that HROs actively pursue multiple and potentially conflicting goals (La Porte & Rochlin, 1994; Rochlin, 1993). This shift is in contrast to earlier formulations that assume HROs only pursue safety related goals, with less emphasis on potentially conflicting production goals—for example, to do more flying (e.g., Roberts, 1990; Weick, 1987). Overall, it is of interest to this research to ascertain how these propositions, criticisms and shifts-in-thinking can enrich the researcher’s understanding of the dynamics of resilient performance in the face of relentless safety and production pressures.

### 2.2.4 Logic of failure

The logic of failure represents a shift from organisational issues around performance to how individuals address the issues relating to uncertainty and exponentially developing problems in complex environments. In his formulation of the logic of failure (Dörner, 1996), Dietrich Dörner presented numerous illustrations that elucidate how and why well-intended actions can sometimes degrade the performance of complex systems. His discussions highlighted some cognitive pitfalls and complex system factors that, in many instances, hamper human efforts to solve complex problems. Although Dörner’s framing of the problem appears to focus on failure, the thesis of his theory did highlight that “humans…can form hypotheses about situations marked by uncertainty and can anticipate their actions by planning”. But, more significantly, Dörner postulates that humans have the capability to expect the unexpected and to take precautions against surprises (Dörner, 1990, p. 463).

In the context of the discussions so far, the logic of failure marks a shift from models of organisational performance to models of human performance. The logic of failure is a very interesting way of looking at how success and failure is created. But, its significance is not just because it identifies a wide range of faulty modes of behaviours. On the contrary, the logic of failure is particularly interesting because it lends significant insight into why people tend to fall into such “faulty” traps in the first place. In essence, it not only provides some experimentally backed reasons for success and failure in complex situations, but also a contextual framework for interpreting action-regulation in complex environments. Besides the framing of the logic-of-failure as a theory of human performance, it is quite distinctive.
to the afore-discussed theories in the sense that it did not engage with the argument on whether organisations are helplessly vulnerable or highly reliable. Instead, it focuses on whether individuals and collectives are indeed capable of demonstrating resilience.

2.2.4.1 The psychology of action-regulation in complex situations

Dörner identifies four patterns of faulty modes of behaviour grounded on the logics that underpin such behaviours, as depicted in Figure 2.2. The first pattern, Dörner claims, represents a tendency to economise limited ‘thinking’ resources. Dörner notes that human conscious thinking is neither very fast nor capable of processing much information per time unit (Dörner et al., 1990, p. 22). Thus, humans tend to quickly resort to ‘economical tendencies’ when a developing problem appears to escalate faster than their thinking can handle. In a sense, this view corroborates Hollnagel’s (2009, p. 88) assertion that the challenge with managing complex situations is not much about its complexity than it is about its manageability. The need to cope with limited resource thinking, inevitably, results in a variety of economical tendencies, including a tendency to selectively search for and attend to information; a tendency to resort to linear extrapolations even when prognosticating variables that are developing nonlinearly; and consequentially, a tendency to fixate on ingrained thought processes even in the face of possibly contradictory demands of ever changing situations.

The second pattern relates to a self-protectionist attempt to validate one’s illusion of competence. Through his experiments, Dörner identified some behavioural patterns that evolve, often unconsciously, in efforts to promote or preserve one’s positive view of their ability to address a situation. He observed that the experimental subjects tended to seek out more familiar information or information that validated their beliefs. As a result, they ignored contrary evidence and, often too quickly, discredited alternative views that appear to contradict their thinking. They made assumptions and took ballistic actions, with little to no effort made to assess the effects of their decisions later on. Dörner observed that the acting subjects tend to evade tracking the effects of their actions, as they seemed unwilling to be confronted with the consequences of their actions. This self-protectionist approach, Dörner claims, enabled them to maintain an illusion of having solved the problem by means of their actions (Dörner et al., 1990, p. 22). Furthermore, the acting subjects engaged in thematic vagabonding by switching focus and ideas aimlessly, with no clearly
defined approach for addressing ill-structured problems and sudden catastrophic developments. In many occasions, the acting subjects focused on irrelevancies rather than on the bigger pictures. This behaviour, Dörner asserts, is largely driven by dogmatic beliefs and prevailing ideas on how the world works.

Figure 2.2: Patterns captured in the faulty modes of behaviour (Dörner et al., 1990, p. 22)

The third pattern relates to what Dörner called ‘the predominance of current problems’ (Dörner et al., 1990, p. 23). Dörner explains that humans are mostly obsessed with the problems they currently have and often do not give much thought to possible future developments. Dörner hypothesises that humans fail to think of future developments because they often view them as ‘problems they do not have’ rather than as ‘problems they do not yet have’. This focus on a ‘currently known’ problem leads to emphasis on what is
seen and a consequential failure to search out what is not readily evident. Actions are then set up to address the current problems, but it is often missed how those actions have inadvertently set up new paths to failure. As a result, weak and diffused signals of aberrant developments get masked against the backdrop of some perceived more urgent problems. The predominance of current problems, therefore, contributes to failure to envisage both the long term and the side effects of present actions, and also contributes to failure to anticipate how present actions might interact to produce new vulnerability (Dörner et al., 1990, p. 23).

The fourth pattern concerns an inability to recall information in our short-term memory, which is best-known as forgetfulness. Dörner suggests that one’s inability to hold information about temporal configurations will affect their ability to posit hypotheses on temporal patterns. As a solution, Dörner proposes ‘spatialisation of time’ wherein time-based diagrams are employed to transform temporal sequences to spatial forms (Dörner et al., 1990, p. 23).

2.2.4.2 Conclusions on the logic of failure

The significance of the logic of failure is less about the concrete modes of behaviours it identifies, but more about how the respective logics underpinning those modes enable researchers to identify the conditions under which a response can be claimed to be appropriate. Dörner posits that myriad forces influence the underpinning logics for actions, not the least of which are domain characteristics, predictability of events and time pressure. Dörner also advocates for strategic flexibility in dealing with complex situations; that is, a deliberate adaption of thinking—not just actions—to fit prevailing situations (Dörner et al., 1990, p. 23). This theory sets up a question as to how practitioners assess appropriateness for their responses and processes of reasoning, particularly when resolving complex and rapidly evolving situations. Empirical evidence from the domain of airline operations control will serve as a platform for comparing Dörner’s logic-of-failure against March & Olsen’s (2006) logic-of-appropriateness. To not repeat discussions unnecessarily, March and Olsen’s views on the logic of action is discussed briefly in a section in Chapter 6, just before the comparative analysis.
2.3 A Socio-Cognitive view of demand in airline operations

Airline flight schedules are frequently subjected to numerous irregularities and unforeseen events. Due to the inherent variation in passenger demand over the course of a week, it is often the case that situations arise wherein modification is needed to maintain the feasibility of the original plan (Abdelghany et al., 2004; Clarke, 1998; Wu & Caves, 2000). Such situations may involve key resources, such as aircraft, crew and ground resources. Moreover, increasing demand for maximum fleet and crew utilization, extensive network routings, global alliances, and partnerships have contributed immensely to the critical capacity situations and airspace congestion that are prevalent in many airports. Airlines are also faced with a host of other irregularities such as inclement weather events, air traffic control (ATC) restrictions, slot request issues, mechanical breakdown, passenger/baggage handling issues, and minimum equipment list (MEL) issues with aircraft. Non-conformance to flight schedules as planned tend to be more detrimental to the schedules for basic airline resources along with other facilities in the broader air transportation system that are necessary for efficient service delivery (Clarke, 1998). In view of these challenges, the priority demand on frontline controllers and the airline IOCC (Integrated Operations Control Centre) has become maintaining the feasibility of an airline flight schedule and ensuring that business continues as far as practicable in the face of myriad variations in demands an airline may encounter.

However, the task of maintaining the feasibility of flight schedules comes with a great deal of demand on the controllers’ cognitive resources. Given the time critical nature of airline operations, the need to demonstrate speed, flexibility and adaptability in the face of surprises has become the distinguishing factor between gaining a competitive edge and bankruptcy (Belobaba, 1987; Kimes, 1989; Yu & Qi, 2004). It is, therefore, desirable that controllers maintain a high level of awareness and responsiveness—relative to pertinent developments and progress in their work environment—to ensure decisions are made rapidly and accurately. But, gaining adequate situation awareness is contingent on controllers sourcing and effectively using operational information across the airline’s computer databases (Clarke, 1998); particularly, information that relates to developing issues from en route flights and ground handling operations at airports. Given the sensitivity of coupling and complex transfers that are executed between aircraft, passengers and crew
during ground handling operations, disruptions could be triggered even by slight variation in task time, unavailability of a key resource, or a combination of seemingly unrelated, discrete events (Abdelghany et. al, 2008). Correspondingly, maintaining a responsive operation is contingent on how quickly the operational practices in place can be negotiated and amended in the face of changing priorities.

Moreover, when viewed from the perspective of a complex adaptive system, the AOC practice is regulated through social interactions between interdependent agents, who are bonded in a cooperative dynamic by common goal, outlook, need, etc. (Uhl-Bien, Marion & McKelvey, 2007, p. 299). Agents that operate within such socially regulated practices tend to adapt to one another’s preferences and worldviews (Marion & Uhl-Bien, 2001), and therefore engage in socially driven cooperative behaviour (Uhl-Bien et al., 2007, p. 299). Against the backdrop of one omniscient agent that underpins many algorithmic formulations, the AOC practice involves many interacting agents, who are likely to not share the same knowledge, motives, rationality, and incentive schemes. Hence, the challenge of managing technical variations is not any more important than the challenge of managing tensions that result from the differences in knowledge, motives, rationality, and incentive. Such adaptive challenges require new learning, innovation, and new patterns of behaviour, as opposed to the more common technical challenges that can be solved with knowledge and procedures already in hand (Parks, 2005; Uhl-Bien et al., 2007, p. 300).

The notion of demand in this context, therefore, relates more to the socio-cognitive workload imposed on controllers of airline operations in an AOC system. The socio-cognitive forces that shape internal variability in the operational processes are captured within the enclosed box in Figure 2.3. Although economic representations of demands—such as passenger traffic demands and myriad external influences that often instigate fluctuations in demand—are also relevant to the conceptualisation of demand in this thesis, they are considered mainly in light of how they may influence the dynamics of socio-cognitive demands on the human controllers and the broader AOC system. An example of such situations would be a case where variation in passenger traffic demands, for whatever reason, necessitated escalation of control to higher echelon governance and/or negotiations with other units or third-party airlines. In other words, fluctuations associated with economic demands are only considered in situations where such variations
consequently led to an increase or decrease in the cognitive and/or social demands placed on the controllers.

**Figure 2.3: Socio-Cognitive demands at the intersection of technical, cognitive and contextual processes**
2.4 Demand variations in airline operations

Whilst the tendency to identify sources of a problem in complex systems has been likened to a Newtonian hunt for “broken parts” (Dekker, 2011), it could sometimes be useful at the initial phases of exploration for gaining insight into “why [operations] that normally go right, sometimes go wrong” (Hollnagel, 2009). Fluctuation in demand is inevitably the norm in airline operations for a number of reasons, not the least of which is the low level of certainty in current demand-forecasting practices. In this section, a categorisation of variations is presented relative to the form of demand it generates. The intention is primarily to highlight both the subtle and the more visible impact of complex relational interdependency on an AOC system. The variations identified are linked to technical performance, organisational dynamics and changes in context.

2.4.1 Variations in technical performance

Beyond the ubiquitous fluctuation in passenger traffic demand, variations predominantly emerge from the intrinsic relationships that exist within an airline operations system. The rules for engaging basic resources, such as aircraft maintenance and crew work-hours, often collide with the practices that are employed to cope with interactive complexity and tight coupling in the system. More often than not, such collisions between rules and practices can only be picked up during actual operations partly due to the weak predictability of the airline business environment and partly due to incessant pressures to maximise resource utilisation. The most affected practices include flight planning, resource scheduling, revenue management, passenger demand forecasting, and schedule recovery (Clarke, Johnson, Nemhauser & Zhu, 1997; Cordeau, Stojković, Soumis & Desrosiers, 2001; Klabjan et al., 2001, 2002).

Generally, the airline planning and scheduling practice is an interactively complex process. There are vast number of rules and conditions that must be accounted for during resource scheduling and its execution, including rules associated with airports, aircraft, crew, and passengers. The interactive complexity of this system is exacerbated when combined with the interdependent nature of the rules and resources spanning across an airline’s networks. These dynamics necessitate that the planning and scheduling problem be sequentially decomposed into manageable stages, with the output of one stage used as the input for the
subsequent stage (Cordeau et al., 2001). Although the decomposition practice appears necessary in order to maintain some degree of tractability in the operational process, it inadvertently results in decisions from prior stages being imposed as constraints on the decision-making processes in the later stages (Dunbar, Froyland & Wu, 2014). Moreover, the coupling between decisions implemented in an earlier stage and the subsequent stages also imply that any variation to plans associated with decisions made in an earlier stage will have a rapid knock-on effect on plans to be executed in the subsequent stages. During tactical operations, for instance, changes in the availability of resources, mechanical failure of a system, or crew sickness would require a quick adjustment to subsequent plans, such as calling upon reserve crew, aircraft swap or transporting passengers using another airline (Clarke et al., 1997; Klabjan et al., 2002).

In addition, many studies of airline operations have largely taken an optimization stance to the airline planning and scheduling problem. As a consequence of its roots in Taylor’s scientific management theory (Taylor, 1911), planning and scheduling formulations tend to be focused on maximising the overall profit. As a result, flight schedules are generated that maximise the utilisation of key resources, such as aircraft and crew, but often leave little slack for accommodating potential variations in practice. In a sense, the quest for maximum utilisation of resources further tightens the coupling between the resources that are considered at the various stages of the airline planning and scheduling process. Dunbar and colleagues (2014) observe that the quests for optimal flight schedules tend to generate schedules that are highly brittle, because they tend to propagate delays rapidly throughout the network. Interestingly, Dunbar et al. (2014) postulate that there is indeed a link between the unintended consequence of tight coupling in flight schedules and “an ever-increasing discrepancy between planned costs and realised operational costs” (Dunbar et al., 2014, p. 68).

Furthermore, airlines have some unique techniques they employ for revenue management, inventory control and passenger booking. Traditionally, airlines apply differential pricing strategy whereby a variety of fare products are offered at different price levels for the same flight (Barnhart et al., 2003, p. 376). Differential pricing is fundamentally driven by a belief that each category of passengers—for instance, leisure versus business passengers—is influenced differently by the pricing and conditions attached to air fares (Belobaba, 1987; Glover, Glover, Lorenzo & McMillian, 1982; Littlewood, 1972). This belief in differences
in the passenger’s willingness to pay more or less than the marginal price underpins the formulation of Belobaba’s (1987, 1989) ‘Expected Marginal Seat Revenue’ (EMSR) that is in widespread use today in most airlines. McGill and Ryzin (1999) explains that differential pricing offers airlines the potential of gaining revenue from seats that would otherwise fly empty and, at the same time, limits the number of low-fare seats with a view to protecting seats for late booking, full-fare passengers (p. 234). Although the benefits of a differential pricing strategy are hardly disputable (e.g., Belobaba & Wilson, 1997; Smith, Leimkuhler, Darrow & Samuels, 1992), it creates further complexity in the operations and introduces immense variation to the tactical control of mismatches between plans and actual conditions on the day of operations (de Boer, Freling & Piersma, 2002, p. 73). Barnhart et al. (2003) further depict the level of complexity a differential pricing strategy can generate using an airline’s seat inventory. They estimate that a medium-sized airline that operates one thousand flight legs per day, using ten booking (fare) classes in its reservation system, and accepting bookings up to 330 days prior to each departure could potentially have a seat inventory that includes over three million booking limits, which can change with each booking that is accepted (Barnhart et al., 2003, p. 377). Booking limits encapsulate evolutionary rules for differential pricing, which often include rules regarding the number of seats that must be reserved for high-fare paying passengers. As shown in Figure 2.4, the booking rules are usually contingent on various parameters, such as revenue data, number of reservations that are already in the system, current number of reservations for high-fare paying passengers, the probability of a no-show event, the expected marginal seat revenue, amongst other things. Consequently, one can argue that an airline that operates one thousand flight legs per day already has over three million routes to complexity in its booking rules alone; and that is, if we choose to ignore the interactions among the over three million rules that make them change with every new booking accepted. In turn, this complexity creates situations whereby slight variations between estimated booking behaviour and actual passenger bookings could affect an airline’s capability to respond to the extra demands on its resources; consequentially, triggering extra coordinative and cognitive demands.
In addition to differential pricing, airlines customarily accept reservations in excess of capacity. This practice, Rothstein notes, helps to reduce potential revenue losses (Rothstein, 1985). Barnhart et al. (2003) explain that the rationale behind overbooking is to maximise the number of bookings to accept for any given future departure, trading off the risks and costs of denied boarding against the potential revenue loss from unsold or spoiled seats (p. 377). However, models that are often employed for revenue management tend to apply a common simplifying assumption that consumer demand for the fare products is independent of other conditions and controls that are applied by the seller (Talluri & Ryzin, 2004, p. 16). In other words, current models largely presume that the fare structure is determined exogenously by a separate airline pricing function, with far less regard (if any) to the complex impact of customer choice behaviour and the availability of discount or more flexible fare-products by other sellers (Barnhart et al., 2003; Talluri & Ryzin, 2004).

Consequently, such models are subject to fundamental imprecision, regardless of the quality of their underpinning algorithms. It is indeed difficult to come up with a satisfactory forecasting model as the precision of forecast decreases with the planning horizon, especially if an airline’s booking system takes reservations up to 330 days from the day of departure. Inevitably, issues of denied boarding often arise from time to time as a result of inaccurate overbooking estimates (Rothstein, 1985; Shlifer & Vardi, 1975). Efforts to
address demands arising from inaccurate overbookings often generate cross-departmental collaboration. Critical cases, where overbooking failure led to mass cancellations, may require the involvement of senior managers in frontline operations control. From an airline’s perspective, any perceived inability of airlines to honour the reservation agreements will have negative impact on customer good will and perhaps draw penalty from the local government authorities (Subaramanian, Lautenbacher & Stidham, 1999).

Ultimately, failure to readjust plans when mismatches occur usually has dire consequences for the later stages of operation (Abdelghany et al., 2004; Yu & Qi, 2004). The need to readjust plans would inevitably generate extra workload—in terms of social and cognitive demands—as various human controllers activate rehearsed coordinative actions to realign their activities in light of changing priorities. There is always extra work required to coordinate activities across functions operating in such a rapidly changing environment.

2.4.2 Variations in organisational dynamics

Some formulations of sociotechnical work systems depict organisations as relatively closed or fixed collective sharing the same goal and engaged in incessant and direct communication. But, Kjeld Schmidt (1990) warns that the notion of a shared goal is murky and dubious. Schmidt suggests that the cooperative process of decision-making in a group is a much differentiated process involving the interaction of multiple goals of different scope and nature as well as different heuristics, conceptual frameworks, and so forth (Schmidt, 1990, p. 6). Contrary to popular views, Schmidt argues that organisations are not particularly perfectly cooperative ensembles, but rather a mixture of collaboration and conflict (Schmidt, 1991, p. 9). As a result, most information generated and processed in organisations are subject to misrepresentation because of the underlying goal incongruence and discord of interests and motives. In the same vein, variations in work prescriptions and style can arise because organisations are not monolithic entities characterised by unity of interests, but are more or less a coalition of individuals and subgroups with differing parochial interests and partially discordant goals and aspirations.

When viewed in light of an AOC domain, variations associated with goal incongruence are typically generated at the interfaces between subgroups within an airline, as well as at the interfaces the subgroups share with external organisations involved in the day-to-day execution of flight schedules. For example, many subgroups and external organisations
usually take part in aircraft turnaround processes at airports, as depicted in Figure 2.5. Each organisation is responsible for different aspects of the ground handling activities conducted to prepare an inbound aircraft for a following outbound flight that is scheduled for the same aircraft. These activities are typically linked in a sequential, time-dependent manner, with little or no room to change the order of sequence in which they are activated. For instance, during a ground handling process, an airline cannot initiate embarkation of outbound passengers without first disembarking inbound passengers (Wu, 2005). The same goes for the order for activating cabin cleaning and catering services, cargo and baggage handling, as well as technical activities such as fuelling, routine engineering checks, etc. (Wu & Caves, 2000). Thus, variations arise largely as a result of incongruence in goals and objectives each organisation pursues as its priority, especially when these goals are not effectively coordinated against other participating organisations’ goals and preferences.

Coordination across individuals and subgroups is achieved by deliberately building a web of connections and cooperative relations. However, the crux of the coordinative challenge is that each airline subgroup possesses ‘partial authority, partial autonomy and partial responsibility’ (Ostrom, 1990) in relation to the extent they can adapt overall operational
goals and activities. Coordinative difficulties are exacerbated because the relationships between the resources controlled by those subgroups are constantly changing, as different actors deploy specific actions to address a perceived local problem. In his analysis of cooperative work, Schmidt shares a scenario where one operator takes appropriate action in response to some likely disturbance. However, this action changes the operative landscape, and sometimes in some ways incomprehensible to the actor. Perceiving this change, another operator, with other responsibilities and perhaps at another location, is prompted to take action of a different kind in order to realign his local plan to changes in the broader operation (Schmidt, 1990, p. 37). But, such mediated, asynchronous cooperation often leads to variation in how tasks are performed, which in turn changes the demand landscape for other controllers, who must strive to maintain flow balance across interdependent resources.

Collectively, these dynamics exert immense pressure on frontline controllers and their supervisors to respond to multiple rescheduling of resources within critical timeframes. In many instances, rescheduling resources and exterminating the source of a disruption (or its broader effects) must be addressed concurrently in order to circumvent potential cascading failure and inevitable loss of control. Such highly intense and time-critical environment imposes not only challenging demands on the physical aspects of the operation, such as coordinating requisite resources (Abdelghany et al., 2004), but also additional workload on the social and cognitive aspects of work (Burns, 2006; Vicente, Roth & Mumaw, 2001). Overall, dealing with variations resulting from dynamic rescheduling of resources generally presents enormous challenges due to the complex network of interdependency between activities regulated by various functions.

2.4.3 Variations in context

The predominant bureaucratic form of control in modern organisations usually requires a formal division of labour and clearly defined roles and responsibility across all hierarchies. In an AOC context, controllers at the frontline are commonly concerned with feasibility of flight schedules and immediate operational safety matters, whereas managers at the blunt-end give priority to compliance with higher-level goals, policies and regulations. However, some contextual forces—including diplomatic, political and socio-economic factors—have been known to instigate a need to adapt formal ways for allocating responsibilities, along
with how work is performed in organisations in general (cf. Cyert & March, 1992; Schmidt, 1990) and in airline operations (Williams, 1994; Wu, 2010). Moreover, contextual forces also include both industry-specific factors that shape the way airlines conduct their businesses (such as market price, work and safety regulations, airport restrictions and curfews, travel policies, new local, national and international security measures) and the broader societal factors that can affect business continuity as well as alter market share and customer loyalty (such as brand image, public opinions and perceptions, relationship with local government authorities, and vulnerability to man-made disasters).

Anecdotal evidence further suggests that the quest for competitive advantage often influence airlines to trade their immediate operational goals (at least temporarily) so as to improve more long-term, higher-level goals during critical incidents. This premise is exemplified in how airlines offer remunerations and compensations in the aftermath of computer glitches or mass cancellations, as a gesture toward restoring good will and public perceptions of their reliability. Nevertheless, changes in context tend to create confusion as to how to prioritise various aspects of the operational requirements and goals. Differences in priority between sharp-end controllers and blunt-end managers often lead to collision in priorities during unforeseen situations; and such collisions can produce results that are not necessarily optimal for the system at large (Burns, 2006, p. 430). Generally, as has been captured in studies of international disaster relief work, events that have significant diplomatic, political, or social implications tend to elicit grey areas, relative to recognising whether authority-responsibility needs to migrate between ‘sharp-end’ operators and ‘blunt-end’ managers, and how such migrations can best be accomplished (detail discussion in Dekker & Supramaniam, 2007). It is interesting from a resilience perspective to capture empirically how such dynamics—in particular, migration of authority—play out in the context of airline operations control. Again, to avoid repeating discussions, variations due to changes in context is explored in greater detail in the following section.
2.5 The Cynefin Framework

The Cynefin framework is a model for making sense of situations across three ontological domains (unordered, ordered and disorder) and four epistemological domains: simple, complicated, complex, and chaotic domains (Kurtz & Snowden, 2003; Snowden, 2002, 2005, 2010; Snowden & Boone, 2007). Given its phenomenological underpinnings, the Cynefin framework does not attempt to categorise systems as simple, or complicated, or chaotic, etc. Instead, it focuses on how people perceive and make sense of situations in various contexts. This framework captures the different states that can exist within a contemporary operational system, with emphasis on appropriate leadership and decision-making styles that each context requires (Snowden & Boone, 2007). This is, in essence, different from simple classification models (e.g., Perrow’s framework on riskiness, Perrow, 1984, 1999) that depicts and maps work systems as non-evolving entities.

The typology discussed in this section makes use of premises abstracted from the Cynefin framework as its basis for discussion, so as to better capture how a routine demand can escalate to an all-out catastrophe. The usefulness of Snowden’s Cynefin framework to this discussion is three-folds. First, it enables discussions of context (that is, a system state) to be aligned with a typology of demand variability that can generate such a state. Second, this framework enables “requisite applicability” in that it proffers a means to recognise a changed or changing context, and at the same time offers the flexibility to switch thinking and behavioural patterns depending on the context of the demand (Snowden & Boone, 2007, p. 75). Third, it proffers a platform for relating disparate models and for integrating the core premises of the framework with abstractions from the other perspectives, including the normal accident, the man-made disasters, and the high reliability theories.

2.5.1 Disorder

At the centre of the Cynefin framework is a state of disorder. According to David Snowden, this domain represents a state where it is unclear which of the other domains is predominant. It is often marked by confusion and insufficient awareness of what the problem is and how it can be resolved (Snowden, 2002, 2005). Consequently, decision makers tend to interpret demand situations according to their action preferences, with the risk of imposing preformed ideas of ‘which adaptation is appropriate’ on the decision-making and response strategies (Snowden & Boone, 2007). The assumption is that the
system will regain some pattern once the nature of demand is identified, or that the system will at the least reflect the characteristic of one of the other domains (Snowden, 2010).

Figure 2.6: The Cynefin framework (Snowden & Boone, 2007, p. 72)

2.5.2 The Simple domain

The *Simple* domain is characterised by linear processes, where cause and effect relationships are fairly predictable and causal patterns can be repeated experimentally or empirically (Kurtz & Snowden, 2003). The decision model typically follows a sense-categorise-respond protocol, whereby decision-makers simply fit the perceived demands into pre-existing categories so as to work out appropriate responses. Responses are usually selected from a set of protocols that have been thoroughly trialled under similar conditions; that is, from a range of well-established “best practices” in the domain (Snowden & Boone, 2007). Snowden further emphasises that the boundary between the simple and the chaos systems could be conceptualised as a cliff, along which lies an unforgiving but complacency zone. This zone represents a state in which deploying a mindless, simplistic assumption could quickly tip a simple system over the cliff into a fundamentally surprising chaos (Kurtz & Snowden, 2003, p. 474), the likes of which has been highlighted by Zvi Lanir (1983) with the Yom Kippur war and Barry Turner (1978) with the Aberfan coal mine disaster, among others.
2.5.3 The Complicated domain

The *Complicated* domain represent situations with a reasonable degree of predictability and order, although the increased number of parts in complicated systems often make them hard to navigate and difficult to understand (Miller & Page, 2007). Nonetheless, the components in a complicated system maintain a degree of independence from one another. Thus, removing one component does not fundamentally alter the overall system’s behaviour except for the specific functions related to the component removed (Miller & Page, 2007, p. 9). Snowden explains that cause and effect relationships exist in such systems, although they are not readily evident to everyone. In most cases, identifying causal relationships require some level of analytical processing and expertise (Snowden, 2002; Snowden & Boone, 2007). The decision model follows a sense-analyse-respond protocol, whereby decision-makers employ analytical methods to make sense of categories before activating responses. A typical response strategy is to apply “good practice”; that is, a range of responses that proffers good enough solution. While clarifying the difference between ‘good practice’ and ‘best practice’, Snowden explains that there is usually different ways of doing things in a complicated system, all of which could lead to a good outcome when the right expertise is applied. These different routes to a reasonably good outcome can be referred to as good practices. Best practice, on the other hand, is a set of practices that has been identified as the best solution trajectory for some specific, well-defined problems—although such problems hardly exist in any of the other systems other than in simple systems (Snowden & Boone, 2007, p. 71).

2.5.4 The Complex domain

In *Complex* domains, cause and effect relationships are intrinsically non-linear and are only obvious in hindsight. There is a high level of interdependence between elements of the system. Lower-level elements interact in often unpredictable ways, giving rise to emergent and sometimes surprising outcomes (Levin, 2002, p. 15). The agents and components in a complex system are linked with one another via a web of connections; as a result, removing one such element significantly alters the behaviour of the overall system (Miller & Page, 2007, p. 10). Snowden argues that the relationship between agents—that is, their connections to one another—can be seen as constraints; the constraints moderate the dynamics in the system, and the evolutionary interactions of elements within the complex
adaptive systems in turn modify the constraints. In this sense, agents demonstrate limited autonomy with regards to the set of responses they can deploy, which are not moderated by the nature of their connections to other agents (Kurtz & Snowden, 2003).

Snowden further argues that the dynamics of a complex adaptive system is not causal but dispositional (Snowden, 2002). The underlying supposition is that one can measure whether a complex system is disposed to move in certain directions, but that the ability to predict disposition does not automatically confer causality (Kurtz & Snowden, 2003; Snowden, 2002). In addition to the traditional notion of adaptation in complex adaptive systems, Snowden further emphasised the notion of exaptation, where a complex system undergoes a fundamental transformation that allows it to adapt to an entirely different regime of operation. In a complex system, the decision model follows a probe-sense-respond protocol. That is, decision-makers first conduct ‘safe-fail’ experiments, as opposed to ‘fail-safe’ designs to make sense of what needs to be done (Snowden, 2010). The results of the test will then guide decision-makers on whether to amplify control, or to dampen it (Snowden, 2002). Responses in complex systems require adaptable and evolutionary way of doing things, what Snowden dubbed as ‘emergent practice’ (Kurtz & Snowden, 2003). It is not necessarily a completely novel practice, but perhaps some combination of practices that yield a different and unique solution.

2.5.5 The Chaos domain

Lastly, the Chaos domain represents situations with far less degree of order than would be expected from a simple, ordered system. Chaos is critical to the process of adaptation and evolution, in the sense that a system in equilibrium is highly susceptible to failure because it lacks the internal dynamics to respond to variations in its environment. Systems at equilibrium are generally too rigid to adapt formally entrenched protocols during periods of change. On the other hand, a system in total chaos is already predisposed to catastrophic failure, as small perturbations tend to cascade freely throughout the system (Kauffman, 1995; Schneider & Somers, 2006, p. 355), a phenomenon that could be pictorially depicted with the metaphor of free fall (Wears & Perry, 2006). Thus, highly chaotic systems cannot maintain their connections. Complex systems theorists posit that a system performs optimally when poised at the edge of chaos (Kauffman, 1991, 1993; Marion, 1999; Mathews et al., 1999; Schneider & Somers, 2006). In chaotic systems, cause and effect relationship
cannot be determined and, like Snowden, some scholars have actually posited that some risks in chaotic systems are simply unknowable (Levin, 2002, p. 12; Snowden & Boone, 2007, p. 74). Snowden proposes an act-sense-respond model of decision-making, as there is always a need to quickly stabilise the position of the system when it accidentally drifts into a chaotic phase (Kurtz & Snowden, 2003, p. 478). He further suggests that any practice will be completely novel in terms of the way things work (Snowden & Boone, 2007, p. 75).

2.6 A typology of demand variability

Demands, from a risk management perspective, are generally interpreted based on a categorisation of their perceived impact on a system. When it comes to safety-critical systems, risk categorisation appears to be based more on the level of threat an event poses to human life and property (e.g., Miller & Lessard, 2001, 2008). However, in view of systems as complex interactive entities, it does appear that conceptual frameworks that only assign rigid classifications and typologies of risks are by far too limited to lending insight into the emergent and adaptive nature of demand situations in modern safety-critical systems. By contrast, risks to successful performance can shift gradually or quickly, which in either case will necessitate different forms of thinking and behaviour in order to stabilise the system (Dörner, 1996). It therefore seem more reasonable to adopt a ‘malleable’ framework that can be useful for making sense of subtle differences in demand situations and recognising shifts in contexts such as the Cynefin framework.

The typology presented in this section is primarily based on the surprise index that a particular event could elicit. This surprise index can also be framed in Zvi Lanir’s words as a fundamental surprise (Lanir, 1983). This index underscores the relevance of predictability in enabling more pre-emptive learning and response strategies (cf. Dörner et al, 1990). Also, in appreciation of Turner’s (1976, 1978) and Perrow’s (1984, 1999) arguments, the surprise index presupposes that failure of foresight and absence of familiar signals play crucial roles in the degeneration of routine demands to an all-out catastrophe. Therefore, instead of focusing only on the severity of events, the surprise index provides a platform for capturing potentially catastrophic near-misses and breaches in an organisation’s assumptions of ‘riskiness’ (Perrow, 1984), even in situations where there is yet no visible damage attributable to a failure in the anticipatory or monitoring processes.
In addition to the surprise index, the typology is also based on the frequency of occurrence of a demand situation as well as its scope of impact on a system. The underpinning thesis is that the more frequent, and hence familiar, events are typically predictable and oftentimes have well-rehearsed protocols for dealing with them. In contrast, the scope of impact is considered important because, with airline operations, variations stemming from a particular type of event hardly ever have the same impact on the operations control system. For instance, crew absence is a well-known scenario that has a well-rehearsed procedure that should be deployed when it occurs. But, this seemingly routine event can have some interesting butterfly effects when a crew-member falls sick in an outstation port, or where the airline has no reserve post. This situation can deteriorate rapidly if it happens at the first leg of a four-leg schedule. This single case can quickly cascade to multiple cancellations and delays if it happens at a peak travel season, such as in summer or holiday events. In other cases, this same event poses little to no threat, probably because it happened at the right place, at the right time.

One crucial, but yet-to-be-tested, assumption of this typology is that the level of surprise is linked, in some sense, to both the frequency of occurrence and the scope of impact. It is hoped that the empirical observations captured in this thesis will help to clarify this assumption. Also, the researcher favours a hunch that the typology of a variation is not necessarily dependent on the source of the variation. This view is supported with due consideration to the fact that even routine variations from the same (physical) source could as well elicit very different scope of demands, as has been argued with the afore-discussed ‘crew absence’ scenario.

2.6.1 The Known Knowns

For ease of exposition, demand variability in simple domains are denoted as type-One variability, also known as the “known knowns”, to borrow from the words of Donald Rumsfeld. Type-One variations are largely routine and localised; also, their threats are assumed to be minimal and reasonably well understood. They usually involve a small set of scheduled resources. In light of Rasmussen’s Rule-Skill-Knowledge (RSK) model, the recovery protocols are mainly ‘skill-based’ and the coordinating protocols are mostly based on tacit knowledge and well-rehearsed routines (Rasmussen, 1983b).
Fundamentally, type-One variations are hardly surprising to airlines because the frequent occurrence of such events often provides impetus for anticipation and learning. As such, expertise is readily available for dealing with their nuances. Perception time is often considered to be reasonably long or, at the least, just enough to allow for efficient deployment of well-rehearsed rules. In addition, the elapse time (the duration of the event) is taken to have a negligible impact on the functioning of the system. In other words, a system can continue functioning despite the presence of a type-One event. This is because, as type-One variability is relatively predictable and understood, they can be reasonably prepared for using buffers, barriers and defences. Generally, the severity of its impact is commonly assumed to be low, except in a highly brittle system. Typical examples include late incoming flights, crew unavailability due to sickness, minor unscheduled maintenance of an aircraft, as well as backlogs and congestions caused by long queues at runways and taxiways (Clarke, 1998). Except for weather and airport-related events, these variations usually affect a single airline.

Although there are usually procedures in place to resolve type-One variability, they can still be challenging enough to warrant multiple cancellations and delays if not managed resiliently (Abdelghany et al., 2004; 2008). Interestingly, Kurtz and Snowden (2003) argue that deploying simplistic behaviours and rules in a complex adaptive system, as one would do in a simple system increases the system’s vulnerability to swift changes in demand (pp. 475-479). Snowden explains that if agents in a system start to rely on simplistic assumptions and to venerate the associated myths, they will effectively drift to a complacency zone (which is along the boundary between the simple and the chaotic in Figure 2.6); and eventually, will fall over the edge of the cliff into crisis (Kurtz & Snowden, 2003, p. 474). This dynamics, in some respects, corroborates earlier discussions on the dynamics of ‘drift to failure’ (Dekker, 2011) and ‘normalization of deviance’ (Vaughan, 1996), as well as Rasmussen’s discussions on ‘flirting with safety margin’ (Rasmussen, 1997; Cook & Rasmussen, 2005). Although the forces that moderate the shifts across these formulations appear to vary slightly, they all produce a catastrophic migration towards a zone of unacceptable performance.
2.6.2 The Known Unknowns

Type-Two variability is generally dubbed the rare-but-known variability—also referred to as the “known unknowns” in Rumsfeld’s quote. This class of variations often share similar triggers with type-One variations; however, it is harder to predict when they will occur and/or how fast the effects can cascade through the system. Other distinguishing features of type-Two variability are that the initiating events tend to have shorter perception time and may also have longer elapse time. Moreover, they seem to impact a vast amount of system components on landfall (for external events) or once released (for internal failures). Consequentially, type-Two variability appears to emerge surreptitiously with little to no warning, and may affect multiple airlines in a region or one airline across a number of airports. The recovery protocols usually fall within the rule and skill-based region—depending on the expertise of the controller and the evolutionary trend of the event (Rasmussen, 1983b). With this class of variations, it is considered that operations will be significantly disrupted while they linger. Severity could swing from a low at some points to a high at other points, resulting in backlogs, delays and multiple cancellations of flights.

Some real-world examples of type-Two variability include the lockdown of Qantas’ domestic and international operations on the 29th of October 2011 and the failure of Virgin’s reservation system, on the 26th of September 2010. Such events tend to challenge current believes on how organisations handle serious performance threats and often provide further incentives for identifying cracks and gaps in the organisation’s underlying assumptions of vulnerability and safety. In light of the Cynefin framework, type-Two events tend to push an already complex AOC system toward chaos, necessitating a vast number of resources to be rescheduled dynamically. Also, as Kurtz & Snowden (2003, p. 474) note, the boundaries between the simple and the complicated states, as well as the complicated and the complex states allow for gradual transitions. Thus, controllers can gradually get back to “normal” operations and be able to regain full operations after the initiating event has passed. The time it takes to recover fully can be conceptualised as one of the indicators of a system’s resilience to this category of events.
2.6.3 The Unknown Unknowns

Type-Three variability is dubbed the extreme, novel, or unknown perturbations, also referred to as the “unknown unknowns” in Rumsfeld’s quote. They represent a class of perturbation that are unprecedented and to which there is no readily available protocol regarding its resolution. It may not necessarily be a completely new event, but it could still be viewed as novel given its fundamental surprise or the sheer terror unleashed by the initiating event. It could emerge from interactions between seemingly routine events or procedures, resulting in a completely novel problem space with far greater impact than the constituent events. Type-Three events are the sorts Barry Turner identified as emanating from failure of foresight (Turner, 1978), and they always call to question current understanding of vulnerability in the system. In light of these characteristics, type-Three variations are assumed to be novel in their scope of impact and parametric dynamics. Type-Three variations are characteristically distinguishable from the others for their high stakes, devastating impact, and lingering consequences. Regardless of the elapse time, the effects are still felt long after the initiating event has ended. Moreover, most airlines may not have a well-articulated procedure for dealing with such situations, as their evolution and dynamics tend to elude what is currently classed as potential risks and threats to the system; hence, the novel dimension of the events.

Even with a sufficiently long perception time, acting subjects can hardly make any meaningful re-organisation of operations. Recovery protocols are largely based on first principles than on rules and tacit knowledge, and often reside within the knowledge region of the RSK model. Both broad technical expertise and specific industry experience are highly essential in managing the effects of such variations. According to Snowden’s propositions, the logic for action regulation is to act first before assessing whether actions can be amplified, dampened or even abandoned (Snowden & Boone, 2007). Furthermore, the impact of a type-Three variation could potentially change the way airlines operate. Type-Three events often create a ripple throughout the industry, pushing airlines to prioritise certain aspects of their operations that were, before the incident, taken for granted. There are often significant changes in the operative landscape in the wake of a type-Three event. However, despite the catastrophic consequences, airlines should be able to reorganise and maintain some degree of functioning in the immediate aftermath of a type-Three event—although not necessarily at the same capacity as their base-line
operations. Correspondingly, airlines are only expected to re-establish full capacity when the broader air transportation system must have returned to its original state, or when the system have dynamically stabilised on the edge of a new normal.

Type-three variability has been typified by several widely publicised events. A real world example of a fairly predictable type-Two event that escalated to a disastrous type-Three event is the confusion amongst the ‘air traffic flow management’ (ATFM) authorities in Europe following the volcanic events of April-May 2010 in Iceland. The lack of a unified control strategy across the ATFM authorities in Europe created a ‘fiasco of volcanic proportions’ (Budd et al., 2011). With regards to transforming an operational landscape, the fallouts of the September 11 2001 terrorist attack and its lingering consequences on aviation-security practices is a vivid depiction of an incident that toppled well-established security practices. Even after 10 years following the event, the ripples still kept the commercial aviation industry scrambling to establish a new normal in security practice (IATA, 2011). But, in light of defying current models of risk and vulnerability in the airline industry, the mysterious case of Malaysian airliner (MH370) vanishing from the sky remains—arguably—the biggest mystery in contemporary aviation history.

### 2.7 Practices for managing demand variability

This section addresses the operational “systems of rules” (Burns, 2006, p. 416) that airlines use to prepare for the endless variety and uniqueness of variations they confront in their daily work. It is intended to uncover how airlines balance between known variations and those situations where they have no clue what will unravel, both in the scale of impact and the dynamics of the variation. With these objectives, extant literature on airline scheduling and recovery practices is reviewed to provide a foundation for reflecting on the operational strategies, as well as the computational techniques and rules airlines apply. The discussions explore mechanisms that airlines employ in their scheduling and recovery practices to address or mitigate the impact of both known and unknown variations. They provide a foundation for reflecting on issues and dilemma relating to contingency planning and schedule recovery.
2.7.1 Airline scheduling practices

The airline scheduling process presents daunting challenges due to complex and numerous factors that must be considered. Traditionally, airline operational planning follows a sequential approach, and is generally handled in two phases—strategic and tactical phases (Barnhart et al., 2003; Clarke, 1998). The goal in the strategic planning phase is to generate optimal plans based on forecasts and predictions made in regards to future demands. In tactical control, however, the goal is to update the original plan during its execution stage in order to maintain the desired level of fitness between plans and actual operating conditions. Due to its sheer size and the complex factors involved, the strategic planning phase is usually decomposed into various stages. These processes are typically handled sequentially, as shown in Figure 2.7.

![Figure 2.7: A simplified illustration of strategic planning and tactical control processes](Adapted from Kohl et al., 2007, p. 150)

2.7.1.1 Schedule Generation

The schedule generation process is concerned with the design of flight schedules of services. The flight schedule specifies the flight legs to be flown and the origin, destination, departure date, time and duration of each flight leg. As the exact conditions on the day of
operations are uncertain, the information used for generating flight schedules is largely determined by forecasts and estimations from historical data on passenger traffic demands, resource and infrastructural capacity, and the unique characteristics of all airports included in the network (Clausen et al., 2010). Moreover, airlines have to carefully select the most promising communities or city pairs whilst taking into account the capacity of infrastructural system and resources available to them, along with myriad restrictions and regulations imposed on aircraft types, gate resources, airport slot, air traffic control, noise curfews, maintenance requirements, crew legality issues, etc. (Barnhart et al., 2003; Abdelghany et al., 2004).

The structure of the flight network can further impose hard limits on the strategy airlines can employ in subsequent stages. A hub-and-spoke network, for example, enables airlines to optimise passenger connections and, in the process, cater for potential variations in plan by creating a pool of resources at the hub stations (Kohl et al., 2007, p. 150). Also, airlines tend to add buffers in flight times in order to allow for some “margin of manoeuvre” (Woods & Branlat, 2011) in the event of an unplanned variation to normal functioning. Extra buffers are often added to ground handling activities at the airport providing a damping mechanism or insulation to the effects of possible disruptions in the aircraft turnaround process to the broader schedule of resources.

2.7.1.2 Fleet Assignment

In the fleet assignment stage, specific types of aircraft are assigned to individual flights as determined in the generated schedule of flights. The objective is to match capacity to estimated passenger demand within the flight network. Thus, the interesting challenge is to minimise the cost of operating a particular type of aircraft and the revenue lost when passenger demand exceeds the assigned aircraft seating capacity. It is in fleet assignment that airlines weigh the capacity of the fleet assigned to particular flights against their respective demand forecasts. Some of the challenges at this stage stems from the inability to determine passenger demand, flying times and ground times \textit{a priori} due to inherent variability in the air transportation system. To prepare against demand variability, a mix of aircraft fleet is assigned to particular routes to make it easier for aircraft swapping in case an actual demand exceeds the forecasted demands.
2.7.1.3 Aircraft Routing and Rotation

After the flight networks are determined and a specific fleet assigned to specific routes, sequences of flights are then generated within each fleet. A routing is defined as “a sequence of flight legs with the destination of one flight leg the same as the origin of the next leg in the sequence” (Barnhart et al., 2003, p. 372). In contrast, an aircraft rotation represents a sequence of flight legs flown by the same fleet that originates and terminates at the same location. To minimise the effect of a disruption, an aircraft can be routed out and back between two stations (for a point-to-point network) or between a hub station and a spoke station (for a hub-and-spoke network). A rotation is typically designed with a view to minimising the degree of coupling and interactive complexity across the network. Hence, a disrupted rotation can be retimed or cancelled without substantial impact on other resources outside the rotation.

As aircraft rotations must respect various types of constraints such as scheduled maintenance and curfews at specific airports, the challenge at this stage is to ensure that each aircraft’s rotation is routed through airports and maintenance stations while respecting all applicable constraints. It is also desirable that sufficient numbers of aircraft of each type be located at maintenance stations periodically. Again, aircraft routing has to consider the possibility of unscheduled maintenance problems, particularly when different types of aircraft are catered for at different maintenance stations (Rosenberger et al., 2002). In spite of these considerations, Barnhart et al. (2003) highlighted an issue with solving the fleet assignment problem before the aircraft routing problems, in that the sequence can lead to violations of aircraft maintenance requirements. A seemingly obvious solution strategy would be to consider aircraft routing and fleet assignment simultaneously. But, this is not always possible in practice given the sheer number and complexity of rules applied at each stage of these two sub-problems.

2.7.1.4 Crew Pairing and Rostering

Crew pairing and rostering are typically handled as two sub-problems. In the pairing stage, the set of flight legs in the network are partitioned into trips that crew will fly (Rosenberger et al., 2002). Afterwards, specific crewmembers—both flight and cabin crew—are assigned to specific flight legs in the rostering stage. Crew pairing and rostering imposes a number of hard limits on the ability of controllers to implement changes in the system during
schedule execution. Firstly, regulatory agencies and collective bargaining agreements specify the work rules and stipulate how flight legs can be combined to create feasible schedules. As a result, crew pairing and rostering have to respect a vast number of restrictions, rules and regulations associated with crew flying time, duty breaks, rest-time, time-away-from-base, etc. (Abdelghany et al., 2004; Abdelghany et al., 2008). Secondly, pilots are usually certified to fly a specific type of aircraft, thus limiting any form of flexibility in swapping crews across fleet. Thirdly, decisions made in the aircraft routing and rotation can potentially restrict the number of choices available to the planner at the crew scheduling stage, prompting a significant increase in crew cost. In other words, constraints implemented in the earlier aircraft routing and rotation stage are invariably imposed on crew scheduling. Fourthly, crew pairing and rostering must consider minimum connection time between flights, particularly when a crew member has to connect between two flight-legs assigned to different aircraft.

Correspondingly, airlines tend to roster cabin crew and flight crew to follow each other and the same aircraft. Standby crew are also deployed at strategic stations to provide additional resources that can be utilised in the event of a disruption (Kohl et al., 2007). Additionally, airlines often have to transport their crew to other airports—referred to as dead-heading in airline operational parlance—in situations wherein a flight was cancelled and the crewmembers needed to be transported to the port of their next rostered duties. As an additional line of defence, airlines usually have various agreements with third-party carriers for the purposes of transporting their crew members to other stations.

2.7.1.5 Tail assignment

In the tail assignment process, specific aircraft from a given fleet are assigned to specific flight legs. So far, with the unidirectional flow of decisions in a sequential process, there is very limited flexibility and margin in regards to options airline schedulers can explore during the tail assignment stage. To deal with demand variability, standby aircraft are placed at strategic stations to provide a means for recovery in the face of variations to planned operations. But, aircraft are an incredibly expensive resource, which can accumulate serious losses even by simply parking at the hangar. As a result, many airlines, particularly the low-cost carriers, rarely deploy standby aircraft routinely.
The tail assignment process concludes the sequential strategic-planning processes, and typically takes place at least 3 to 12 days in advance of the day of operation (Clausen et al., 2010). The flight schedules are handed down to the frontline controllers a few days to the day of operation, when a feasible operational schedule that satisfies key constraints must have been generated.

2.7.2 Schedule recovery practices

A range of events can trigger discrepancy between plans and actual operations thereby raising questions whether further action is required to get the operations back to plan. In the events where adjustments are required, it is the responsibility of frontline controllers to identify and evaluate possible courses of actions from the aircraft, crew and passenger perspectives. This section outlines the processes involved in a schedule recovery problem along with the considerations that controllers take into account when managing diverse and often conflicting goals and requirements.

2.7.2.1 Aircraft recovery

Many formulations of schedule recovery processes appear to start with the aircraft perspective, partly because the number of aircraft is far fewer than the number of crew members and partly because the number of rules for aircraft scheduling is less complex as well (Clausen et al., 2010, p. 813). Prior research has investigated situations where one or more aircraft became unavailable, necessitating flight retiming and reassignments in order to minimize the total passenger delays (e.g., Teodorović & Guberinić, 1984). To date, the central objective in aircraft recovery is to reconstruct a feasible aircraft routing, without violating maintenance constraints or substantially increasing crewing and passenger delay costs. During a recovery process, airlines commonly employ a range of techniques to maintain flow balance for aircraft, crew, and passenger flow (Rosenberger et al., 2002, p. 363). Some common techniques that airlines employ to maintain aircraft flow balance include flight delays, flight cancellations, increased cruising speed, aircraft swapping, and aircraft ferrying (Kohl et al., 2007; Lettovský, Johnson & Nemhauser, 2000).

With respect to flight retiming, departure delays are commonly preferred as they are the least intensive in terms of the cognitive workload involved as well as the possibility of accumulating additional operating costs. A departure delay can be initiated by simply
retiming a flight to allow for necessary maintenance rectifications to be conducted or when there is a need to make-up for variations in task times associated with ground handling activities. A delay, generally, has minimal impact on flow balance, as delaying a flight-leg may not drastically upset aircraft connections in the network. In some cases, an airline may choose to increase cruise speed to catch up with an estimated arrival time. Usually, there is a cost associated with increased fuel burning when an aircraft is cruising at a higher speed. But, in some cases, this option may not be available particularly during very busy periods. As a result, an airline may rather opt to cancel a flight leg if significant delay has been incurred.

In contrast to delays, cancellations often disrupt the flow balance of resources across the network and usually require some rerouting activities to maintain aircraft flow across the network. But, rerouting aircraft in practice can sometimes be a lot more cognitively tasking than simply making additional cancellations. As a result, airlines often switch aircraft where possible to accommodate for possible passenger spills, a technique commonly referred to as aircraft swapping. Swaps can be made within or across fleet types. The advantage of aircraft swapping over cancellation or rerouting is that flow balance can be achieved by simply matching passenger demands across different aircraft types, whereas with a cancellation or rerouting, additional cancellations and rerouting will be required to maintain flow balance. Thus, switching aircraft can be a useful strategy to reduce the extent of additional cancellations that must be made, as no aircraft is temporary removed from circulation (Rosenberger et al., 2002, p. 363). In such cases, controllers can utilise short-cycle cancellation strategy if the planning stages—particularly aircraft routing—allowed for a short-cycle rotation technique, such as an out-and-back rotation from a hub station to a spoke station and then back to the starting hub station.

On a more drastic move, an airline may choose to ferry an aircraft from one airport to another. Ferrying is an expensive recovery strategy but can be a useful strategy when an aircraft needs to be repositioned for a future flight that starts at a different airport other than where it is currently positioned. Large airlines often have spare aircraft positioned at their major hub stations. Spare aircraft can be handy when it comes to swapping or ferrying aircraft, or when there is an emergent need to replace an aircraft that suddenly became unserviceable.
2.7.2.2 Crew recovery

The goal of crew recovery is to use the available crew resource more effectively in a disrupted situation (Rosenberger et al., 2002, p. 363). Therefore, as with aircraft recovery, airlines tend to retime flight departures where necessary until the scheduled crew members are ready. Retiming is often used in situations where available crew have a few more hours before they become legally available to fly after their compensatory rest or compulsory work break. But if the break applies to only a few crew members, airlines can use standby crew to replace only the crew members that can no longer complete their duties due to regulatory reasons rather than replacing the entire crew (Abdelghany et al., 2004; Kohl et al., 2007). Thus, reserve crew can be called upon to take up the duty, while the crew members that are replaced will be reassigned to a later duty, as depicted in Figure 2.8.

![Diagram of Crew Recovery](image)

*Figure 2.8: Crew recovery via swapping (Adapted from Clausen et al., 2010, p. 817)*

In the event that a flight leg is eventually cancelled or where a crew needs to resume their duty at a different station other than where they are currently positioned, deadheading can be used to reposition the crew from the current airport to the airport where their next duty
would resume (Lettovský et al., 2000, p. 340). Deadheading allows for flexibility in the operations control, in that the crew can be transported on any type of aircraft as passengers, rather than made to wait for the specific fleet they are licensed to fly (Barnhart et al., 1994; cited in Lettovský et al., 2000, p. 340). Moreover, Rosenberger et al. (2002) also note that airlines often have reciprocal agreements that allow crews to deadhead on other airlines for free (Rosenberger et al., 2002, p. 363).

2.7.2.3 Passenger recovery

The main objective in passenger recovery is to evaluate possible recovery options that minimise passenger inconvenience and to propose an optimal rebooking plan. Passenger rebooking options are evaluated based on a range of metrics, including: the duration and costs of delay; the commercial value of the passengers involved, which is often a function of the booked fare class and frequent flyer information; costs associated with offloading a booked passenger due to overbooking or cancellation; costs associated with compensations (e.g., costs of upgrades) and hospitality care of disrupted passengers; and costs linked to the inevitable loss of goodwill due to downgrades, and frequent or prolonged delays (Shlifer & Vardi, 1975). All these factors are taken into consideration to varying extents before a decision is made whether to delay, reroute or cancel a flight. Other than the set of rules that apply to passengers, the technical application of delays, cancellations and rerouting from a passenger perspective is very similar to those of crew and aircraft recovery.

2.8 Conclusion

Several concepts and metaphors reviewed in this chapter have provided insight into the dynamics that propel a system to migrate towards a tipping point, such as the notions of drift into failure, incubation of disasters, normalisation of deviances, and flirting with safety margins. The thesis that falls out from the arguments of the normal accident theorists and the man-made disasters theorists is that organisations operating high-risk technologies are inevitably vulnerable to some familiar and normal processes of organisational life that subvert even the best intentions of the acting subjects. Interestingly, the chapter has also uncovered some propositions that claim that organisations can learn to organise for high reliability and to avoid catastrophic system failures by cultivating a culture of mindfulness. These researchers pointed to some organisations they believe have demonstrated high
reliability, and have further mastered the craft of prioritising safety, recognising the changing shape of vulnerability, and creating strong cultures that afford vigilance and responsiveness. The overall thesis of the discussions in this chapter appears to be that the counter-productive dynamics, which make a system helplessly susceptible to catastrophic failure, are rooted in the same everyday processes that facilitate resilience, including some cognitive, social and political forces.

Moreover, the techniques and approaches that airline schedulers and controllers employ to deal with uncertainty and fluctuations in demands were also reviewed in this chapter. As expected, a reasonable effort has gone into replicating some of the rules and techniques that practitioners apply in algorithmic programmes. However, it appears that socio-political and organisational forces are hardly considered in current theoretical models of airline operations, even though they are very visible in the decision considerations made in practice. Some of the challenges that seem to advance this incongruity between theoretical models and practice include the continuing struggle to maintain computational tractability, the practicality of using probability forecasts to model a highly fluid operations control process, and the difficulty in estimating appropriate performance targets \textit{a priori} when modelling such a highly fluid process. But, even with advances in computational capabilities, it does appear that the incessant push for optimality in airline scheduling will continue to challenge our best efforts for a long time.

It is, therefore, reasonable to seek an alternative view to the airline operations control problem: a view that can provide a broader perspective on the organisations that perform \textit{on-the-day} coordination of schedule execution, as well as the \textit{system-of-rules} they apply. But, more importantly, a view that can capture not only the key influential forces but can also elucidate the dynamics that shape the forces and how their interactions reverberate back to the broader organisational systems of rules and practices. In some respects, this literature review suggests that there is a glimmer of hope for resilience in complex, adaptive sociotechnical systems. Of particular note is the idea that humans can “expect the unexpected” and make anticipatory responses to address potential demands and risks in the system. In the next chapter, the discussions will shift toward extant literature on resilience theory with a view to developing a case for resilience in complex sociotechnical systems.
CHAPTER 3

RESILIENCE IN COMPLEX SOCIOTECHNICAL SYSTEMS
A ‘RESILIENCE ENGINEERING’ PERSPECTIVE

The stage for an accidental course of events very likely is prepared through time by the normal efforts of many actors in their respective daily work context, responding to the standing request to be cost-effective.

Jens Rasmussen (1997), on the Dynamic Path to Failure

People [are often] required to be both efficient and thorough at the same time—or rather to be thorough when in hindsight it was wrong to be efficient.

Erik Hollnagel (2009), on Efficiency and Thoroughness Trade-offs

Success and failure have the same origins; only the outcome can distinguish one from the other.

Ernst Mach (1838-1916), on the Origins of Success and Failure

OVERVIEW: Investigations of how people cope with complexity in high risk systems—such as nuclear power plants, health care and aviation systems—have revealed how human decision-makers actively devise defences to guard against potential paths to failure, compensate for unacceptable conditions and gaps in knowledge, and create conditions necessary to address potential surprises. This chapter presents a review of resilience studies across six research areas that cover extensive investigation of both natural and engineered systems. It opens with a thematic exploration of constructs across the six research fields with the aim of constructing a conceptual understanding of what resilience is and how it can be grounded within a complex sociotechnical context. Findings from the review, amongst other things, highlight pertinent argots and metaphors that have emerged in the study of resilience across such diverse contexts and fields of study. The argots and metaphors—in conjunction with several notions drawn from human factors, business continuity and safety engineering research streams—were then applied as the underpinning framework for analysing the various depictions of resilience. Overall, the discussions provide vital connections between abstract metaphors and practical strategies: connections that proffer a theoretical framework with which to examine the underlying drivers and enabling conditions that support resilient adaptations in an airline operations control domain.
3.1 Introduction

The notion of resilience offers a befitting way of looking at how people in their daily work navigate through normal variability of everyday demands so as to maintain dynamic stability in the system. The ‘resilience engineering’ perspective acknowledges that all human adaptive systems are seldom trouble-free, mainly due to their inherent complexity as well as gaps in fitness between expectations and reality (Hollnagel, Nemeth & Dekker, 2008). In light of safety-critical operations like the airline operations control, this perspective provides a way of looking at the relentless conflicts between pressures for profitability and pressures to meet safety requirements. More significantly, the ‘resilience engineering’ perspective considers that safety and production processes are intertwined and must therefore be managed by improvements rather than by constraints (Eurocontrol, 2009).

A ‘resilience engineering’ perspective is particularly relevant to this investigation in that it proffers a framework for elucidating the challenges airlines face in sustaining their economic viability, while at the same time taking into account potential impact of economic decisions on the safety aspect of their operations. Findings of the ‘resilience engineering’ perspective have shown, amongst other things, that people do cope successfully with uncertainty and complexity in high-risk systems by actively devising defences to guard against potential paths to failure, by compensating for unacceptable conditions and gaps in knowledge, and by creating conditions necessary to address potential surprises (Hollnagel, Pariès, Woods & Wreathall, 2011; Hollnagel, Woods & Leveson, 2006; Woods, Dekker, Cook, Johannesen & Sarter, 2010). In a sense, this perspective accentuates responsiveness in creating and maintaining the enabling conditions that confer resilience so as to sustain positive adaption in the face of surprises.

Section 3.2 presents an evolutionary account of the resilience perspective in safety research. In Section 3.3, an expository discussion on the meaning of resilience is presented based on six premises drawn from diverse contexts and academic fields. A description of a conceptual framework of resilience in an adaptive sociotechnical context follows in Section 3.4, with emphasis on the essential characteristics of resilience illustrated with Rasmussen’s dynamic safety model. Thereafter, a detailed discussion on the four cornerstones of resilience follows from Sections 3.5 to 3.8, with emphasis on the strategies that have been adopted in practice and theoretical abstractions of behavioural markers of resilience relative
to the respective abilities. This chapter concludes with a summary of research gaps and frameworks that are of interest in framing the investigative process; particularly, the research design, data collection, interpretation and representation.

### 3.2 The genesis of a resilience perspective in safety research

History has it that the notion of resilience in safety research was advanced by concurrent but independent efforts of scholars, who set out to understand the dynamics of human error (Amalberti, 2001; Dekker, 2006a, 2006b). Prior to the emergence of the resilience perspective, interests in human contributions relative to industrial accidents grew dramatically following major catastrophic accidents in the late 1970s; in particular, the Three Mile Island nuclear disaster of 1979 and the Tenerife runway collision of 1977. The central focus was to improve safety through the reduction of human error (Amalberti, 2001). The underpinning assumption, implicitly or otherwise, seems to be that the machine component of a human-machine system is infallible. Hence, restraining human erratic behaviour became an obsession for safety regulators, while accident investigations became increasingly centred on error tabulation and root cause analysis (Woods & Hollnagel, 2006; Rasmussen, Nixon & Warner, 1990; Woods, Johannesen, Cook & Sarter, 1994). These assumptions reinforced emphasis on the demerits of human irrationality in major accidents and further generated interests on how human-reliability issues lead to the degradation of otherwise “safe” systems through examination of human “erratic behaviours” (Green, 1990; Reason, 1990; Swain & Guttmann, 1983; Woods et al., 1994).

In view of such interpretations, organisations responded with lengthy and heavily constrained procedures with a view to ensuring that workers go about their daily tasks as directed (Hale & Swuste, 1998; Hale, Heijer & Koornneef, 2003). The procedures were designed to be followed religiously as the Levitical laws. Hence, any misfortune, whether directly or indirectly linked to deviations from laid-out task sequences and normative procedures, was pinned on human error (Rasmussen, 1999a). But, as investigations of how complex systems produce success as well as failure progressed, scholars that took a more systemic route to the investigation of ‘human error’ raised compelling contentions on how the label is applied in explaining causality (e.g., Leplat & Rasmussen, 1984). In a position paper presented at the NATO conference on human error, Erik Hollnagel pointed out that
errors are not special actions, but the product of the same cognitive process that produces so many correct and appropriate actions (Hollnagel, 1983a). Hollnagel contends that it is ‘erroneous’ to seek to understand error without understanding action. Jens Rasmussen, for his part, argues that the actions that sometimes produce error are heavily motivated by a response to make up for holes in formal descriptions of work and in the systems design (Rasmussen, 1982, 1983).

In support of these views, other scholars echoed that “human error” is nothing more than an attribution after the fact—in the sense that it is more of a conclusion arrived at after an investigation rather than the “root cause” of a problem (Woods et al., 1994; Woods, Dekker, Cook, Johannesen & Sarter, 2010). This insight, together with corresponding findings in many other disciplines, led to the conclusion that system failures cannot be simply attributed to the limitations of the frontline operator (Hollnagel, 2002; Rasmussen, 1999a; Rasmussen et al., 1990; Reason, 1990; Rochlin, 1999; Woods & Cook, 2002). In other words, failure does not simply occur because of the erratic human behaviour or the unreliability of frontline operators. Rather, it is more of a symptom that arises from a systematic migration of organisational behaviour under the pressure to be cost-effective (Dekker, 2002, 2007; Rasmussen, 1997; Rasmussen et al., 1990; Reason, 1990). This new perspective accentuates positive human contributions by highlighting how frontline operators adapt formal descriptions of work and pre-specified guidance to meet prevailing conditions, thereby filling in gaps between work-as-designed and work-as-performed (Hollnagel, 1993a; Rasmussen, 1982, 1999b; Reason, 2008).

Nonetheless, this new thinking did not completely obliterate the spotlight on human actors as it was still argued that ‘erroneous’ actions could stem from a range of factors, including organisational, technical as well as human factors (Hollnagel, 1993a; Rasmussen, 1982; Reason, 1995). It did, however, orchestrate a shift from emphasis on ‘what goes wrong’ and all its negative implications for the human operator to emphasis on ‘what goes right’. More significantly, this insight charted a whole new way of looking at the roles that organisational culture, technological artefacts and the human actors play in the routine operations of highly dynamic, large-scale systems; as well as the implications of their potential interactions for cognitive systems engineering (Hollnagel & Bye, 2000; Hollnagel & Woods, 1983, 1999; Rasmussen, 1999b; Rasmussen & Vicente, 1989). With knowledge gained in the ‘great debates’ (e.g., the NATO conference on Human Error in 1983), safety
researchers began to emphasise more systemic and organisational view of ‘actions’ rather than simply attributing error to an individual frontline actor (Dekker, 2006b; Hollnagel, 1983, 1998; Rochlin, 1999). Modelling of risks in tightly coupled systems further revealed systemic failure as stemming from the very adaptive processes that are expedient to cope with the standing request to be cost-effective and the highly dynamic nature of complex adaptive systems (Cook & Rasmussen, 2005; Rasmussen, 1997). Along this line, researchers found that human efforts directed to addressing variability in “normal” everyday operations could, at times, dynamically combine in ways that could lead to catastrophic consequences or simply yield unexpected non-linear effects—a phenomenon that has been described with the concept of functional resonance (Hollnagel, 2012a).

These insights, in conjunction with numerous corroborating findings, led to a mass exodus from error tabulation and models that emphasise ‘what goes wrong’ toward ‘resilience engineering’ approach, which accentuates ‘what goes right’ (Hollnagel, Woods & Leveson, 2006; Hollnagel, Pariès, Woods & Wreathall, 2011). Thus, the resilience engineering perspective emerged as a collective shift in thinking towards risks and safety management in complex sociotechnical systems. Among their many interests is understanding “…why certain decisions made sense to human operators at the time of their occurrence” (Woods et al., 2010, p. xx). Although research in ‘resilience engineering’ is still in its formative stages, it has paved a new way of looking at risk and organisational capabilities to sustain performance over time (see Hollnagel, Woods & Leveson, 2006; Hollnagel, Nemeth & Dekker, 2008; Nemeth, Hollnagel & Dekker, 2009; Hollnagel et al., 2011).

Nevertheless, the diversity of academic disciplines and work domains where the resilience paradigm has been applied often lead to confused interpretations of some key underpinning constructs that remain unresolved to date. Clearly, a tighter conceptualisation of key constructs that underpin the notion of resilience is crucial at the heart of developing a well-grounded theory of resilience in sociotechnical systems and in advancing resilient practices in safety-critical domains. Extensive accounts of the events that triggered this shift, as well as the leading researchers that laid the foundation for resilience engineering, can be found in the recounting of “the second story” (Woods et al., 2010, p. xxi), “a tale of two safeties” (Hollnagel, 2012b), and “the chronicle of the confused consensus” (Dekker, 2006b).
In search of meaning: What exactly is Resilience?

Scholars in diverse academic disciplines have used the term resilience to describe—a system’s ability to withstand some form of perturbation. Following Bhamra, Dani & Burnard (2011), the resilience perspectives reviewed in this study are selected from different research streams—ecosystems management, natural resource management, supply chain management, individual and community psychology, business continuity studies and safety engineering. Each of these fields has a reasonable number of publications that address the notion of resilience. The conclusion drawn by the Bhamra and his colleagues is that the concept of resilience across the six research streams is closely related to the ability or capability of a system to return to a stable state after a disruption (Bhamra et al., 2011, p. 5376). However, a closer look at the characterisations of resilience across these disciplines reveals clear differences in the philosophical and contextual assumptions that underpin their respective depictions of resilience. The intention here, therefore, is to shed light on such underlying assumptions with a view to gaining insight into the meanings that have been associated to resilience in varied contexts. Besides, the reasons for going beyond representations of resilience that are directly applicable to sociotechnical systems or safety-critical organisations are: firstly, to gain a well-informed insight of what resilience really is; and secondly, to avoid a potential pitfall of being myopically constrained by a specific area of study. Therefore, six premises abstracted from the various characterisations of resilience across the different research streams reviewed are employed in this section as a framework for discussing the meaning of resilience within a complex sociotechnical system’s context.

Resilience as the ability to absorb variations in demand

The first premise along the lines of ‘what resilience is’ relates to the attribution of resilience as the ability to absorb variations or to withstand adverse impact through the instrumentality of buffers, barriers and defences. The idea of deploying barriers and buffers mainly connotes ‘toughening’ a system in a way that makes it invincible to potential attacks. This concept, however, is heavily linked to robustness—a construct that generally depicts the degree of insensitivity of a system to mutations (in natural and biological systems) or degradations (in sociotechnical and physical systems) relative to some system parameters that would be affected otherwise by a perturbing force (Haines, 2009a; Jens, 2002; Stelling,
Sauer, Szallasi, Doyle & Doyle, 2004). The idea of absorbing shocks and variability captures a vital element in some conceptions of resilience: a presupposition that demonstrating an ability to absorb disturbances automatically validates a system’s resilience capability (e.g., Walker & Salt, 2006, p. 62). Of course, having buffers and barriers creates extra layers of protection against attacks and variances (Haimes, 2009a, 2009b). However, buffers are always finite and typically planned a priori based on a model of likely future events. As such, the use of buffers and barriers do not guarantee automatic success when a disruptive event befalls a system, because it is impossible to make exact predictions relative to the dynamics of all potential threats that could possibly affect a system (Leplat & Rasmussen, 1984). Some element of flexibility is, therefore, needed to ensure that defences are dynamically balanced in order to handle potential future events. Moreover, buffers that are deployed incrementally can interact in unanticipated ways, making it harder to model or visualise the path to failure (Dekker, 2011; Rasmussen, 1997). Consequentially, resilience should be reserved for those systems that not only have adequate defences, but also maintain the capability to dynamically balance buffers and reconfigure barriers in order to handle unexpected variability (Hollnagel, 1983; Woods, 2006). The ability to absorb shocks and variations is, therefore, only an aspect of the several facets of resilience.

### 3.3.2 Resilience as the ability of a system to adjust its functioning

The second premise relates to the notion that resilience is the ability of a system to adjust its functioning. This premise, in some ways, evokes an impression that a system is resilient as long as it can reconfigure its functioning successfully in the face of adversity. On a face value, this statement makes sense. But, what exactly is the nature of the ‘adversity’: is it a well-anticipated variability or a novel challenge? Although discussions in psychology literature acknowledge the presence of adversity as a criterion for attributing resilience, their emphasis on positive adjustments tends to suggest little or no difference between resilience and adaptation (e.g., Luthar & Cicchetti, 2000; Masten & Obradović, 2006). Investigations of complex adaptive systems, however, have both shown that all systems adapt in some ways (Csete & Doyle, 2002; Woods & Branlat, 2011a). Some systems are well adapted to function under normal operating conditions and some expected variability, but cannot be easily adapted to function under novel conditions (Pariès, 2011a).
In airline operations, for instance, researchers often develop highly sophisticated algorithms with the aim of optimising the use of expensive airline resources (Wu & Caves, 2000; Rosenberger, Schaefer, Goldsman, Johnson, Kleywegt, & Nemhauser, 2002). In spite of the ultra-high efficiency afforded by this practice under specified conditions (Bratu & Barnhart, 2006), it often leaves the system operating precariously along its boundaries of acceptable performance. As a result, unforeseen variability stemming from external disruptions or internal situation-induced performance variability tends to cascade quickly through the network. The overall system performance, in turn, degrades abruptly even under slight variation from the expected operating conditions (see Abdelghany, Shah, Raina & Abdelghany, 2004; Lettovský, Johnson & Nemhauser, 2000; Wu, 2005). These dynamics thus buttress the objection that resilience—at least in highly dynamic and tightly coupled sociotechnical systems—cannot simply be the ability to adapt positively. Systems that adapt positively to expected adversity, but are chronically maladapted to variations that fall outside the planned-for situations cannot be said to be resilient (Woods, 2006). Therefore, systems that demonstrate resilience attributes are those that possess the capability to readily reconfigure their functioning with a high degree of success in the face of both anticipated and unexpected variations in operating conditions. Nonetheless, this revised premise still captures only an aspect of the essence of resilience—the responsiveness ability.

### 3.3.3 Resilience as the ability to bounce back

A third premise relates to one of the most referenced attributes of resilience: the ability to bounce back after a disturbance. This premise captures a crucial but often confused facet of resilience, especially in the ecological and socio-ecological descriptions of resilience. At one point, some scholars from the ecological research stream posit that, when bouncing back, a system retains essentially the same relationships, functionality, structure, identity, feedback, etc. (e.g., Holling, 1973; Walker, Holling, Carpenter & Kinzig, 2004). In another article published in conjunction with some of the original authors that put forward the prior argument (e.g., Folke, Carpenter, Walker, Scheffer, Elmqvist, Gunderson & Holling, 2004; Gunderson, 2000; Peterson, Allen & Holling, 1998), the idea that a system’s structure can be redefined as well as the emergence of a new regime of operating was proposed. Both scope and time militated against a thorough analysis of works from the ecological/socio-ecological streams to ascertain, more definitively, whether the seemingly confused accounts is a product of a sudden shift in thinking or a more problematic
conceptualisation. But, despite the lack of clarity in ecological depiction of the bouncing back metaphor, a common idea that leaps to mind when mapped onto a sociotechnical context is that systems that demonstrate resilient behaviours can regain their original structure and functioning—perhaps up to a certain threshold. However, there appears to be a lack of consensual representation from ecological research as to how such systems behave when thresholds are crossed—that is, whether a system bounces back to retain essentially the same relationships and structure or whether it establishes new forms of interdependencies and functioning.

A postulation that can be readily abstracted from studies within business continuity and safety engineering perspectives is that the dynamics of bouncing back is contingent on the nature of the event that disrupted the normal functioning of the system. As discussed in Chapter 2, a typology of adversarial events can be represented as, the known knowns, the known unknowns and the unknown unknowns relative to a system’s ability to anticipate these events. Following a similar characterisation of resilience situations, Ron Westrum argues that being resilient to a type I situation is not a guarantee that either the system will be resilient to type II or type III situations1 (Westrum, 2006, pp. 55-65). In agreement to the discussions in Chapter 2, Westrum concludes that a resilient system under type I situation will not be necessarily resilient under type III. Westrum also notes that demonstrating good recovery ability does not always mean, or guarantee, good foresight skills (Westrum, 2006, p. 65). In view of the ecological discussions, one can argue that a system might regain its original functioning and structure following a type I situation without needing adjustments; the same system may need minor adjustments after a type II situation in order to continue functioning acceptably; and a type III situation in most cases will require a major transformation in both the system’s functioning and structure for the system to be able to survive the devastation caused by the disturbance. Thus, Westrum’s position lends strong support to a rather ubiquitous phenomenon in sociotechnical systems—that is, the view that whether a system maintains same structure or whether it

1 Type I situations are regular threats; that is, threats that are largely predicted and in some cases, expected. Type II situations are the irregular threats; that is, the low-probability but devastating events. Type II threats provide an understood, but still challenging problem. Type III situations are the unexampled events, the types of which cannot neatly be envisaged in foresight. Such events often require a shift in mental framework in regards to anticipating and responding to the events (Westrum, 2006, pp. 55-65).
transforms to a new functioning is contingent on the type of situation encountered (Westrum, 2006).

### 3.3.4 On resilience and ‘speed of response’

For some reasons, researchers who conduct ecological studies downplay the role of ‘speed of response’ in their formulations of resilience in ecosystems (e.g., Walker et al., 2004). In fact, the idea of speed of response has been referred to as “engineering resilience”, sometimes with an almost sarcastic undertone: not in the sense of resilience engineering but more in the lines of ‘the sort of resilience that engineering practitioners and researchers talk about’ (e.g., Folke et al., 2004, p. 558; Walker & Salt, 2006, pp. 62-63). While recognising that response speed is not the measure of resilience (as in, the only measure of resilience), it is nonetheless a critical aspect of resilience measurement in most natural and engineered systems, including sociotechnical and biological systems. Anecdotally, the relationship between ‘survival rate’ and ‘response rate’ during natural and man-made disasters (including medical emergencies) reveal that the speed of response is not only an essential factor, but also a reliable indicator in determining whether a system is responsive or not. This premise has been demonstrated in studies of resilience in diverse complex adaptive systems. From a safety perspective, an easy example is provided by the mass fatality—about 1,800 casualties—that resulted from the failure of Senegalese navy to quickly mobilise rescue missions to save passengers of *MV Le Joola* ferry that sank off the coast of Gambia in 2002. Survivors reported that many of the victims held onto logs of wood and debris hoping for rescue, but some had to let go when it appeared rescue was not forthcoming (McCollum, 2010).

Again, when viewed through an economic lens, the speed of response could as well be the difference between competitive advantage and bankruptcy. This premise is vividly captured in the account of Nokia’s and Ericsson’s responses after they temporarily lost a key component supplier, due to a minor fire at a Philips factory in Albuquerque, New Mexico in 2000. After the approximately 10-minute fire, Philips factory was closed for several months to allow for a decontamination procedure to be implemented, forcing both Nokia and Ericsson to source for an alternative supplier. Using this case, Sheffi highlights how corporations that readily adapt their operations can gain competitive advantage over entities not as well prepared for unforeseen contingencies. More specifically, Sheffi
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recounts how Nokia quickly mobilised other sources of supply and kept its production lines running, while LM Ericsson did not move as fast and incurred losses of more than $400 million (Sheffi, 2005; Yu & Qi, 2004). This particular case and many other recent extreme events (e.g., Fukushima nuclear power plant explosion, Deepwater horizon explosion, Mt. Eyjafjallajökull volcanic eruption) provide ample evidence that resilience in a sociotechnical context requires more than just demonstrating an ability to bounce back as may well be the case in ecological systems (Holling, 1973; Walker & Salt, 2006). Beyond bouncing back, it is required that systems respond adequately in a reasonably good time to diverse sets of perturbations, even under extremely difficult situations that threaten the survivability of a system—such as threats of nuclear catastrophe, or threats of millions of gallons of crude oil gushing into the ocean, or threats of total annihilation of a culture through acts of war and terrorism (Dekker, 2007; Rabinovich, 2004; Sheffi, 2005).

3.3.5 Resilience as the ability to foresee and evade

The question as to whether sociotechnical systems can anticipate potential threats takes the resilience debate from a reactive to a more pre-emptive paradigm. Resilience engineering studies lead a contention that beyond responding speedily to untoward events, it is expedient that a system demonstrates also the ability to recognise and avert potential threats to its existence and goals (Hale & Heijer, 2006). Successful cases of resilience in practice show that impact of disturbances on a system can be contained reasonably and response time shortened if the system was able to identify and address potential vulnerabilities long before an adversarial event occurred (Westrum, 2006). Regrettably, there are also cases of failure—for example, where operators did not detect deteriorating situations—that point to lack of vigilance, failure of foresight, or dynamics that are only visible with the benefit of hindsight (McCollum, 2010; Perrow, 1983; Woods, 2009).

Clearly, a large body of empirical work conducted in several high-risk, safety-critical domains lend support to the supposition that the ability to foresee and evade potential threats is a hallmark of resilience in sociotechnical systems (Hale & Heijer, 2006). But, suffice for now to end this discussion on the note that being resilient also demands that individuals and organisations remain sensitive to ways a system may fail (Hollnagel, Nemeth & Dekker, 2008; Nemeth, Hollnagel & Dekker, 2009). The relationship between resilience and anticipation is explored in greater depth later in Section 3.6.
3.3.6 Resilience as a system property, a system state or a process

The idea that resilience is an innate trait of an individual has long been challenged in the literature of child development and family therapy (Luthar, Cicchetti & Becker, 2000; Rutter, 1999; Ungar, 2004, 2008). Likewise, the notion of resilience being a property of a system has for long been considered an old wives’ tale in the contexts of cognitive systems and organisational studies (Hollnagel & Woods, 2006). However, there is yet some confusion in the use of terminologies and designations; phrases like ‘resilient systems’ or ‘highly resilient systems’, which are ubiquitous in the literature of resilience engineering. The apparent ambiguity in the use of such phrases in some ways projects an image that resilience could actually be viewed as a property of a system. In contrast, many elaborate explanations of what resilience is—within the resilience engineering paradigm—appears to suggest that resilience is more of a characteristic of how a system performs and, as such, systems can only demonstrate resilient behaviours (Hollnagel & Woods, 2006). It has also been posited that a system’s resilience can deteriorate over time unless it is maintained through “dynamic balancing acts” (Woods, 2006, p. 29). If the view of resilience as a quality of functioning is correct, then it can be extrapolated that mechanisms that engender and support resilient behaviours needs to be sustained in order to ensure readiness for action as situations demand. In other words, systems can be said to be resilient at some time and brittle at some other times, depending on how the mechanisms that proffer resilience are maintained. This conclusion raises a question regarding whether phrases like ‘resilient systems’ and ‘highly resilient systems’ are actually misnomers or simply ambiguous “slips” that could do with a little more clarity in articulating exactly what is being referred to when used in research documents.

A somewhat related argument is whether resilience is a process or a state of a system. Resilience or the lack thereof has been represented in some occasions as a state of a system over a significant period (e.g., Sundström & Hollnagel, 2006; Hollnagel & Sundström, 2006), but has also been captured in the descriptions of one-off successful activities and mechanisms deployed in response to a challenge event (Cook & Nemeth, 2006; Pariés, 2011b). Following from the several representations and descriptions of resilience, it appears that resilience mainly concerns the “how” of individual or organisational behaviours: how local actors recognise that adaptive capacity is falling or inadequate to address potential future squeezes (Woods & Branlat, 2011a), how organisations balance the
pressure between efficiency and thoroughness (Hollnagel, 2009a), how organisations regulate their functioning to avoid *going solid*\(^2\) (Cook & Rasmussen, 2005) or ‘drifting into failure’ (Dekker, 2011). All these characterisations of ‘how individuals or organisations behave’ depict resilience mainly as a process. But, following the idea of resilience being a demonstrable capability, it may well be argued that these behaviours might achieve a dynamically stable state over significant time, even though the stability may only be temporal. This phenomenon has been depicted (although not exactly used to argue this point) using Rasmussen’s dynamic safety model (cf. section 3.5), where a system learns to stabilise its *Brownian* movement-like drifting of its operating point along the marginal boundary (Cook & Rasmussen, 2005). This depiction lends support to the idea that resilience can be adequately represented as a ‘transient state’ of a system if behavioural markers of resilience are sustained over a sufficiently long period (Hollnagel & Sundström, 2006). The key contentions that are bound to arise in this argument though are: what is “adequate” and how long is “sufficient”? Perhaps the notion of resilience being a state of a system is what some researchers have embodied in their characterisation of ‘resilient systems’ and ‘highly resilient systems’. Both time and scope do not permit for a more extensive investigation on this discussion. Nevertheless, it is an issue that demands a broader attention by experts and practitioners alike in order to support a more cohesive and clearer articulation of a theory of resilience in a sociotechnical system’s context.

### 3.4 Resilience in an adaptive sociotechnical context

The discussions around ‘what resilience is’ have elucidated the various facets of resilience, each necessary but inadequate to stand as a sole representation of resilience in a complex sociotechnical system. The conceptualisation of resilience in this section draws on Rasmussen’s formulation of safety in a dynamic society (Figure 3.1) to capture the interplay amongst some essential attributes of resilience (Woods, 2006). It is, however, worth acknowledging a vital limitation in using this ‘simplistic’ one-operating-point metaphor to represent typical sociotechnical systems, which can be largely distributed with many different parts or functions interacting in very different ways. The assumption presented in

\(^2\) The metaphor of “going solid” captures a technical situation, wherein the operating characteristics of a steam boiler suddenly become difficult to manage due to liquefaction of the steam-water mixture in the boiler (Cook & Rasmussen, 2005, p. 130).
this thesis is that the operating point represents the emergent characteristic of the \textit{interrelating functions} as a whole (the very same property that could yield systemic failure from a series of complex, non-linear combinations) rather than a \textit{summation} of the operating points of each organisational part or function.

Figure 3.1 captures how a system’s operating point naturally migrates toward a boundary of functionally acceptable performance, which is shaped by the very objectives and constraints that define both the formal descriptions of work and the system design. The farther away an operating point is from section D, the lesser the risk of failure (in the form of accidents and incidents), but with higher costs in efficiency and effort. Conversely, the farther away a system operates from section A, the higher the chances of failure, but with lesser costs in efficiency and effort. Section B represents a safe space within which local actors can operate freely without generating adverse incidents. Section C represents a margin of affordable risks an organisation is willing to take; that is, their willingness to
operate farther away or closer to the *hardly visible* boundary of acceptable performance (represented as broken lines because they are mostly not always visible in foresight, but after a safety breach has occurred). Conversely, the marginal boundary of acceptable performance is represented as a hard line because it depicts current organisational stance relative to the distance actors are directed to maintain away from the actual-but-hardly-visible performance boundary. In addition, safety culture campaigns provide impetus for regulating or dissuading potential “flirting with the margin”, which in turn helps to checkmate marginal creeps into the zone of unacceptable performance (Cook & Rasmussen, 2005).

Using the dynamic safety model, the ability to bounce back from an adversity can be linked to the position of the operating point from the boundary of functionally acceptable performance. The closer a system’s operating point is from the boundary, the harder it will be for it to recover successfully in the event of a “fundamental surprise” (Lanir, 1983). Interestingly, the marginal boundary is also hardly visible when organisations are under perennial cost pressure and, even when noticeable, could change more quickly than actors would realise. Therefore, organisations with a good safety culture typically define a marginal boundary that enables them to keep a safe margin between their current operating position and the actual boundary position. As depicted in Figure 3.1, the size of the margin is heavily influenced by management pressure toward least cost and local actors’ preferences for workarounds that require least effort. Consequentially, the size of the margin is always changing as objectives and constraints evolve, and as local actors adapt their performances to cope with mismatches between plans and reality (as captured in Figure 3.2 and Figure 3.3).

When Wood’s (2006) resilience attributes are viewed through the lens of Figure 3.1, the *buffering capacity* becomes the determinant of a system’s ability to absorb internal variations and external disruptions. Stacking up defences proffers many protective advantages, but at the same time makes the migration process less visible. One implication of this is that a local violation of one of the defences will, most probably, not have an immediate noticeable effect. The defences will very likely degrade systematically through time under the influence of management pressure toward efficiency and as local actors gravitate toward least effort (Rasmussen, 1997). Over time, the degradation of defences could subtly lead to risky flirting with the margin and subsequent marginal creeps until the marginal
boundary gets to a precarious point, where failure becomes inevitable in the event that one actor inadvertently releases a hazard through violation or a necessary situation-induced response. This trend was implicated in the Longford gas disaster.

Furthermore, the dynamics of the system behaviour as it approaches the performance boundary becomes the key indicator of its tolerance; that is, “whether the system will gracefully degrade as stress/pressure increase or whether it will collapse suddenly when pressure exceeds its adaptive capacity” (Woods, 2006, p. 23). The flexibility designed into the system, on the other hand, determines the extent to which local actors can navigate freely within the safe space without transitioning into risky modes of operation.

This representation of forces that push organisations to ignore their safety nets, in many respects, reveals how success is achieved in an adaptive sociotechnical context. Therefore, the working definition of resilience that corresponds to the characterisation of resilience, as depicted in the illustration of the dynamic safety model is: “the ability to [recognise and quickly] adjust a system’s functioning prior to, during and following changes and
disturbances, so that it can continue to perform as required after a disruption or a major mishap, and in the presence of continuous stresses” (Hollnagel, 2009b, p. 117). Therefore, a hallmark of resilience is to monitor and dynamically balance the various influential forces that tend to push a system toward the zone of unacceptable performance.

The following sections address the four cornerstones of resilience—responding, anticipating, monitoring and learning—with the aim of eliciting a set of behavioural markers of resilience relative to each resilience ability. The discussions focus predominantly on concrete strategies that have been deployed in various domains of practice to deal with wide-ranging variances. More importantly, the discussions aim to accentuate ‘what goes right’ in these events, as well as how failure could have been averted where necessary.
3.5 Responding

In an airline operations context, responding to fluctuations in demands over an extended period (or as necessary, given the specific events) is arguably the most challenging and the most critical part of ‘the day of operations’. On this day, the responsiveness of an airline’s operations control system is put to test relative to its capability to handle the disruptions and unforeseen demands that arise every day, whether they involve aircraft, crews, ground resources, irregularities such as weather, air traffic control restrictions, slot request issues, mechanical reasons (Clarke, 1998). Even under extreme or novel demand variability, an operations control system is still expected to achieve some reasonable degree of success in key performance areas including—but not limited to—fleet and crew utilisation, fuel consumption, payload factor, and customer satisfaction. These challenges are likely to be exacerbated by gaps between planned-for resources and the actual demands on the day. An AOC system’s ability to respond can be further pushed to the brink by mismatches between pre-specified guidance, event-specific experiences and relevant competencies on one hand and the actual operational requirements on the other (Dekker, 2003). Faced with these challenges, the pressure to sustain expected efficiency gains and at the same time meet other operational and stakeholder requirements, therefore, necessitates that back-end decision makers develop a whole new approach to managing demand variability across the entire system. This approach must support local actors’ abilities to adapt to changes in daily operations without, inadvertently, setting up disastrous resonating effects (Hollnagel, 2012a). The remaining parts of this section explore the dimensionalities of Jean Pariès’ statement: “how to establish (now) and maintain (tomorrow) a readiness to respond (at any time in the future)” (Pariès, 2011a, p. 3).

3.5.1 Readiness to Respond

Readiness to respond is typically assumed to correlate with the level of articulation in pre-defined rules and contingency plans that guide the operations of a system. This is partly because operating rules and plans could easily act as a trigger for collaboration across a distributed control team (Nezamirad & Higgins, 2007). In a sense, operating rules and plans provide a strong force towards a shared understanding of situations and a common framework for team behaviour, thereby reducing the need for costly coordination efforts (Grote, 2004). However, there are subtle pitfalls in this assumption, not the least of which
is the supposition that plans are specifically optimised at management levels and then frozen and passed down to local operators for implementation (Fawcet, Magnan & McCarter, 2008a, 2008b). To be precise, Taylor’s ‘scientific management’ paradigm presupposes that performance variability can be designed out of the system; and as a consequence of this mechanistic view of control, operating rules and procedures are deployed as tools for regimenting work processes (Taylor, 1911). In order to achieve these regimentation efforts, detail instructions are stipulated on how work must be performed, allowing only little (if any) degree of freedom for most anticipated variations. However, it seems no more plausible that rôle following of rules will effectively bring highly dynamic and complex work processes under control, than a fully automated decision-making system can respond to non-specified disruptive scenarios. In other words, rôle following of pre-specified rules is highly insufficient to address the complex and dynamic nature of modern sociotechnical systems (Hollnagel, 1993b; Hale, Heijer & Koornneef, 2003; Rasmussen, 1983b). In many aspects, enforcing compliance to rules actually limits the operators’ ability to manoeuvre through local pressures and challenges that are not captured in the prescribed procedures (Dekker, 2003).

Consequently, studies have emerged that contest such traditional, hierarchical control approach by showing that plans are satisfied during execution with a great deal of input from human experts. This premise is typically exemplified in the role of human experts in handling uncertain situations and variances at the shop-floor level (Higgins & Wirth, 1995; Nezamirad, Higgins & Dunstall, 2004). Another practical example is the investigation of how aircraft maintenance mechanics adapt procedures in the face of local challenges and pressures to keep up with schedules. Dekker (2003) alludes to the premise that following procedures, as originally designed, can actually lead to inability to get the job done, and further described how workers develop informal work routines and “normalised”, peer-fuelled (as opposed to management-endorsed) conformances to deal with gaps in the prescribed procedures (Dekker, 2003). This assertion is clearly in agreement with works that highlight the limitations of following procedures as designed using workers’ deployment of a work-to-rule strategy in labour disputes and strikes (Hale & Borys, 2013). From this perspective, plans are regarded primarily as “…resources for situated action” (Suchman, 1987), not a blueprint for hierarchically regimented actions (Grote, 2004). It is, therefore, not surprising that the ability to monitor gaps between centralised procedures
and local practice has been identified as a hallmark of ‘high reliability organisations’ (Rochlin, 1999; Weick, 1987; Weick, Sutcliffe & Obsfeld, 1999).

It therefore appears that maintaining a readiness to respond requires not only a well-articulated contingency plans and operating rules, but also a reasonable degree of freedom for local operators to adapt plans to local contexts, particularly when dealing with mismatches between reality and planned-for situations (Dekker, 2003; Pariès, 2011b; Woods and Shattuck, 2000). But, beyond having relevant and readily deployable resources for most expected variances, being prepared also means that a human adaptive system must maintain the capability to deploy additional or different kind of resources and/or expertise to be better positioned to successfully address potential surprises (Woods & Branlat, 2011a). This is particularly important during events that have an unusual spread in time and space such as the 2010 volcanic ash disruption of European airspace (Budd, Griggs, Howarth & Ison, 2011) and the 2004 Boxing day tsunami (Smith, 2006). The question, therefore, arises as to how the individuals and subgroups at the airline operations control centres address issues around gaps in perception between ‘blunt end’ staff (operations’ planners and personnel in charge of developing operating procedures) and the teams involved in schedule execution at the ‘sharp end’.

A potential consequence of the proposed necessity to allow for a reasonable degree of freedom in an operating procedure is a double bind: in the sense that this strategy could pose a risk to safe and thoroughly integrated operation and, at the same time, could readily become a potential source of resilience. More pragmatically, given a leeway in specification of actions and emphasis on efficiency related goals, the pressure to be cost-effective can influence controllers to prioritise easily measurable acute and efficiency goals (e.g., on-time performance, capacity and resource utilization). A focus on acute goals could jeopardize more chronic and harder-to-measure goals—such as safety lapses and subtle failure of foresight—leaving the system drifting precariously toward the edge of failure (Dekker 2003; Hollnagel, 2009a; Rasmussen, 1997). Conversely, following a tightly regimented procedure as designed can lead to a situation where operators end up solving the prescribed, but the wrong, problem (Hale & Borys, 2013). Since informal work systems appear useful for addressing gaps between pre-defined protocols and work as actually performed, another question arises of how to balance the risks between unsuccessful adaptation due to incomplete knowledge or poor judgment on one hand and rote rule
following despite indications that adaptation is necessary on the other (Woods & Shattuck, 2000). Clearly, enforcing strict adherence to management-endorsed operating rules does not seem a reasonable way out of this double bind. This dilemma is vividly captured in Dekker’s argument:

“Tightening procedural adherence, through threats of punishment or other supervisory interventions, does not remove the double bind. In fact, it may tighten the double bind—making it more difficult for people to develop judgment at how and when to adapt. Increasing the pressure to comply increases the probability of failures to adapt—compelling people to adopt a more conservative response criterion. People will require more evidence of the need to adapt, which takes time, and time may be scarce in cases that call for adaptation” (Dekker, 2003, p. 236).

On this note, scholars from both safety and business-continuity research streams appear to agree on a possible way out of the double bind: supporting local operators in developing requisite initiative and judgment skills in order to better assess what adaptations are necessary and what adaptations are suicidal to the system’s ultimate goals (Bruns, 2009; Dekker, 2003; Feldsman & Pentland, 2003; Woods & Shattuck, 2000). It is, therefore, surmised that rather than simply enforcing procedural adherence, local operators need management-backed guidance on how to navigate through local challenges and pressures in order to compensate for potential limitations in the pre-specified protocols. Building on this idea, this research seeks to gain insight into the level of authority frontline controllers have, and their competence, in making substantive cognitive judgments in adapting procedures to local contexts.

3.5.2 Capability for Continuous Regulation

In some respects, the idea that ‘training in cognitive judgement alone can address the multifaceted gap between actual and planned-for situations’ sounds rather optimistic. Anecdotal evidence does suggest that local operators are already making such substantive judgements. However, it still feels that perhaps there is more to the cognitive competencies that sharp-end controllers bring to bear in coping with the vagaries of demands that keep such complex and highly dynamic system working so well so much of the time. An interesting research agenda would be to find empirical evidence that could explain how cognitive judgement, and perhaps other less salient drivers, influences ops-controllers
ability to deal with unforeseen demands that come up in their everyday routines, along with events that fall outside the design envelope. Along this direction, the contextual framework for proactive crisis-management developed by Bergström and colleagues (2011) is an appropriate foundation for exploring behavioural markers of resilience relative to sustaining the capability to respond under routine and novel situations. The activities that are explored in the following sections, therefore, comprise of the core components of the framework for proactive crisis management—information management, communication and coordination, decision-making, and effect control.

3.5.2.1 Information management

Advances in information and communication technologies have changed significantly the nature of how individuals and subgroups manage flow of information during collaborative activities, particularly in a context of computer-mediated work (Baites, Dickson, Sherman, Bauer & LaGanke, 2002; Kiesler & Sproull, 1992; Weisband, 1992). Whilst there are obvious benefits from this advancement, it sometimes poses a great challenge relative to effective management of information. One assumption of this thesis regarding information management is that controllers of modern sociotechnical systems will more likely be overwhelmed by large items of information that demands some sort of attention than their counterparts few decades ago. Given a situation of high frequency of data coming through multiple channels, there are higher chances of missing the connections between relevant pieces of information amidst noisy, irrelevant data (Crichton, McGeorge & Flin, 2007). Again, it is possible that, under such circumstance, the salience of an item of information, rather than its relevance, assumes the key criterion for attending to incoming streams of data. Eventually, when overwhelmed by high volume of data, controller might resort to skimping on validating reported facts or chasing up conflicting items of information (Hollnagel, 2009a). Also, where relevant information is less salient, its relevance might easily go unnoticed as controllers will likely focus on more salient data streams. A combination of two or more of these issues with dealing with deluge of data could lead to all sorts of difficulty with formulating a comprehensive understanding of the unfolding situation, and could even lead to poor conceptualisation of the developing problem (Crichton et al., 2007; Endsley, 1995a; McLennan, Omodei, Holgate & Wearing, 2007).
With regards to managing complex information flow, studies have emerged that describe how actors in complex and highly dynamic systems deal with the challenges posed by the increasing needs for real-time information management. For example, an empirical study of strategic information search in 50 manufacturing companies highlights how executives consider and look for relevant features of information depending on the environmental characteristics that triggered the search (Daft, Sormunen & Parks, 1998). Similarly, it has also been reported that actors in some complex work domains actively search for information deemed ‘need to know’ (Crichton et al., 2007), as well as employ diverse mechanisms to verify and validate potentially conflicting items of information (Axelsson, 2006). As a way of coping with high streams of data, Dörner (1996) suggested that high volumes of data could be sorted, distributed and shared using explicit and commonly shared goals. Thus, given the need to manage high volumes of data and to validate incoming items of information during operations control activities, it would be interesting to identify cognitive behaviours and strategies deployed by frontline controllers in response to informational challenges that arise in their day-to-day operations control activities and how those strategies evolve during crisis situations.

3.5.2.2 Communication and coordination

Bergström et al (2011) highlighted some critical features of team communication and coordination activities that are necessary to perform resiliently in the face of situations that challenge traditional set-up of functions and communication channels (pp. 46-48). First, a clearly defined role along with a shared understanding of authority and responsibility across members of the team is crucial for sorting and distribution of relevant information to specific personnel during an unusually high influx of data. Clarity of roles, responsibilities and authority allows for a quicker communication across teams when adaptation of traditional functional structure or reformulation of tasks is required to evade potential cascading failure (Dekker & Suparamaniam, 2007). It is further argued that this clarity could support workload regulation to relieve overloaded team members (Bergström et al., 2011). A recent empirical investigation of crisis management in a large transportation system further showed that not only roles or tasks are adapted during a crisis situation. There was also observable change in communication processes, from routine computer-based, textual communications to more verbal (over the telephone and face-to-face) communications with significant increase in foot traffic and aggravated sense of urgency.
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(Deary, Walker & Woods, 2013). This finding both reiterates and reinforces some of the phenomena that Dörner captured in his experiments and case studies (Dörner, 1996). An interesting line of inquiry would be to examine how ops-controllers adapt forms of communication and coordination; as well as how responsibility and initiative is adapted across team members during escalating situations.

3.5.2.3 Decision Making

To ensure successful functioning of the systems they control, people in their daily activities make series of choices (sometimes unconsciously) based on the extent of information available to them. In contrast to the rationalist processes of decision-making (Simon, 1991, 2000), those choices are hardly one-off selections made in favour of the best alternative. Rather, those choices are usually a series of inter-related selection activities that are intrinsically part of the work process that is being controlled and, in hindsight, are attributed for favouring one alternative over other possible alternatives (Hollnagel, 2007). Decision-making, when viewed from a natural work environment, is never unproblematic. Some of the difficulties surrounding decision making in natural work settings relate to the ill-defined nature of the problems, highly dynamic and distributed environment, rapidly changing goals, multiple and sometimes conflicting streams of data, open-ended facts that can be interpreted in many different ways, and so forth (Brehmer, 1990; Klein, 2008; Rasmussen, 1991; Schneeweiss, 2003). Thus, decision-making in complex sociotechnical systems requires a good understanding of the situation in the system, even when cues are not readily available but must be constructed from large streams of data (Endsley, 1995a, 1995b). In order to make sense of the situation, decision makers need to rigorously sift through the vast data that are available to them, and deliberately manipulate cues so as to derive inferences and meaning from the data (Klein, 1997, 2007).

An unfortunate consequence of the fluid nature of operations in most sociotechnical systems is that data loses relevance with time. That is, information derived about a situation is only valid if implemented within a certain window of opportunity (Hollnagel, 1993b). In airline operations, for instance, a delayed decision may no longer be feasible at the time of implementation because the relationships between resources have changed over time and space (Abdelghany et al., 2008; Igbo, Higgins, Dunstall & Bruce, 2013). Therefore, decision-making must be quick, pragmatic, responsive to change, and above all amenable
to myriad constraints (Bruce, 2011). Along this line, some scholars have argued that certain situations require quick response selection rather than spending time on costly alternative evaluations geared towards finding the optimal response (e.g., Hollnagel, 2007; Snowden & Boone, 2007). That is, an alternative that is quick to implement is preferred, in many cases, over one that takes longer even though the latter might have been a better option. Studies have also emerged that showed how people use simple heuristics to reduce the number of alternatives based on certain attributes that are deemed “important” by the decision maker, as opposed to deploying a rationalist-style trade-off in choosing from alternatives (Zsambok & Klein, 1997).

Moreover, the use of pre-specified guidance, particularly in routine or familiar situations, has shifted the responsibility of the decision-maker from ‘finding out what to do’ to ‘figuring out how and when to adapt pre-specified guidance to actual situations’ (Hollnagel, 2007). Faced with time pressure and increasingly intractable complex systems, decision-makers usually resort to simple and yet robust heuristics to guide quick response selection. Interestingly, it has been found also that high levels of uncertainty push decision-makers towards more analytical, knowledge-based problem solving processes (Kurtz & Snowden, 2003; McLennan et al., 2007). This phenomenon could be explained in light of the novelty or unfamiliarity with the situation, which greatly limits the usefulness of pre-specified guidance (Hale, Heijer & Koornneef, 2003). But, there is yet another dimension of complexity involved when decision-making is distributed. Such complexity arises primarily because coordination efforts and negotiation of choices must aim to balance between conflicting views so as to ensure specified objectives are achieved (Schneeweiss, 2003). This complexity is exacerbated during escalation of demands under novel challenges or when a known problem is rapidly deteriorating. The key argument that has been raised regarding decision-making in escalating situations is that the process can neither be based on consensus nor structured in a way that allows only the team leader to make all the decisions. Rather, it is argued that every team member should be allowed to make decisions within the bounds of an explicitly defined goal or set of goals (Bergström et al., 2011). Clearly, this approach will inadvertently increase the demand for coordination and quick updates on changes across the distributed decision-making network in order to keep such a distributed system functioning.
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3.5.2.4 Effect control

In characterizing dynamic fault management in the face of cascading disturbances, David Woods (1994) identified four types of responses: mitigate fault consequences; break disturbance propagation paths; terminate fault source; and clean up after-effects. When an event occurs, the first logical approach is usually to locate and terminate the fault at the source. Evidence for this presumption is not hard to find: a basic human instinct that would quickly manifest during common household incidents such as a leaking water pipe is to cut off supply to the water pipe before dealing with the flooded room. It is almost comical and “irrational” to attempt mopping up the floor while water is still gushing from the broken pipe. Likewise, this instinct is equally demonstrated in most industrial incidents and accidents, even during investigation of such events: find the root cause and fix it (e.g., Baker, 2007). While recognizing the misuse of causality theory and the murky debates surrounding root cause in accident investigations, it seems reasonable to suggest that the ability to identify a potential root cause and the capability to terminate the fault at the source are critical steps toward recovering successfully from an incident or accident that has already happened (Woods, 1994).

But, this logic does not apply to all cases. Many complex systems typically face myriad challenges, both intrinsic and external, which cannot be terminated at the source even when the fault source can be located. In particular, events that are easily attributed to acts of nature (e.g., earthquakes, tsunamis, hurricanes, etc.) or man-made disasters (e.g., acts of terrorism, wars, etc.), in most cases, transcend the authority of typical organizations that control most sociotechnical systems and thus leave very little or no option for termination at the source. Even though termination is not a logical option during such events, a number of man-made disasters and even acts of nature are to some extent predictable and thus can be prepared for before the disturbance eventuates (Cook & Nemeth, 2006). It is, therefore, typical for organizations that operate in earthquake- or hurricane-prone areas to have built-in buffers and defenses that allow them to absorb or mitigate potential impact of such anticipated events. Nonetheless, some events are less predictable and the scale of their impact can only be dealt with after they have occurred. Even when potential demands have been anticipated to some degree, the actualities of the event may differ widely from what was anticipated (Rabinovich, 2007). Therefore, a hallmark of resilience during both foreseen and unforeseen demand escalations is to demonstrate the ability to make pre-
emptive adjustments to a system’s functioning prior to the challenge event and, at the same time, maintain real-time responsiveness necessary to address possible gaps between the actual and the anticipated events (Deary et al., 2013; Hollnagel, 2009b). This response approach will likely place the system in a better position to weather through the consequences of the anticipated event and still maintain “normal” functioning with minimal set-backs or damages to its core operations.

Further, the increasing coupling and interdependencies between components of modern sociotechnical systems sometimes lend them to adverse consequences of actions intended to address unusual variations in demand (Perrow, 1984). Whilst local controllers are usually mindful of such unintended consequences arising, there are occasions where a combination of factors could trigger unforeseen resonance effects (Hollnagel, 2012a). Unless adequate measures are in place to contain such effects, negative resonance can amplify and propagate through the network leading to ungraceful degradation or quick cascading failure (Walker, Deary & Woods, 2013). Hence, it makes sense that controllers should be made aware of the mechanisms in place that can be deployed to forestall disturbance propagation across the system (Woods, 1994). One strategy that is commonly employed in airline operations control is to isolate the affected link(s) in the network: that is, disconnect the affected flights from the rest of the routing network. A typical practice is to cancel heavily affected flights, delay the ones that are moderately affected to accommodate the increased demands, and then dynamically reschedule resources (both flight and cabin crew members) along with passengers using capacity borrowed from the cancelled flights (Abdelghany et al., 2004; Bratu & Barnhart, 2006).

After a disturbance or sudden fluctuations in demand has been terminated, mitigated, or contained, the next logical move is to deal with the after-effects of such disturbances. Many events leave in their wake wreckages and trail of debris (both metaphorical and real) that need to be cleaned up and perhaps reconfigured in order to re-establish normal functioning. As discussed earlier based on Westrum’s argument, cleaning up after-effects could simply mean getting a system back to its original functioning prior to the challenge event or a more radical adjustment of the system’s structure and functioning to ensure continuing survivability and readiness to respond to the next demand escalation (Westrum, 2006). Regardless of the level of devastation caused by a challenge event, a resilient recovery should ensure some reasonable degree of continuity to a system’s functioning.
even where immediate full functioning is not possible. Efforts directed towards recovery must respect a certain window of opportunity in which what needs to be done must be done before the after-effects lead to a whole new set of consequences (Hollnagel, 2007). This argument lends strong support to the premise that the speed of recovery is certainly a critical marker of resilience, contrary views notwithstanding. Table 3.1 presents a summary of resilience markers relative to the responding ability.

*Table 3.1: Responding – Knowing what to do*

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
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</thead>
<tbody>
<tr>
<td>Readiness to respond</td>
<td>Maintaining relevant and readily deployable contingency plans</td>
</tr>
<tr>
<td></td>
<td>Maintaining requisite resources for most expected events</td>
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<tr>
<td></td>
<td>Maintaining the capability to engage additional resources in the event of unprecedented situations that escape foresight</td>
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<tr>
<td></td>
<td>Having a clear criteria for activating responses/special functions</td>
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<tr>
<td>Ability to regulate interactions across multiple centres</td>
<td>Maintaining the responsiveness to reorganise communication and coordination processes in the face of changing situations</td>
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<tr>
<td></td>
<td>Having clear criteria for adapting authority and responsibility across echelons and across functions</td>
</tr>
<tr>
<td>Capability for continuous regulation</td>
<td>Having clear protocols for managing complex information flow</td>
</tr>
<tr>
<td></td>
<td>Knowing how and when to match a changing and ambiguous set of rules to a changing and ambiguous set of situations</td>
</tr>
</tbody>
</table>
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3.6 Anticipating

The traditional *after-the-fact* analyses of many systemic and organisational failures—particularly those that were attributed to intrinsic factors—often point out that warning of impending disaster were missed leading up to the failure events. For example, following the 1984 accidental release of methyl isocyanate at the Union Carbide chemical plant in Bhopal India, the 2005 explosion of BP refinery in Texas city and the 1992 Westray mine disaster in Nova Scotia Canada, investigators found a series of minor incidents relating to lax safety practices that could have been picked on as precursors of disaster in the three cases (Baker, 2007; MacKenzie, Holmström & Kaszniak, 2007; Glasbeek & Tucker, 1993; Tucker, 1995; Shrivastava, 1995a). But these precursors were not adequately addressed and eventually culminated to fatal explosions (Cooke, 2003; Shrivastava, 1995b). Likewise, in the wake of the Challenger accident, it was found that NASA and Morton Thiokol managements failed to follow up on gut feelings and expressed concerns relating to launching the Challenger space shuttle in cold weather in attempts to avoid further launch delays (Vaughan, 1997, 2004). Seventeen years later, a similar pattern re-surfaced in the lead up to the Columbia accident, but this time NASA was reluctant to re-assess the vulnerability of the Columbia space shuttle to foam strikes in the face of compelling evidence, at least when viewed in retrospect (Woods, 2003, 2006, 2009).

Whilst these accidents span diverse operational processes and complex work domains, the common denominator appears to be a breakdown in safety consciousness in a continual struggle to meet perennial cost and schedule pressures (Rasmussen, 1993; Shrivastava, 1995a). Given a trade-off between intangible long-term *thoroughness* benefits and measurable short-term *efficiency* efforts that yield immediate production benefits, it makes sense that managers will in some, if not most, cases skimp on thoroughness to satisfy efficiency goals (Hollnagel, 2009a; Marais & Saleh, 2008)—such as simplifying operational procedures, reducing frequency of checks and maintenance activities, reducing training hours or budget, etc. (Lawton & Parker, 2002). What is not readily obvious, however, is how the different actors miss to see that the system is gradually drifting towards a zone of unacceptable performance (Dekker, 2007; Rasmussen, 1997); and as a result, losing its capacity to respond gracefully to unexpected variability or escalations in demand, a
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phenomenon that has been described with the metaphor of ‘going solid’ (Cook & Rasmussen, 2005).

Moreover, scholars have for long posited that the difficulties with deriving meaning from data under conflicting goals and uncertainty could be linked to failures of foresight and breakdown in sense making (Turner, 1976; Weick, 1993; Woods, 2009). Developing and sustaining foresight in the face of rapidly changing circumstances requires that all actors maintain a recognisable model of the future. In other words, it is important that human actors in complex systems have a collective understanding of how different forms of demands could stretch system resources and impact its capability to maintain a safe and profitable operation in the future (Bolstad & Endsley, 2005; Woods & Branlat, 2011a). But to sustain this capability, a system has to develop adequate mechanisms to look into the future, and be able to readily capture new developments within the system and its environment (Hollnagel, 2011a).

3.6.1 The role of indicators

Controllers of complex operational processes typically make use of data and metrics, mainly referred to as indicators, in order to develop an understanding of current operating state of the system and to derive expectations of potential states in the foreseeable future (Hopkins, 2007, 2009; Hale, 2009; Mearns & Flin, 1999; Wreathall, 2011). In a functional sense, indicators provide evaluative information or data concerning the operation or output of a system (Øien et al., 2010; Øien, Utne & Herrera, 2011; Webb, 2009). In this section, the classification of indicators focuses on the nature of information they provide (whether it is warning information, a status update or a process outcome) in relation to a specific event and where such information lies in the timeline of the event (before, during or after the event). Some indicators, current indicators, provide real-time information regarding the system’s operating conditions; thereby allowing for concurrent adjustments of the system input, core processes and, where possible, the environment in which the system operates (Wreathall, 2011). On the other hand, there are indicators that can only provide retrospective information regarding the state of the system, and are thus referred to as lagging indicators (Erikson, 2009; Dyreborg, 2009; Hudson, 2009). Both of these categories of indicators are very useful for monitoring situations in and around the system, and for responding to actual problems (Wreathall, 2011).
But, on a more proactive level, some indicators are useful for recognising emergent patterns and features that are indicative of early signs of developing threats. Such early warning signals, commonly referred to as *leading indicators*, afford many advantages in making pre-emptive adaptations and in addressing unacceptable developments or, at the very least, mitigating their potential effects (Grabowski et al., 2007; Harms-Ringdahl, 2009; Rieman & Pietikäinen, 2012). The benefits of recognising and forestalling potential systemic failure particularly in high risk systems, therefore, necessitates that controllers develop the ability to make sense of leading but often weak indicators of developing threats (Hale, 2009; Webb, 2009). It is worth noting that leading indicators are not only useful for addressing potential threats. Leading indicators also allow for exploitation of opportunities from favourable developments in the environment, which can place the system in a better position to respond to future squeezes on scheduled resources (Woods, 2003, 2009). A practical example relative to airline operations context would be identifying a transhipment opportunity that allows frontline controllers to rebook passengers on a transit flight, thereby freeing up resources (aircraft, crew, catering trolleys/consumables, etc.) that were scheduled for the original flight.

Although great efforts have been made to resist being dragged into the fiery debates on the distinction between leading and lagging indicators as reported in a 2009 special issue of the ‘Safety science’ journal, it is worth taking a stance in relation to how the notion of indicators is used here. Accordingly, this thesis takes a *relativist* position (Hopkins, 2009) to the classification of indicators, in that an indicator might be interpreted as leading or lagging depending on contextual factors around a specific event and on the information the indicator provides. Following Erikson’s argument, a failure during testing could be interpreted as a lagging indicator. But, this same failure can also be seen as a leading indicator if it allows the system to adjust its functioning in order to avoid similar failure in an actual operational event (Erikson, 2009, p. 468). A similar argument was advanced by Dyreborg (2009); however, with less clarity on the claims of a causal relationship between leading and lagging indicators. For his part, Hale (2009) also highlights the distinction between failure during testing and failure during operation. However, Hale’s position is contrary to the thesis position because Hale appears to lean more toward the opinion that there are absolute leading or lagging indicators, which are independent of contextual factors besides the event timeline (Hale, 2009). Overall, the thesis of this research is that it
is more beneficial to understand how these indicators contribute to safety and effective control of a system’s operations rather than to focus on all the distinguishing features of a leading or a lagging indicator (Mearns, 2009; Wreathall, 2009). Consequently, the following sections are centred on behavioural markers of resilience that have been reported in other safety-critical domains: behaviours that support controllers’ ability to foresee the latent cracks and the changing shape of vulnerability relative to the way work is performed in the system.

### 3.6.2 Ability to develop and sustain foresight

One of the key challenges of modern sociotechnical systems is the increasing level of coupling between functions, and the inevitable complex web of interactions that result from such tight coupling of functions and resources (Perrow, 1984). A direct implication of the resultant web of interactions is that authority and responsibility are often distributed across functions making it harder for actors in the system to develop a comprehensive awareness of the system state at any given time (Dekker & Suparamaniam, 2007; Vaughan, 1997). In order to detect faint and distributed signals under such conditions, organisations have to develop mechanisms to quickly retrieve and integrate information from different units and functions (Axelsson, 2006). Such mechanisms are surmised to support fast abstraction of meaning from even seemingly unrelated events so as to keep latent vulnerabilities from combining and generating new paths to failure. Furthermore, human controllers need to constantly anticipate possible consequences of decisions made to address diverse pressures (Hollnagel, 2012a; Woods & Branlat, 2011b). It is the presupposition of this thesis that such understanding is useful for deriving more accurate expectations of potential threats to a system’s operations and for supporting anticipatory adjustments long before such threats become reality.

From a practical standpoint, anticipated models are rarely precise and sometimes might even differ significantly from reality. However, they do provide mental exercise necessary to explore functional interdependencies in the system and how these functions might interact to produce future bottlenecks and possibly new paths to failure (Lant & Mezias, 1990). The exercise mechanisms may relate to technological artefacts that allow operators and decision makers to pre-empt potential threats and vulnerabilities to their daily operations, or to specialised skills and expertise needed to create a comprehensive,
simulated model of the future. For example, frontline controllers in airline operations use sophisticated software programmes to model how the current state of the system—in conjunction with anticipated changes in demands and the environment—could impact future resource schedules spanning three to four days for domestic flights and up to a week for long-haul international flights (Clausen et al., 2010; Kohl et al., 2007). But, for an adequate model to be maintained, frontline controllers need to constantly revise their knowledge of local conditions at the ports, ground operations, equipment, and weather situations. Such knowledge is surmised to be critical for making sense of more dynamic situations, which are harder to envisage in formal procedures (Dekker, 2003; Dekker & Suparamaniam, 2007; Bolstad & Endsley, 2005).

3.6.3 Recognition of global implications posed by localised threats

It is widely accepted that everyday actions taken to address a vast array of pressures may sometimes generate latent risk conditions with serious safety and/or productivity implications (Dekker, 2007; Hollnagel, 2012a; Rasmussen, 1997). It is, however, easy to miss the wider implications of such threats even when they have been identified as potential local threats. Evidence from the literature suggests that being too close to low-level activities often obscures noticing when latent conditions develop from actions targeted toward solving low-level problems (Lay, 2011, p. 253). In the same light, some scholars have argued that the inability to take proper actions in a reasonable time could be linked to weaknesses in organisations’ ability to handle ‘faint’ signals, or diffuse symptoms of developing problems (e.g., Axelsson, 2006; Vaughan, 2004; Woods, 2009). This view is clearly in line with the supposition that the ability to develop and sustain “requisite imagination” (Adamski & Westrum, 2003) is a critical feature of resilience.

By definition, faint signals are indicators that provide information on vulnerabilities and emerging threats in a process, but which are often hard to spot. Diffuse indicators, on the other hand, are symptoms that are indicative of impending problems arising from interactions between disparate threats that often emanate from different sources (Wreathall, 2011; Axelsson, 2006). Such developments could seem harmless in themselves, unless when viewed through the lens of contextual pressures. For example, increasing frequency of flights to accommodate new demands (particularly, during holidays/special seasons) may seem harmless, and often gives an impression of a system that can adapt
quickly in the face of new demands. But, given the squeeze on aircraft turn-around time to accommodate the increased frequency, a fully loaded aircraft with a few passengers needing accessibility assistance could signal a possible delay-initiating event stemming from disembarkation and subsequent cleaning of the aircraft. The squeeze on aircraft turn-around time could, in effect, lead to cascading delays if one flight turned late, or if ever there is a minor maintenance or other forms of emergency (Abdelghany et al., 2004; Clausen et al., 2010). These dynamics requires that human controllers not only develop their capability to harness faint signals, but also to develop an ability to draw links across diffuse signals of localised threats (Axelsson, 2006).

A related dilemma facing many human controllers in sociotechnical systems is the lack of specificity regarding when to flag a latent local problem as a global operational threat (Lay, 2011). In other words, not knowing how bad a developing sign of trouble can get before raising a red flag for a shift in operating mode. Given heavy constraints on time and resources, it would be difficult to justify such calls a priori particularly if hindsight reviews of past events showed a good number of false alarms and events that could have been handled without escalating the operating mode. To complicate matters, it is not unlikely that a developing problem could be more of a threat to a different unit other than the source unit where it originated. For instance, a decision to delay a flight at a given airport for whatever reason might have a flow-on effect on several other flights originating from different airports. Therefore, not knowing how a developing situation might impact operations across the network necessitates a system-wide review of risks across functions even under seemingly insignificant anomalies.

The other side of this argument is that chasing up every sign of a developing problem will impact negatively on the efficiency of the system. Hence, Axelsson (2006) argued for clear-cut ways of reporting a developing problem so everyone is aware of recent developments: such as the use of crosschecks involving diverse expertise and competencies. In the specific case reported in Axelsson (2006), representatives from different functions in the organisation met regularly to discuss general developments and specific anomalies in their various units. Such meetings proffered an opportunity to maintain a system wide awareness of operational status, and further gave a diffuse problem a chance to be consulted by the different competencies and functions represented (pp. 151-154). According to Axelsson (2006), this mechanism supported the decision makers’ ability to review various
perspectives, which has been identified by other resilience engineering scholars as a behavioural marker of resilience (e.g., Woods, 2006).

Perhaps one way of dealing with the issue of faint and distributed signals is to extend controllers’ cognitive capacity to quickly identify changing shape of risks using technological artefacts. In many safety-critical systems, auditory and visual warning systems have long been used to support controllers’ ability to detect erroneous or problematic processes. But nowadays, more sophisticated ‘decision support systems’ (DSSs) are becoming ubiquitous (Rasmussen, 1985a, 1985b; Rasmussen & Goodstein, 1987). DSSs are mainly designed to support controllers’ ability to forecast temporal and relational patterns of change under normal, everyday operation as well as when responding to an unexpected disturbance (Chan, 2005). DSSs are particularly necessary in airline operations control given the numerous, complex rules and the cost structures that make it difficult to find feasible solution manually. A substantial body of work has shown that DSSs support controllers’ ability to navigate complex work rules and restrictions in a reasonably good time (e.g., Barnhart et al., 1998). Of course, deploying DSSs in a dynamically changing business environment provides many opportunities as well as challenges. It is, therefore, of interest to this research to understand how the various DSSs in use at the airline operations control centres support and/or limit human actors in their daily work.

3.6.4 Maintaining a constant sense of unease

Another critical marker of resilience relative to the anticipating ability is the ability of human controllers to maintain vigilance even when it appears the system is under control (Dekker, 2011). Given that most modern sociotechnical systems are neither fully tractable nor fully predictable, it is important that human operators remain critical of the ways both anticipated and unexpected events could impact a system, and further maintain a realistic sense of the system’s capability to address such situations (Hollnagel and Woods, 2006). As a consequence of these, complex systems should periodically re-evaluate their position relative to their boundary of functionally acceptable performance (Cook & Rasmussen, 2005). Moreover, the necessity to survive in rapidly changing and complex environments requires that human adaptive systems sustain the capacity for “spontaneous changeability” (Stacey, 1995). There is also a need to explicitly define and classify risks as acceptable or unacceptable and to pre-empt strategies to address a wide range of risky situations.
Anticipatory adjustments are pivotal to future resilience primarily because past experiences and successes are fundamentally flawed predictors of future responsiveness. Hence, past successes should not be taken as the yardsticks for determining future course of action. Custodians of complex sociotechnical systems must, therefore, periodically revise their risk management plans to reflect how work is actually performed given the most recent developments in the system (Hollnagel, Nemeth & Dekker, 2008). They must also maintain the ability to anticipate adequate contingencies and capabilities that are commensurate to current threats facing the system, as well as potential threats that may arise in the future. This requires a realistic assessment of the system’s capability to address the critical and the potential, as well as its ability to recognise when the system is beginning to over-compensate under enormous efficiency pressures (Hollnagel, 2009; Woods & Branlat, 2011a). It would be interesting to uncover how the airline operations control system implements strategies and mechanisms to prevent complacency and to maintain a realistic sense of its ability to deal with the actual, the factual, the critical and the potential (Hollnagel & Woods, 2006; Hollnagel et al., 2011). Table 3.2 presents a summary of resilience markers relative to the anticipating ability.

Table 3.2: Anticipating – Knowing what to expect

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to develop and sustain foresight</td>
<td>Requisite imagination</td>
</tr>
<tr>
<td></td>
<td>Reflective practice</td>
</tr>
<tr>
<td>Quick recognition of global implications of localised threats</td>
<td>Use of cross-checks involving diverse expertise and competencies</td>
</tr>
<tr>
<td></td>
<td>Extending cognitive capacity using technological artefacts</td>
</tr>
<tr>
<td>Maintaining a constant sense of unease</td>
<td>Developing countermeasures against complacency</td>
</tr>
<tr>
<td></td>
<td>Maintaining a realistic sense of abilities</td>
</tr>
<tr>
<td></td>
<td>Being sensitive to the changing shape of vulnerability</td>
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</table>
3.7 Monitoring

The preceding discussion on a system’s anticipating ability have highlighted the need to delineate accurately a model of future operating conditions, and with the model assess the capability of a system to cope under wide-ranging demand variations. Of course, it is important to understand how different forms of demand could stretch system resources and impact its capability to maintain a safe and profitable operation. However, it is even more pertinent to actually detect early signs that a system is starting to decompensate and be able to monitor the changing shape of risks, along with a range of contingencies that is available to forestall extreme degradation (Woods, 2006). In this regard, Sundström and Hollnagel (2011) have suggested three parameters that are necessary for a system to be able to monitor (and if required, control or regulate) such variability in demand or performance:

(i) A view of the system that is being monitored;
(ii) A view of what is to be monitored (e.g., processes, outcomes, resources, interactions); and
(iii) Data and metrics required to perform the monitoring (Sundström & Hollnagel, 2011, p. 186).

Gaining an accurate view of a system requires insight into its structure, culture and functions, including a system’s control architecture, its team communication strategies & processes, functional interdependencies, values and beliefs, etc. (Woods & Hollnagel, 2006). Likewise, monitoring an extremely variable process demands more than just a view of the output of the process; it needs a comprehensive understanding of critical points in the process that are most vulnerable to input variation and changes in the system or its environment (Wreathall, 2011, p. 61). The first two parameters (views of the system and the processes that need to be monitored) have been well elaborated elsewhere in this thesis (cf. Chapter 2). The focus in this section, therefore, is on the third: understanding both the nature and the characteristics of the data and metrics required to perform monitoring.

3.7.1 Desirable characteristics of indicators required for monitoring

Regardless of whether a leading, current or lagging indicator is used, there is a set of desirable characteristics that an indicator should possess in order to effectively support
monitoring of system operations. Following suggestions in the literature (e.g., Hale, 2009; Hollnagel, 2011a; Wreathall, 2011), the following characteristics represent a brief abstraction of the desirable attributes that a well-defined and valid indicator should have:

(i) **Observable**: an indicator should be sufficiently sensitive to even slight changes in system input and/or alterations in the environment. The elapsed period (i.e., time lag) between actions and outcomes should be reasonably low in relation to the timescale at which the system operates, so that controllers can monitor side effects of actions targeted towards addressing specific threats.

(ii) **Perceivable**: it is not just sufficient to observe or notice changes, an indicator should also support quick discernment of emerging patterns of potential threats as well as afford quick comprehension of current operating situations. In other words, an indicator should be simple to understand and easily relatable to key output variables.

(iii) **Quantifiable**: information provided by an indicator must be measurable and can be calibrated with a reasonable measure of accuracy.

(iv) **Objective**: information provided by an indicator should elicit more normative interpretations rather than subjective interpretations that can vary with changes in viewpoints and timescales.

(v) **Accessible**: an indicator should be readily available in forms that do not require specialist discrimination skills or demand high cognitive workload.

(vi) **Reliable**: information provided by an indicator should be sufficiently dependable for making concrete operational decisions and further act as basis for anticipatory, concurrent or remedial adjustments.

### 3.7.2 Behavioural markers of resilience relative to monitoring

Indicators generated in actual operations rarely embody all the attributes described in the preceding section (Hopkins, 2007). For example, the sheer complexity of modern sociotechnical systems and the resultant functional interdependencies—spanning multiple functions and even external organisations—together form a constellation of barriers that mask easy detection of developing threats and opportunities (Perrow, 1984; Rasmussen et al., 1990). As a consequence, operators and controllers are inadvertently exposed to the risk of downplaying or altogether missing warning signs of developing problems (Cooke, 2003;
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Shrivastava, 1995a; Tucker, 1995). The need to avoid missing subtle indicators of potential failure necessitates that controllers keep up with the most current model of situations within the system and its environment (Baker, 2007; Dekker, 2011). However, all is not bad news, as stories of how controllers have successfully adapted to monitoring challenges have also been reported in the literature (Mumaw, Roth, Vicente & Burns, 2000; Vicente, Roth & Mumaw, 2001). It is, indeed, appropriate at this point in the discussion to explore some of the behavioural markers of resilience as well as cognitive strategies that controllers of high-risk operations have employed in dealing with monitoring challenges in complex and adaptive sociotechnical systems.

3.7.2.1 Detecting early signs of decompensation

Decompensation is a term mostly used in medicine and psychology to denote a loss of ability to maintain appropriate defences; in some cases, resulting in abrupt or gradual degradation towards undesirable states (Hartling & Luchetta, 1999; Horowitz et al., 2004). Likewise, complex adaptive systems start to decompensate when their defences are stretched beyond their capacity for coping (Woods & Branlat, 2011a). The notion of decompensation in psychology is, in some respects, analogous to the metaphor of drift toward failure in resilience engineering. For example, both concepts suggest that the ‘bits and pieces’ of events that culminate to eventual failure are not easily visible at the onset; however, they can be easily picked on with the benefit of hindsight (Dekker, 2011). From an airline operations control perspective, detecting early signs of decompensation or drift toward failure may involve noticing that a system’s capacity for future adaptive actions is being (or has been) compromised (Clausen et al, 2010; Kohl et al., 2007), recognising that reserves are being used up much quicker than they can be replenished (Abdelghany et al., 2004), or identifying threat dynamics that could lead to bottleneck or cascading failure (Abdelghany et al., 2008). It is, therefore, not surprising that the ability to notice a gradual and often subtle erosion of a system’s defences has been identified as a critical marker of resilience (Woods, 2009; Woods & Branlat, 2011a). The following discussions highlight some strategies that have been used in both airline operations control and comparable domains to effectively capture early warnings of decompensation and drifts toward failure.

(i) Use of dedicated human-machine monitoring systems

The ancient practice of positioning a watchman on a watchtower appears particularly
significant in this context. Studies of monitoring and supervisory control in cognitive systems (e.g., Mumaw et al., 2000; Sheridan, 1982; Vicente et al., 2001) have highlighted the importance of having dedicated units to monitor both current and future states of a system and its environment. A key advantage of having dedicated monitoring personnel is that they can exploit unmediated signals with their senses that technological systems may not be designed to capture (Vicente et al., 2001). But, a combination of human-machine dedicated monitoring will be of immense ‘synergistic’ advantage to monitoring safety-critical systems.

This premise is buttressed in the fatal crash of Comair Flight 1591 on the morning of August 27, 2006. Dedicated monitoring personnel would have proved a vital line of defence in detecting that the Bombardier Canadair regional jet had taxied to the wrong runway (runway 26) even after the captain had confirmed receipt of clearance to take off from runway 22. Transcript reports suggest that the air traffic controllers on duty attended to other administrative business and, therefore, did not notice the erroneous act. A somewhat similar dynamics was also uncovered in the crash of Singapore airliner SQ006 in Taiwan during a typhoon in 2002. The poor weather condition was blamed for the air traffic controller’s loss of visibility, which consequentially led to an inability to detect erroneous taxiing (again!) to a wrong runway (in this case Runway 05R) after the pilots confirmed the assigned runway 05L. Although bad weather played a role in diminishing visibility, lessons drawn from the review of this accident support the contention that human-machine surveillance support during taxiing could have proven an important line of defence (Flight Safety Foundation, 2002). An example of such surveillance system is the taxiway lighting control system now operational in Changi airport Singapore, with which air traffic controllers can detect deviations and conflicts and then issue revised directives to pilots, such as “to follow the green”. It is claimed that such dedicated monitoring system can “detect conflicts in multiple taxi routes and provide an interlocking system of taxiway centreline and stop bars to resolve conflicts” (Flight Safety Foundation, 2002, p. 10). Such systems are particularly useful for mitigating the dangers of taxiing to the wrong runway during cases of runway closure and the unlikely events of multiple runway re-assignments. Perhaps such dedicated monitoring system would have been instrumental in detecting those ‘erroneous’ actions which, in turn, would have helped in averting both accidents.

Of course, implementing such dedicated lines of defence will increase operating costs in an already economically challenged business environment. Nevertheless, regulators and
controllers of high-risk systems must find ways to balance between investing all cognitive resources in dealing with immediate demands and proactively searching for potential developments that could compromise future adaptive capability (Woods & Branlat, 2011a). Also, during periods of severe or prolonged perturbations such as the 2010 eruptions of Mt. Eyjafjallajökull, roles should be made adaptable in such a way that personnel can be quickly redeployed to dedicated monitoring units to keep track of the turn of events, along with their implications for the system’s performance (Budd, Griggs, Howarth & Ison, 2011). Given a relentless pressure to be cost-effective, it would be interesting to examine how these trade-offs are balanced in an airline operations control context.

(ii) Proactive, knowledge-driven monitoring

Whilst the use of dedicated monitoring systems offer profound advantages in detecting early signs of decompensation, human controllers still need to interpret numerous indicators that are detected. Investigations of nuclear power plant operators reveal that human operators must demonstrate a thorough knowledge of how the system works—its internal structures and modes of operation—to be able to prioritise what to look for at any given period (Mumaw et al., 2000). Moreover, some cognitive system scholars have also suggested that human controllers need to make use of their expertise to diagnose patterns that are indicative of potentially damaging threats long before all requisite ingredients add up (Reason, 1990; Dekker, 2011). A controller’s expertise and experiences are also critical in noticing the changes that are likely to have more devastating effect on future state of the system, the resources and performance indicators that are likely to be affected most, and the contingencies that are available to tackle such escalations. It is also beneficial to know how a system have succeeded or failed in the past when confronted with unanticipated demands that fall outside its base design of operation (Hollnagel, 2011b). Evidence abound in the literature of how operators and controllers in various complex work domains draw from both past experiences of specific events and expert knowledge on how work is actually done—as opposed to how work is designed to be performed—to make sense of developing problems (Dekker & Suparamaniam, 2007; Hollnagel, 1993b; Rasmussen et al., 1990). In other words, they appropriate both “episodic” and “declarative” knowledge (Vicente et al., 2001) in order to compensate for the gaps in the formal descriptions of work. Proactive, knowledge-driven monitoring has also proved useful for correctly interpreting ‘faint’ and ‘diffuse’ signals of developing threats (Axelsson, 2006), which is
critical for preventing loss of control due to more reactive, opportunistic and scrambled responses (Hollnagel, 1993b).

(iii) Clearly defined thresholds and referents

The reactive, messy responses deployed during the 2010 eruptions of Mt. Eyjafjallajökull is a chilling reminder of how a well-anticipated event could degenerate into a complete fiasco when there are no unified understanding of its risks as well as contingencies to deal with the event. The media reported that seismic activities started as far back as end of 2009, yet the air traffic management authorities within the EU zone did not consider proactively validating their contingency plans until the volcano finally erupted in March 2010 (Birtchnell & Büschner, 2011; Budd et al., 2011). As a consequence of a lack of clearly defined threshold for risk assessment and a commonly agreed referent for validating potential impact, more than 100,000 travellers were heavily inconvenienced and the commercial air transport sector incurred over 1.7 billion US dollars in lost revenue (Budd et al., 2011).

Clearly, there is need to have well-defined thresholds for actions and inactions in relation to most anticipated threats. Bergström and colleagues explain that cooperating units need to agree on certain pre-set thresholds, and also share commonly agreed referents for determining alternative courses of actions should they be confronted with a rapidly changing situation or events that fall outside the pre-set thresholds (Bergström et al., 2011). As depicted in the Eyjafjallajökull eruption saga, a major challenge to cross-functional and cross-organisational collaborative responses is redefining thresholds on-the-fly when imminent threats fall outside of the base model for which the referents were designed. This challenge suggests that collaborating organisations and subgroups need rigorous mechanisms not only to monitor potential threats as they evolve, but also to maintain explicit goals and shared understanding of probable implications across all units concern. Although it is not necessary that all units partake in every decision making (see argument in Bergström et al., 2011), all units need to agree on pre-defined roles and responsibilities in relation to the collective response plans to avoid the potentiality of ‘working at cross-purposes’ with each other (Cedergren, 2011; Woods & Branlat, 2011a). Unfortunately, conflicting purposes and plans across air traffic management authorities were very prominent in the catastrophic fiasco that ensued following the volcanic eruption (Budd et
al., 2011). It is important to note that such thresholds—like operating points in Rasmussen’s dynamic safety model—are hard to see and are also hardly static in practice (see Rasmussen, 1997; Rasmussen & Svedung, 2000). Nevertheless, having clearly defined thresholds can serve as a basis for cross-functional knowledge elicitation, and in turn support more effective predictions as to whether a developing problem will stay within (or fall outside) the defined boundary for anticipated threats. Table 3.3 summarises key behavioural markers of resilience relative to monitoring as have been highlighted.

Table 3.3: Monitoring – Knowing what to look for

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detecting early signs of decompensation</td>
<td>Use of dedicated monitoring systems</td>
</tr>
<tr>
<td></td>
<td>Proactive, knowledge-driven monitoring</td>
</tr>
<tr>
<td></td>
<td>Having clearly defined thresholds and referents</td>
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</table>

3.8 Learning

There are many aspects to learning when studying how organisations accumulate, share and apply knowledge in their everyday operations. In view of the many interpretations and meanings that have been presented in the literature of organisational learning, it is important to first explain key constructs, terms and assumptions that underpin the discussions in this section. Learning is viewed as an on-going construction of knowledge through private or collective inquiry of the fundamental assumptions and theories that underpin the organisational routines, including the rules, procedures and norms on which work practices are based (Argyris & Schön, 1978). It feeds into the cumulative knowledge and competences that exist within an organisation (Levitt & March, 1988). Organisational knowledge is mostly acquired through individual learning (Brown & Woodland, 1999; Herdberg, 1981), and shared through employee-to-employee interactions (Polanyi, 1962, 1966) as well as through formal, knowledge creation processes (Nonaka, Byosiere, Borucki & Konno, 1994; Nonaka, von Krogh & Voelpel, 2006). The shared knowledge is stored as rules, procedures, norms and practices that define corporate transactional patterns and
codes of conduct among its members (Lam, 2000; Levitt & March, 1988). Although this conception takes a cumulative view of organisational knowledge, it does not necessarily imply that organisational knowledge is the sum of individual member’s knowledge in an organisation (Argyris & Schön, 1978; Herdberg, 1981). Rather, organisational knowledge is seen as an emergent property of an organisation, which is shaped by both active and latent mechanisms by which individual assumptions and experiences are translated into collective knowledge (Glynn, 1996).

A corollary of this view of organisational learning is that the notions of organisational memory and collective mind do not refer to concrete or reified cognitive abilities possessed by an organisation, as has been suggested (e.g., Sanderlands & Stablein, 1987). On the contrary, both terms are used as metaphors to represent respectively the underlying knowledge that is encoded or embedded in the organisational routines and processes (Levitt & March, 1988) and the unwritten rules that defines “heedful interrelations of actions” in an organisation (Weick & Roberts, 1993). Individual knowledge is transferable, but given that knowledge resides in an individual, it can also move with the individual as they traverse through different organisational units and across organisations (Lam, 2000). Hence, individual learning could be lost if not encoded into a more accessible routine, particularly with turnover of personnel through time (Argyris & Schön, 1978). This premise is exemplified by the case-study of Henry Black, a soon-to-retire vaccine R&D expert, who disseminated his knowledge to a number of individuals. But, the recipients—fuelled by an organisational culture that does not recognise knowledge as a manageable resource—chose to internalise their learning for personal gains. This consequentially led to individual knowledge being appropriated for purposes of control and defence with little production of new knowledge (Brown & Woodlands, 1999). This example buttresses the argument that while individual learning is a necessary step towards developing a rich organisational memory, it can only enrich collective knowledge if there are adequate mechanisms in place to codify such knowledge in ways that make them more accessible to relevant employees regardless of personnel turnover or passage of time (Levitt & March, 1988).

However, the notion of learning in itself is an extensively studied but highly contested concept, and also demands a clear articulation of the underlying assumptions of learning as they apply to this study. The cognitivist school of thought argues that learning may result in observable conceptual change but not necessarily a behavioural change (Friedlander 1983
cited in Huber, 1991; Marton & Booth, 1997; Tennyson & Rasch, 1988). The behavioural theorists, however, contend that learning can only be said to have occurred when there is an observable change in behaviour, perhaps a change in the way work is performed (Argyris & Schön, 1978; Cyert & March, 1963; Brown & Duguid, 1991; Fiol & Lyles, 1985). The constructivist theorists, for their part, posit that learning in organisations involves active construction of new knowledge mediated by social milieu and organisational context in which work is performed (Giddens, 1976; Gioia & Sims, 1986). One implication of the social view of learning seems to be that people in different organisations can learn differently depending on the culture and other social factors that influence work practices in their respective work groups (Douglas, 1987).

Assessing changes in cognition as a way to measure learning in complex sociotechnical work settings poses some serious challenges, not the least of which is the difficulty in capturing tacit or ‘difficult-to-articulate’ knowledge using current methods like questionnaires and verbal protocols (Argote, 2013; Hodgkinson & Sparrow, 2002). There is ample evidence to suggest that people, in many cases, find it hard to clearly articulate how they carry out their tasks (Polanyi, 1962, 1966). Studies have further highlighted concerns with using verbal protocols and descriptions of mental activities (Ericsson & Simon, 1993). It is also safe to assume that the distributed nature of cognition in large-scale, sociotechnical systems will inevitably exacerbate the difficulty in conducting accurate assessment of meta-knowledge across the different parts of an organisation (Brauner & Becker, 2006). Of course, an organisation can develop a conscious awareness of relationships as well as learn about its environment without obvious change in practice (Friedlander, 1983). However, such learning would be difficult to measure when there is no “hard” evidence that the learning actually took place rather than in the minds of individual members. Therefore, assessing changes in cognition as a measure for learning in organisations is inadequate, particularly when the focal interest is on explicit behaviours and work practices that support system’s or organisational resilience.

By contrast, measuring changes in behaviours and work practices can easily bring to light difficult-to-articulate or “tacit” knowledge (Polanyi, 1962). However, this proposition incites another argument regarding whether learning must be beneficial to an organisation as to warrant a change in behaviour. Considering that the main domains of application that are relevant to this research are under perennial cost and safety pressures, it seems
appropriate to adopt a stance that learning must contribute to improved practice to count. It follows, therefore, from these arguments that the behavioural and the constructivist approaches appear to be more appropriate for assessing how local actors and organisations construct learning from their experiences (Cyert & March, 1963; Gioia & Sims, 1986). A corollary of this premise is that the application of learning is mainly purposive and tends to influence behaviours more positively (Dodgson, 1993). People can learn unintentionally, but the focus of learning here is the intentional dimension of learning, that involves purposeful internalisation, externalisation, combination, and socialisation of knowledge in order to improve the way work is performed (Nonaka et al., 1994).

Further, it is a truism that people and organisation alike learn from both success and failure, and supporting evidence for this supposition has been widely published (Fisher & Burrow, 2003; Starbuck & Farjoun, 2005). Consequentially, our interpretation of organisational learning presumes that learning is demonstrated behaviourally and, in the grand scheme of things, contributes to the learner’s effectiveness regardless of whether the direct outcome of learning is negative or positive. The latter assumption is buttressed by the reasoning that a failed experimentation or product testing can still provide useful lessons to an organisation (see Hale’s (2009) and Dyreborg’s (2009) arguments on safety indicators in Section 3.6.1).

Correspondingly, some behaviours that are of interest to this research include how an organisation develops and progressively adapts routines around which their work practices are constructed (Levitt & March, 1988); how individual experiences are captured and translated into institutionalised experience (Yelle, 1979); how shared assumptions are developed and questioned when necessary (Argyris & Schön, 1978); how an organisation learns to adapt to changes in its environment (Cyert & March, 1963); and lastly, how the gains of learning is fed back into work practices and routines (Brown & Duguid, 1991).

### 3.8.1 Ontological and epistemological dimensions of learning

Lam (2000) characterised the nature of knowledge using two dimensions: the ontological dimension (individual or collective) and the epistemological dimension (explicit or tacit). The interaction between the two dimensions produced four pertinent constructs that are useful for elucidating how knowledge exists in organisations. The discussions in this
section appropriate these constructs to explore the various challenges posed by each form of knowledge.

At the individual level, *embodied* knowledge (individual-tacit) represents those tacit or difficult-to-articulate operational skills and know-how possessed by individual members (Polanyi, 1962). It is acquired through practical experiences in the relevant context, by doing rather than by formal indoctrination (Polanyi, 1966). It is action-oriented, heavily automatic and has a personal quality that makes it difficult to formalise or communicate (Lam, 2000). It does not usually fit into a conscious or ‘rationalised’ decision-making schema (Spender, 1996). Transfer of tacit knowledge requires close interactions and the build-up of shared understanding and trust between the one who possesses the knowledge and the recipient (Lam, 2000; Polanyi, 1966). As a result, it is the most ‘at risk’ form of knowledge in an organisation, as it is prone to lost with turnover of personnel. By contrast, *embrained* knowledge (individual-explicit) is more abstract theoretical knowledge acquired through a formal education or training system. It depends on individual’s conceptual skills and cognitive abilities. Unlike tacit knowledge, this form of knowledge can be codified more readily or deduced from formal, scientific theorems without the need for a specific knowledge expert (Lam, 2000). In addition, it is much easier to communicate and transfer than tacit knowledge.

On the organisational side of things, *embedded* knowledge (collective-tacit) refers to an emergent form of knowledge (e.g., unwritten rules in routines) that helps to shape organisational norms and codes of how work is actually performed in an organisation, as opposed to prescribed rules. It is reflected in collective idiosyncrasies along with shared beliefs and understanding within a community of practice. It is organic and dynamic, and capable of supporting effective communication and complex patterns of interactions in the absence of written rules (Lam, 2000). Embedded knowledge mirrors Weick and Robert’s conceptualisation of “heedful interrelation of actions” or the notion of ‘collective mind’ in an organisation (Weick & Robert, 1993). Transfer of embedded knowledge requires contextual socialisation and informal indoctrination of the ‘way work is done around here’ (Lam, 2000; Levitt & March, 1988). The risk of losing this form of knowledge is higher when there is a generational turnover of personnel, whether a mass retirement of older members or a mass influx of new personnel. On the other hand, *encoded* knowledge (collective-explicit) represents ‘objectified’ knowledge conveyed by signs and symbols (e.g.
hard information indexed and stored in an organisation’s knowledge base, written rules and procedures). It tends to generate a unified and predictable pattern of behaviour and output in organisations. The abstraction of individual’s experience and knowledge into encoded knowledge also facilitates centralisation and control in organisations. However, encoded knowledge is not without its disadvantages in that it is inevitably simplified and selective, and for the most part fails to capture and preserve the tacit skills and judgements of individuals (Lam, 2000).

3.8.2 Learning loops

Learning occurs as human agents reflect on the values, policies, objectives and other contextual factors that inform their everyday actions (Schön, 1983). From this perspective, the level of learning achieved is largely contingent on how far people—motivated by the learning culture in their organisation—are willing to question the cognitive maps that guide their understanding of how success is achieved. It also depends on people’s ability to bring under scrutiny other peripheral factors (such as corporate values, theories and assumptions) that guide the sets of actions taken or at least that influence action selection processes (Argyris, 1992). Along this line, Argyris & Schön (1978) have popularised the notions of single-loop, double-loop and deuteron learning. Collectively, these provide a good representation of the different levels of learning that an organisation can achieve.

Single-loop learning is said to have occurred when local experts modify the means (a set of actions) required to get to an intended outcome, most probably following an observation that the prescribed rules do not apply in certain context. The strategy developed in the process can then be reapplied whenever the challenge and its variants reoccur. What differentiates single-loop learning from the others is that it only questions the appropriateness of current practice, thereby allowing the practice to be corrected or modified within the bounds of an established policy (Argyris & Schön, 1978). In resilience engineering parlance, it can be said that organisations operating on the single-loop level are those that are content with finding ways to deal with the consequences of situations rather than seeking ways to address the more systemic factors that brought them forth.

By contrast, double-loop learning not only requires questioning the means taken to achieve a specified outcome. Beyond that, it encompasses a critical review of the assumptions and
models on which actions are based, thereby eliciting a higher level knowledge that could be useful for revising policies, protocols or even corporate objectives. Double-loop learning is distinctive from the single-loop learning in that it encourages a shift in the frame of reference or theoretical lens that underpins current practice (Argyris & Schön, 1978). Thus, new strategies and objectives that transcend current policies and protocols can be developed, either as extensions of current rules that prescribe how work should be done or as replacements. A hypothetical example would be an organisation that initiates a major investigation of its incident reporting protocols to ascertain whether it is in fact founded on a valid model or assumption. Work appraisals that not only focus on “root cause”, but also explore systemic factors and seek broader explanations for their findings fall under this category of learning.

But beyond using learning to identify and address systemic problems, deuteron learning requires a periodic appraisal of the systems and structures that facilitate learning. In this sense, the learner reviews previous episodes of learning or failure to learn through a systematic reflection on the appropriateness of the actions taken in light of what the outcomes could have been if different actions were taken. More importantly, the learner questions the underpinning models of learning and seeks alternative explanations—the second stories behind the fact (Woods & Cook, 2002; Woods et al., 2010)—that could disconfirm current conceptions that drive learning in the organisation. In the process, new knowledge is produced about how the learning system in place facilitated or inhibited a more comprehensive understanding of the events reviewed. Modifications are then made as necessary in order to improve the quality of learning in the organisation (Argyris & Schön, 1978, p. 4). In a sense, a successful application of deuteron learning could result in a paradigm shift that can revolutionise the state-of-play in an industry, and raise new industry leaders. The rise of Apple in mobile communication technologies, Facebook in social media, and Microsoft in the world of computing, are a few examples of recent shifts in thinking that not only orchestrated change in industry leadership, but also changed the dynamics of play in their respective industries.
3.8.3 Learning from Experience

This section captures some factors that influence experiential learning. The factors covered include the novelty of experience, ambiguity of experience, spatial location of experience, timing of experience with reference to an event, frequency of experience, and recency of experience. These factors are used in this section to ground the notion of ‘experiential learning’ in organisational studies within a resilience engineering framework.

3.8.3.1 Novelty of experience

A novel situation has a way of radically challenging and reshaping current frames for learning and paradigms used for interpreting experiences. Particularly, in practices where irregular operation is the norm, there is a continual struggle to balance between refining a known protocol (often reactive and incremental) and exploring new possibilities more proactively. The literature on experiential learning offers two learning practices that are employed by organisations as a way of strengthening their preparedness for both routine and novel events: “exploration and exploitation” (March, 1991). It is generally accepted that exploration relates to learning gained through experimenting new ideas and new ways of performing work (He & Wong, 2004; Katila & Ahuja, 2002), while exploitation (although contrary views have been argued) represents learning gained in the process of refining and adapting routine knowledge to other familiar situations (Benner & Tushman, 2003). Notwithstanding the lack of agreement in definitions, a more beneficial question appears to be whether these two practices are complementary or antagonistic to each other (March, 1991). A corollary of this debate is whether pursuing exploration and exploitation concurrently or intermittently will be more beneficial to an organisation. To this end, March (1991) argues that organisations that engage more in exploration with less attention to exploitation will probably be more adaptable to new situations, but at the present, risk high costs of experimentation without necessarily gaining many of its benefits. On the other hand, organisations that favour exploitation over exploration are very likely to be proficient and well adapted in their routine tasks. However, they run the risk of being trapped in their local knowledge space with a consequential loss of adaptive capability in the face of a new situation (p. 71). In many aspects, March’s argument echoes similar sentiments that have been vigorously emphasised in the resilience engineering literature (Pariès, 2011a; Woods & Branlat, 2011a).
With regards to the strategy that is most appropriate for balancing the trade-offs between exploration and exploitation, studies in organisational learning have proposed ‘*ambidexterity*’ and ‘*punctuated equilibrium*’ (Benner & Tushman, 2003; Burgelman, 2002; Christensen, 1998; Levinthal & March, 1993). Ambidexterity refers to “the synchronous pursuit of both exploration and exploitation via loosely coupled and differentiated subunits or individuals, each of which specializes in either exploration or exploitation” (Gupta, Smith & Shalley, 2006, p. 693). In contrast, punctuated equilibrium relates more to “temporal cycling between long periods of exploitation and short bursts of exploration” (Gupta, Smith & Shalley, 2006, p. 698) with no organizational differentiation or specialized units attending to either. Given the possibility of multiple demand situations occurring concurrently in airline operations control, it would be interesting to gain insight into how airlines address the need to develop expertise for dealing with novel challenges and the need to develop more sophisticated routines for everyday functioning. More specifically, how the need for balance informs resource assignment strategies for the purposes of learning and control.

### 3.8.3.2 Ambiguity of experience

Learning in organisations involves a series of interactions between adaptation at the individual or subgroup level and adaptation at the organisational level (Cangelosi & Dill, 1965; Prange, 1999). Such heedful interrelation most times results in a shared understanding or collective mind about a situation (Weick & Roberts, 1993). In other cases, however, it is much more difficult to comprehend what has happened, which makes it hard to interpret causality—or to determine success or failure—due to ambiguous feelings that certain experiences arouse (Levitt & March, 1988, p. 323). The likelihood of drawing incorrect inference from such interactions are confounded when there the different parties involved adopt different frames of references, or when there is fragmentation of experience across individuals, subgroups and the broader organisation (March, 2010). Nevertheless, people still propose explanations because of bureaucratic pressures to find “answers”, despite ambiguity in causality (Dekker & Suparamaniam, 2007). Levitt and March argue that organisations tend to relapse into “superstitious learning” and blind specification of targets, when the processes that produce successful outcomes become increasingly unclear (Levitt & March, 1988). The lack of clarity could potentially lead to target specifications that are either too conservative or too optimistic. Furthermore, delays between actions and outcomes make causality more ambiguous to interpret and, in turn,
increase the likelihood of incorrect attributions and inferences from an experience (Bohn, 1994; Repenning & Sterman, 2002). An interesting line of inquiry is to learn how airlines verify the appropriateness of the performance targets they set, as well as the contributions of historical records of past successes, past targets, past failures, and other related factors, to an organisation’s ability to monitor and regulate its performance targets.

### 3.8.3.3 Spatial location of experience

The spatial location of experience is described relative to geographic and functional distribution. Functionally, experience can be loosely or tightly coupled across different subgroups, each with specialized knowledge on an aspect of the operation. Geographically, experience can be concentrated at one centre of control or distributed across geographic locations. In other words, subgroups are either collocated at the same facility or distributed across geographic locations. Organisations usually adopt various mixes of these attributes depending on the nature of their operations. Notwithstanding, each of these attributes has implications for organisational learning in complex sociotechnical systems.

Organisations typically rely on informally shared understandings of experiences and skills gained on the job (Dekker, 2003, Polanyi, 1966). Inferences drawn from such tacit knowledge are more often recorded in the culture of organisational stories and in the shared perception of “the way things are done around here” (Levitt & March, 1988). Loose coupling of functions, even though it acts as buffer to prevent cascade of undesirable effects, leads to a number of learning issues including (i) a likely situation where different subgroups are affected by an event in different ways thereby generating different experiences; and (ii) a likely situation where different subgroups draw inconsistent inferences from the same experience (Levitt & March, 1988). Likewise, control centres that are distributed may have more access to local knowledge, but might have issues with knowledge sharing across the entire operations-control system (Ahuja & Katila, 2004; Cramton, 2001). These conditions could easily generate disagreements over interpretations of routines and formal procedures, which could in turn incite different subgroups to develop alternative stories that interpret the same experience quite differently. Subculture can develop in the process as stories turn into histories and histories encoded into formal routines of how things are done in those subgroups (Levitt & March, 1988, p. 324).
From a learning point of view, it is of interest to this research to investigate the nature of relationships and shared interpretations that exist among subgroups relative to their positions in the operations-control network; that is, the relationships between subgroups in a geographically collocated centre and those that are outside the centre. It is important to highlight that variances in interpretations is not necessarily a bad thing. According to resilience engineering studies, variances are necessary for the development of alternative stories that may, at some point, call into question widely held beliefs and long standing organisational cultures. Indisputably, wide variances in interpretation will easily engender disagreements and distrust, but sameness in interpretation will quickly degenerate to “group think” (Janis, 1972), leaving an organisation with little or no means to monitor its assumptions. How to balance between these two options is an open question, but one that has serious implications for organisational learning.

### 3.8.3.4 Frequency of experience

The frequency of events is broadly classified as high-probability-low-impact (HPLI) event and low-probability-high-impact event (LPHI). LPHI events have a way of attracting organisational attention as a basis for learning, probably due to their implications for safety and business continuity (Leveson, 2011; Pariès, 2011b). One benefit of LPHI events is that they reveal how prepared organisations are in dealing with the unexpected (Rerup, 2009; Starbuck, 2009). More importantly, they challenge current conceptions of threats and elicit a more rigorous assessment of current strengths and weaknesses relative to newly identified threats and their possible variants (Christianson, Farkas, Sutcliffe, & Weick, 2009). It is also likely that such insights may encourage reflections on whether future risks and their associated costs are affordable (Leveson, 2011).

However, the limitations of over-relying on LPHI events as basis for learning are also clearly evident. Hollnagel’s “conditions for learning” posits that an event needs to occur with a sufficiently high frequency for it to be considered suitable for learning (Hollnagel, 2011b, p. 193). Hollnagel contends that rare events do not always provide the right experiences for learning, one of the reasons being the likelihood that some of the lessons learned must have been forgotten before a similar situation reoccurs (pp. 193-194). This stance parallels similar concerns that rare and infrequent experiences present significant challenges to learning as they are, for the most part, hard to interpret (Lampel, Shamsie, &
Shapira, 2009; March, Sproull, & Tamuz, 1991). It could be inferred from March and Levitt’s discussions that one of the many possible explanations for the difficulty in interpreting infrequent experiences could be linked to how organisations encode, store and retrieve lessons of experience over time (Levitt & March, 1988). An observation made by Levitt and March (1988) is that organisations learn by encoding inferences from history into routines that guide behaviour. With turnover of individuals that actually witnessed the events of history, emotional attachment to lessons of history gradually wears off. And as time passes, history becomes increasingly inaccessible while routines become more pronounced. However, routines are subject to continual adaptation in response to local pressures, short-term productivity goals, and as new experiences come to light (Rasmussen, 1997). Gradually, the essence of some historical lessons is lost in the process, resulting in confused interpretation of history and difficulty in untangling facts from myths when a similar event reoccurs in the future (Levitt & March, 1988; Zollo, 2009).

Nevertheless, there is another side to this frequency story that is of interest to the study of resilience. Organisations tend to be more proficient in dealing with highly frequent events, prompting them to rehearse specific set of routines more than others. As Levitt & March (1988) observed, the success of those routines in coping with more frequent events, in turn, increases their frequency of adoption. As a result, less attention is reserved for exploration and for developing the organisation’s competency with regards to alternative (and possibly better) routines. The successful outcomes, however, holds some pitfalls in that organisations become entangled in a competency trap, where “favourable performance with an inferior procedure leads an organisation to accumulate more experience with it, thus keeping experience with a superior procedure inadequate to make it rewarding to use” (Levitt & March, 1988, p. 322). The potentiality of a competency trap introduces yet another fascinating challenge and ambiguity to learning in organisations.

3.8.3.5 Timing of experience

Timing of experience relates to the period an event that triggered an experience occurred; that is before, during or after an actual event that requires its application. Experience can be gained prior to an incident that demands its application (Carrillo & Gaimon, 2000; Pisano, 1994). Evidence from organisational studies also suggests that cumulative experience can be acquired on the job over a period of time (Argote et al., 1990; Dutton &
Thomas, 1985). There is also the notion of post-mortem experience, where experience is gained through analysis of a past event (Ellis & Davidi, 2005). Nonetheless, the focus of the discussion here is whether learning exercises that are designed to enrich personnel knowledge and experiences are deployed prospectively (before an event that requires its application) or retrospectively (after such an event has occurred).

Retrospective learning tends to be more common in organisations, as people tend to search for alternative routines when there are clear signals that the current routine is becoming inadequate to cope with the evolving nature of threats facing the system (Huber, 1991). Given the costs associated with learning, some scholars have advised that efforts directed toward solving a problem or capitalising on an opportunity be viewed as having a satisfactory probability of success (e.g., Schwab, Ungson & Brown, 1985). Not surprisingly, some scholars have gone as far as proposing that search-prompting signals have to be very loud and received from multiple sources before a search can be justified (Ansoff, 1975). A contrasting view based on research in high-risk safety-critical systems cautions, however, that waiting for “loud” signals before responding to a situation can be very risky, especially if the situation is deteriorating rapidly but the signs are diffused across the system (Woods, 2011). Lessons constructed from real-world cases have shown that waiting for loud signals will, very likely, lead to scrambled control and in some cases total loss of control with dire consequences (Hollnagel, 1993b; Leveson, 2011; Rasmussen, 1997).

By contrast, prospective learning offers the advantage of exploring what happens and how changes in the environment could potentially influence the state-of-play in the system (Hollnagel, 2011b). Axelsson’s findings evince that organisations need to develop the ability to pre-emptively sense weak signals of developing problems and be able to deploy agile learning strategies to cope with possible new situations well before they eventuate (Axelsson, 2006). Other studies have equally discussed how organisations applied prospective learning approaches in the form of experimentation and training drills to test the limits of their routines, explore new routines, assess their adaptability to fast changing and unfamiliar environments, and develop other technical and transversal skill-sets (Hedberg, Nystrom & Starbuck, 1977). Organisational self-appraisals across and within subgroups have also proved useful for developing shared understanding of the subcultures within different subgroups, understanding of the different interpretations that exist in different subgroups, collective view of how work should be performed and an opportunity
to reflect on how the different subgroups could interrelate more productively (Argyris, 1983; Deary 1983; Peters & Robinson, 1984; Shrivastava & Schneider, 1984).

The overwhelming emphasis on more proactive approaches notwithstanding, prospective learning do present some challenges of its own. The dynamics of some task structures are so complex that it is hard to adequately capture using simulated exercises. Moreover, real-world experimentation is not always an option in some contexts given myriad risks and costs factors. For example, one cannot adequately rehearse for or carry out proper military combat that encapsulates the full emotions and sense of danger involved in real war scenarios. Of course, risk analysis tools, such as HAZOP and simulation software, may be of some use for prospective learning, but they still cannot remove completely the uncertainty surrounding the nature of the next challenge event (Brehmer & Dörner, 1993). Therefore, it would be interesting to investigate how organisations deal with such limitations in learning prospectively, along with how they reconstruct lessons from past events to fit prevailing and future conditions.

3.8.3.6 Recency of experience

The recency of experience relates to the distance-in-time of an experience relative to a situation that requires its application. The recency-effect theory proposes that more recent experiences are recalled faster and perhaps clearer than more distant ones (Bjork & Whitten, 1974). An individual’s ability to retrieve knowledge from past experience is governed by the cognitive processes that bring about recall and forgetting. An item of experience is committed to long-term memory through an elaborative rehearsal process (Goldstein, 2011). The memories are then encoded by way of connections and associations to related cues, as well as prior semantic and episodic knowledge in the long-term memory (Howard & Kahana, 1999; Raaijmakers & Shiffrin, 1981). However, experiences committed to long-term memory are subject to decay resulting from a natural forgetting process (Thorne & Henley, 2005). As a result, the connections, cues, or associations to an item of experience deteriorate with the passage of time exacerbating the difficulty to retrieve relevant experiences from ‘long-term memory’ (Atkinson & Shiffrin, 1968).

The recency effect also has similar impact on the broader organisation, because the collective knowledge in an organisation still depends on an individual’s ability to recall routines that are not captured in formal rules and procedures (Hastie et al., 1984; Johnson
& Hasher, 1987). As argued earlier, knowledge can be lost from an organisation’s active memory as more experienced personnel leaves the organisation and as histories that shape organisational norms depreciate over time (Argote, Beckman, & Epple, 1990; Benkard, 2000; Darr et al., 1995; Neustadt & May, 1986). Unless the implications of experience can be transferred from those who experienced it to those who did not, the lessons of history are likely to be lost through turnover of personnel (Levitt & March, 1988). As with the frequency case, it has also been found that organisations have difficulty retrieving relatively old, unused knowledge or skills (Argote et al., 1987). It is, therefore, necessary to elucidate the antecedent conditions that influence the rate of depreciation of experience in an organisational context.

### 3.8.4 Antecedent conditions and basis for learning

The discussions on learning have so far highlighted a number of issues and gaps that are of interest to this research and to organisational learning in general, with particular view on how different attributes can influence the ability of individuals, subgroups and organisations to learn from their own experiences. However, it has not really addressed the issue of the kind of experience on which learning in organisations should be based. In order to gain a comprehensive understanding of what has happened, what happens and what will happen, proponents of resilience engineering, for the most part, have argued vigorously that it is more reasonable to adopt successful experiences (what goes right) rather than catastrophic failures and accidents as the basis for learning (e.g., Hollnagel, 2011b). Along this line, Hollnagel proposed three antecedent conditions for learning:

(i) Situations that are used for learning must occur with a sufficiently high frequency to create reasonable opportunities for learning;

(ii) The situations must sufficiently similar or be comparable in some sense to allow generalisations to be made; and

(iii) There must be sufficient opportunity to verify that the right lessons have been learned (Hollnagel, 2011b, pp. 193-194).

The reasoning behind the advocacy for a shift-in-thinking—that is, from a focus on what goes wrong, to a focus on what goes right—is not unfounded. Accident investigations do not always provide useful information that supports a comprehensive understanding of
how a system normally functions (Hollnagel, 2008). In some occasions, they can confound what is known about the underlying processes that lend some degree of resilience to everyday functioning. This was the case with the attribution of human error in the interactions involving human and machine agents, making humans the villains rather than heroes that make up for gaps in poor designs (Rasmussen, 1982, 1983; Reason, 1990). Such attributions led to theories that view humans as sources of brittleness rather than of resilience and, in the process, concealed how latent factors and systemic conditions combine to complicate everyday functioning in the lead up to an accident (Hollnagel, 1983). The masking occurs because the outcome of most accident investigations are often influenced by the theoretical views or frames-of-reference adopted in the investigation, a phenomenon that has been described with the phrase “what-you-look-for-is-what-you-find” (WYLFIWYF) (Lundberg et al., 2009). An inevitable consequence of the WYLFIWYF factor is that investigators tend to search for evidence that confirms their theory and to discount alternative explanations and evidence that might disconfirm it—a phenomenon that has also been described as “distancing through differencing” (Cook & Woods, 2006). Moreover, investigations of major accidents are typically fuelled by bureaucratic pressure to find ‘root causes’ and construct explanations for events that are yet vaguely understood and perhaps still evolving. As a consequence, accident investigations tend to easily degenerate to “hunting broken components” and “finding culprits responsible for the mess” rather than on constructing broader systemic lessons that will be useful for developing more resilient defences against reoccurrence (Dekker, 2011). Paradoxically, findings from major accident investigations at times tend to bias what we know of the present and what we think of the future (Hollnagel, 2008).

Due to scope restrictions, it is not necessarily the intention of this study to investigate empirically all the issues and questions raised in relation to learning in organisations. Perhaps the findings from this study will provide some hints for progress and future work in some of those directions. The agenda for now is to understand the basis and antecedent conditions for learning in light of concrete manifestations of learning in practice. The analytical strategy is to maintain an open mind as much as is necessary to call into question current assumptions of what constitutes effective learning in organisations. Behavioural markers of resilience in relation to learning have been abstracted from the discussions in Section 3.8 (Table 3.4) and will be applied as a starting point for data collection.
Table 3.4: Learning – Knowing what has happened

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
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<tr>
<td>Having the right basis for learning</td>
<td>Maintaining the capability to learn from the right experiences</td>
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<tr>
<td></td>
<td>Having adequate mechanisms for capturing and translating an individual’s tacitly developed knowledge into institutionalised routines</td>
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<tr>
<td></td>
<td>Maintaining a rigorous protocol for verifying that the right learning has indeed occurred</td>
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<tr>
<td>Openness to contrary views and alternative explanations</td>
<td>Maintaining the ability to develop and question shared assumptions and interpretation of routines</td>
</tr>
<tr>
<td></td>
<td>Maintaining the ability to question the frames-of-reference that underpin current routines and work practices</td>
</tr>
<tr>
<td></td>
<td>Maintaining the ability to question the means taken to achieve specific outcomes</td>
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<tr>
<td></td>
<td>Maintaining the ability to question the underpinning models of learning</td>
</tr>
<tr>
<td>Capability for continuous learning</td>
<td>Recognising knowledge as a manageable resource</td>
</tr>
<tr>
<td></td>
<td>Recognising the need to learn new ways to adapt</td>
</tr>
<tr>
<td></td>
<td>Maintaining the right balance between exploratory and exploitative learning</td>
</tr>
<tr>
<td></td>
<td>Maintaining the ability to avoid extremes between a widely varied interpretation of routines and group-think</td>
</tr>
<tr>
<td></td>
<td>Periodic appraisal of the systems and structure that facilitate learning</td>
</tr>
<tr>
<td></td>
<td>Maintaining the ability to feed back the gains of learning into work practices and routines</td>
</tr>
</tbody>
</table>

3.9 Conclusion

In this chapter, the meaning of resilience was explored by taking a deep look into the various concepts, notions, argots, and metaphors that have been developed across six research fields. The goal was primarily to gain understanding on how resilience can be conceptualised within a sociotechnical framework and perhaps, in the process, uncover subtle oversights and limitations in current formulation of resilience in safety-critical systems. Descriptions and representations of resilience embedded within a diverse range of
practices were then examined, which in turn provided a theoretical foundation for the field investigations, and will further serve as an explanatory framework for making sense of the field results. More broadly, the discussions in this chapter may be summed up as reflections on how a system regulates its everyday functioning to meet pre-specified targets without drifting into a zone of functionally unacceptable performance; how local adaptive actions (on one hand) provide a leverage for resilience in highly fluid operations, but (on the other hand) sometimes combine in incomprehensible ways to erode global resilience; how resilience is maintained through dynamic balancing acts in the face of unremitting safety and production pressures; and how a system learns to anticipate a model of its future from current operating conditions along with its past successes and failures.

In light of finding new ways to engender resilience in frontline operations, a promising research agenda would be to capture new degrees of freedom originating from the dynamics of inter-relations between frontline controllers and their supervisors. It is the supposition of this thesis that such degrees of freedom would improve the ability of frontline controllers to wade through myriad challenges inherent in the AOC system, and yet be able to exploit new or emergent opportunities in the system. In addition, there are certain assumptions highlighted in the literature of organisational studies that are of interest to this resilience study. Of particular interest are the observations of behavioural patterns in organisations that underpin James March’s discussions relative to ‘organisational learning’ (see Levitt & March, 1988, p. 320). In summary, Levitt and March posit that organisational routines are based on the interpretations of the past more than anticipations of the future. This proposition suggests that organisational actions are heavily history-dependent rather than future-focused, and are therefore adapted incrementally in response to feedback from outcomes. Ostensibly, this proposition has very serious implications with respect to their contributions to the resilience, or otherwise brittleness, of a system. They are, therefore, worth exploring in greater depth through the lens of the resilience engineering framework: first, to elucidate how these assumptions play out in light of the challenges posed by weak predictability and the associated intractability of complex and rapidly evolving operations; and second, to confirm or otherwise disconfirm the assumptions in part or whole.
CHAPTER 4

RESEARCH DESIGN AND METHODOLOGICAL CONSIDERATIONS

The physical features and characteristics that one person focuses upon as being significant determinants of someone else’s attractiveness are (thankfully) open to a great deal of individual variation within which any one conclusion cannot be said to be ‘more correct’ than the other.

Ernesto Spinelli (2005), on the Equality of Truths

To every object, there correspond an ideally closed system of truths that are true of it and, on the other hand, an ideal system of possible cognitive processes by virtue of which the object and the truths about it would be given to any cognitive subject.

Edmund Husserl (1859-1938), on a Closed System of Truths

OVERVIEW: This chapter reflects on the research design, with particular focus on the key methodological considerations that underpin the research process. The overall goal is to articulate the complex links between key methodological considerations in the research design and the position of the researcher relative to myriad theoretical perspectives and philosophical worldviews. This research design appropriates synergy from seemingly conflicting methodological traditions, which are considered to be in agreement with the ontological and epistemological orientations that underpin this study. On a more practical level, the research design draws primarily from ethnography and the grounded theory methods. Complementally, the analytical operations borrow insights from deductive qualitative approaches. This research further subscribes to Husserl’s view of phenomenology: that we experience the phenomena of the world rather than its reality. Consequentially, the resultant thesis of this research recognises the existence of multiple renditions of lived experiences, given that people are very likely to experience the phenomena of their world from different perspectives and to interpret their perceptions using different frames of reference. The overarching thesis of this chapter is that we may never ascertain the precise dynamics of lived experiences; but we can still recognise patterns toward more objective representations of such experiences as new evidence emerges and as knowledge developed about the experiences are repeatedly applied in both similar and new contexts. It is the researcher’s belief that the more we research, the more we know about our world. As science is progressive, new evidence is bound to either strengthen or invalidate long held beliefs. This thesis forms the core of the considerations underpinning this thesis.
4.1 Introduction

Air crash investigation is replete with cases that can best be described as enigmas shrouded by mysteries. One such enigmatic event relates to the crash of Aerolinee Itavia’s flight IH870 *en route* from Bologna Italy to Palermo on 27 June 1980\(^3\). In the wake of the accident, the Italian government undertook numerous investigations. What was known, or rather commonly believed, was that IH870 crashed into the Tyrrhenian Sea, as a result of some mid-air explosion, killing everyone on board. However, the exact event that led to the explosion is still one of aviation’s enduring mysteries. Earlier investigations aimed at piecing together what caused IH870 to crash yielded very different and conflicting accounts. The more popular accounts include the possibility of a missile fired by a French navy aircraft that was engaged in a four-nation dog fight with a Libyan fighter jet, a possible mid-air explosive decompression, and an explosive bomb on-board the aircraft.

On 23 January 2013, an Italian criminal court ruled in favour of the missile theory based on conclusions reached by the pioneer investigators in the initial investigation, which by the way was conducted with less than 40% of the plane’s wreckage. Interestingly, this ruling was handed down despite contrary opinions expressed by key international aviation experts that examined additional parts from the plane’s wreckage during a later investigation, along with corroborative views expressed by some of the pioneer investigators that retracted their support for the missile theory. Unfortunately, these later views were disregarded by the Italian court of law in the official report on what caused IH870 to crash. Whilst the later investigation still lacked sufficient evidence to make conclusive claims regarding the actual cause of IH870’s demise, it did argue convincingly that the missile theory is far from the cause of the accident. To date, the events that led to the crash of Aerolinee Itavia’s flight IH870 remain an open debate and still only a speculation at best.

More topically, the disappearance of Malaysia Airlines’ flight MH370 *en route* from Kuala Lumpur to Beijing on 8 March 2014 represents a new class of enigmatic events in contemporary aviation history—that airliners can indeed vanish from the sky without leaving any meaningful trace. According to BBC World-Asia news\(^4\), MH370 lost contact

\(^3\) This story is sourced from a YouTube video of Air crash Investigation, Season 13, Episode 06 (YouTube video titled ‘Massacre over the Mediterranean’).

\(^4\) BBC World-Asia News: Hunt for Malaysian Plane; (http://www.bbc.com/news/world-asia-26626715). As both sources are not particularly “academic”, the stories are only employed for allegorical purposes.
with Air Traffic Controllers less than an hour after take-off. Uncharacteristically, there was no distress signal or message sent either to computers on ground or to any Air Traffic Control tower. Since the disappearance of MH370, multiple theories and different versions of the event have emerged, each in some sense grounded on the little evidence available to the parties concerned. A widely held theory, based on the limited data available, is that the plane flew off course and crashed in the Southern Indian Ocean off the west coast of Australia. But, unlike the crash of IH870, no confirmed evidence from the plane’s wreckage has been sighted. The paucity of hard evidence has expanded the range of speculations regarding the whereabouts of MH370 and further exacerbated the difficulty in piecing together what happened to the airliner on that fateful night.

Incidents such as the loss of flights IH870 and MH370 have, time and again, highlighted the limits of scientific ways of knowing and the relativity of scientific accounts. In particular, they reveal the limits of empiricism as a theory of knowledge. In an empirically driven world, events that do not leave enough tangible or visible trails of evidence often prove very difficult to explain. The questions that arise when faced with such scenarios include whether the limitations of empiricism in providing a more definitive explanation imply that all accounts relating to the events that led to the loss of both flights be considered as equally valid? Do such limitations also justify the popular qualitative research mantra that no account should be regarded as ‘more correct’ than the other? What if more evidence was made available; does it still mean that the new evidence would not prove some accounts to be indeed more accurate than others? More importantly, does relativity in scientific accounts discount the existence of reality? These questions together form the foundation for the philosophical and methodological debates explored in this chapter.

Section 4.2 reflects on the mix of perspectives and philosophical assumptions that underpin the research design and the methodological considerations. Section 4.3 presents a view of the ‘Grounded Theory’ method that fits the underlying philosophical orientations of this thesis. Section 4.4 also reflects on the methodological considerations that are made in the research design as well as in the process of its execution. This chapter concludes with a reflection on the contributions of the underpinning philosophical and methodological orientations in ensuring the credibility of the research process and the authenticity of the research outcome.
Chapter 4: Research Design and Methodological Considerations

4.2 Philosohical reflections

Many researchers in the social sciences have acknowledged that the values, interests and fundamental commitments of a researcher to specific theoretical orientations inescapably influence their approaches to research design (Vasilachis de Gialdino, 2011). With this acknowledgement comes a necessity to make explicit all assumptions that underpin a research design, particularly when presenting research findings by the instrumentality of written reports. For this reason, it makes sense to first clarify the researcher’s stance regarding the philosophical orientations that underpin this study. Before delving into the murky debates relating to methodological issues in qualitative research, meta-philosophical assumptions and considerations that are embedded in this thesis are explored. The meta-philosophical discussions serve as a framework for making sense of the design considerations and the assumptions that were made about the practice under investigation. These assumptions are in turn useful for reviewing the appropriateness of considerations that are made to address emergent issues in the course of executing the research design.

4.2.1 Relativity in scientific accounts

In view of the two cases presented in the preceding section, there are certainly vast possibilities regarding what might have happened to the two airliners. However, as Perrow (1999), Pidgeon (1997), and Shrivastava (1987) have echoed, theories regarding such disasters are usually shaped by the many interests that colour the way different social and political groups perceive what has happened. Particularly, in cases that have a high level of political and diplomatic interests, experts and authorities often employ very different frames of reference in constructing their views of events. More often than not, such perceptions are by far more important than what actually happened, because they drive interpretations and decisions in the aftermaths of critical events. This is precisely the case in the aftermath of both IH870 and MH370 disasters, wherein diverse interests including legal, political and diplomatic relations continue to shape the renditions of those events amongst different social and political groups.

But, despite the possibility of limitless interpretations, this research advances a proposition that the availability of more relevant information could show that some of the accounts were indeed more correct than others. The fallout of several notable disasters lend strong
support to this premise; in particular, how the medical community downplayed the theory that there is a possibility of cross-species infection in the Mad Cow disaster long before the first incident was reported (Gherardi et al., 1999; Ratzan, 1998), and, how NASA discounted evidence that was contrary to their frame of reference in the lead up to the Columbia space-shuttle accident (Woods, 2006, 2009). The common denominator between these two (and many other notable) events is that the evidence collected after the fact did reveal that some concerns (or theories) that were raised but discounted or downplayed by people with authority were indeed more correct than the officially held views. In the cases of IH870 and MH370, similar ‘more correct’ patterns are evident in the retraction of the missile theory by some pioneer investigators that proposed it after subsequent investigations of the IH870 disaster proved that their theory is hardly viable, and in the iterative re-calculation of the potential crash site for MH370 as new radar evidence became available.

In general, the underlying thesis of this research posits that scientific accounts of lived experiences are largely reflections of the frames-of-reference employed to piece together how things work in the world investigated. Each individual’s perceptions and interpretations would very likely be shaped by a number of factors that are hardly constant across any given population. But, while multiple theories and accounts are possible, it is the supposition of this thesis that the theories developed from such abstractions of experience will embody only an aspect of the overall picture. This argument is particularly relevant in that it calls for rigour when unmasking the many interpretive layers that often colour the actual events so that a more credible and objective—even though still approximate—representation of events can be produced. This means that a more insightful representation is possible as new evidence becomes available or as a theory is tested in new contexts. The implications of holding a ‘more correct’ view of scientific accounts are well clarified in the ontology section. The implications are also reflected in the mechanisms that are embedded in the research design to enhance rigour and credibility of the research process.

### 4.2.2 Ontological worldview

The ontological position of this thesis is grounded on Husserl’s view of phenomenology: “that we experience the phenomena of our world rather than its reality” (Spinelli, 2005, p. 31). One implication of this stance is that people experience the phenomena of their world
using diverse frames of references, thereby giving rise to a closed system of perceptions and the possibility of abstracting multiple accounts that are all true of their perceptions (Husserl, 1982). The research process is, therefore, tailored toward understanding the phenomena (the *variant*) of social experiences rather than a fundamental reality (the *invariant*) in its literal sense (Spinelli, 2005). It follows from the underlying premise of this ontology that it is difficult to describe ‘reality’ as it is due to, inter alia, limitations in human perceptual ability, limitations in the vocabulary available to interpret what is perceived, limitations in our theoretical frames-of-references, and limitations in current scientific ways of knowing.

The ontological stance of this research is poised on two distinct premises. The first premise relates to situations where a reasonably comprehensive set of evidence can be determined, but is not equally accessible to all parties. The set of evidence in question relates more to informational and empirical evidence, and therefore less to causal links and root cause. In such situations, factors such as proximity to the source of evidence and other socio-political forces dictate, who gets access to critical information, and, the level of access an individual can get to those critical pieces of evidence. Again, there are usually many interests that colour what is reported, often resulting in substantial cover-ups and the occasional fiddling with evidence (e.g., Pidgeon, 1997; Pidgeon & O’Leary, 2000). Such is the situation with business collaborations between competitors, disaster investigations, and investigations of work practices in general. These are the sort of investigations of interest, where availability of untampered evidence could show that some accounts are, as a matter of fact, more precise than others (e.g., Ratzan, 1998; Woods, 2006, 2009).

Of course, this premise does not discount the possibility of other cases, where there may be possibly many variations, with each variant being correct in its own right. The second premise relates to situations where there are multiple frames of references, but no comprehensive set of evidence for one to establish unequivocally that one frame-of-reference is indeed more correct than the other. Such situations are exemplified in the diverse religious beliefs, political inclinations, cultural orientations, and the subjective determinants of beauty and attractiveness. In examining such situations, the ontological stance of this thesis concurs with Spinelli’s assertion that there is no all-encompassing frame of reference, wherein one can justly promote one variant to be legitimately more correct than the other (Spinelli, 2005, p. 29).
This thesis subscribes, therefore, to a view that relativity in scientific accounts does not
discount reality or fundamental truth; rather, it focuses and emphasises the existence of
multiple abstractions of reality. A corollary of this proposition is that relativity is partly a
reflection of the various frames of references people bring to investigations and partly the
inability of human sensory systems to perceive or interpret reality as it is.

4.2.3 Epistemological worldview

Epistemologically, the thesis position is shaped by the difficulty in capturing and/or
representing lived experiences more definitively in qualitative research. The research design
leans largely toward empiricism as its theory of knowledge. As such, the research process was
designed to elucidate the variants of controllers’ perceptions, which should be useful for
theorising or speculating on the nature of the invariants of controllers’ experiences (Spinelli,
2005). Correspondingly, ethnographic approach was applied, in conjunction with insights
from Blumer’s symbolic interactionism (Blumer, 1969) during the investigation of demand
variability in the processes of airline operations control (AOC). The perspective of
symbolic interactionism facilitates adequate capturing of the dynamics of cognitive
interactions and social inter-relations, as experienced by controllers in the AOC domain.
Furthermore, the analytical procedures draw on Husserl’s phenomenology (Zahavi, 2003;
Husserl, 1982) and the grounded theory tradition (Glaser & Strauss, 1967) to underscore
the importance of holding at abeyance the imposition of set beliefs, biases, explanatory
theories and hypotheses upon the experiences investigated, either at the start of any
investigation or before it becomes useful to do so (Spinelli, 2005). The analytical operation
also draws on René Descarte’s rationalism (Markie, 2004) and Charles Peirce’s abduction logic
(Psillos, 2009; Reichertz, 2009) to fill in gaps in knowledge due to perceptual and
interpretive limitations associated with empiricism.

This pluralistic stance underscores the premise that “paradigm co-existence constitutes not
an exception but rather a rule” in qualitative research (Vasilachis de Gialdino, 2011, p. 12).
By taking multiple routes to this inquiry, the research design takes advantage of the
complementary—as opposed to the antagonistic—contributions of these scientific ways of
eliciting knowledge. Moreover, the integration of several epistemological perspectives
owing to their various practical contributions highlights an element of Pierce’s pragmatism
embedded in the research design. A vital implication of taking a pluralistic stance is that
inductive, deductive and abduction reasoning can be employed where necessary in constructing explanations relative to the phenomena captured in this study. The rationale is to minimise the limitations of using empiricism as the sole theory of knowledge. Applications of these theories of knowledge are explicitly highlighted in the considerations that underpin the research process.

Lastly, grounded on Charles Peirce’s doctrine of fallibilism (Kompidis, 2006), the thesis of research concurs to the fallibility of scientific knowledge, in the sense that new evidence could disprove previously held claims and beliefs. It follows from this argument that each application of a scientific knowledge would, potentially, highlight limitations in that knowledge. The insights gained will then lead to iterative modifications toward a better understanding of the explanatory prowess and limitations of such knowledge. This argument lends strong support for the notion that some accounts can indeed be more precise than others, from the view that there will be no need for iterative understanding and theory modifications if otherwise. As a consequence of this epistemological position, this research is very open to subsequent revisions of its explanations, underlying assumptions, and the philosophical arguments that underpin its meta-theses, if new compelling evidence suggests otherwise.

4.3 Grounded Theory as inspiration

‘Grounded Theory’ (GT) encompasses a set of analytical operations that is used to generate formal theories that are founded on concrete social situations (Glaser, 2002; Strauss & Corbin, 1998). The GT analytical operations are very beneficial for developing conceptual explanations regarding the properties of social phenomena, as well as to the relationships between the properties and the conditions at which those relationships exist (Bryant & Charmaz, 2007; Charmaz, 2006; Strauss & Corbin, 1990). Analytical operations is a decorative term for the analytical techniques and assumptions that, together, form the essential methods of the grounded theory perspective, such as concurrent data generation and analysis, open coding, axial coding, advanced coding, theoretical sampling, theoretical sensitivity, theoretical saturation and writing memos (Strauss & Corbin, 1998). Theoretical sampling involves selective elicitation and analysis of data towards the focusing stage of study (that is, the advanced coding stage). As opposed to random sampling in statistical
analysis, theoretical sampling enables a reconnection between substantive findings and theoretical discussions in the literature. Theoretical sampling is also very useful for saturating categories (that is, the theoretical saturation process) by identifying nuances in the emerging findings and themes that are related. Memos largely serve as lubricants that facilitate abductive abstraction of the relationships amongst codes (Birks & Mills, 2011; Charmaz, 2006).

As depicted in Figure 4.1, there are three levels in the coding process: the initial (open) coding, the intermediate (axial) coding and the advanced (focused) coding. The initial coding stage allows for the identification of cases, responses and views of interest. Instruments that are often coded include interview transcripts, paraphrased conversational notes and narratives of case scenarios. The codes produced during the initial (open) coding stage provide a foundation for the development of categories through axial coding. The relationships across axial codes can then be identified during the advanced (focused) coding stage. During the advanced coding stage, themes derived from the literature were used to reconnect substantive findings from the field to theoretical discourses in the literature. Figure 4.1 summarises the analytical process followed in this study.

![Figure 4.1: The analytical process (After Punch 2005 and Nezamirad 2008)](image_url)
Grounded theories are not only fit to account for empirical situations observed in a social setting, they are also understandable to both researchers and the people they research (Locke, 2001). Besides, they are useful for predicting, explaining and interpreting variations captured in the studied phenomena (Birks & Mills, 2011; Glaser & Strauss, 1967). In grounded theory, formal theories are generated through systematic, comparative analysis of data, rather than simply testing preconceived theories (Glaser & Strauss, 1967). An important justification for using grounded theory in this research design is that its roots in pragmatism and symbolic interactionism befit the epistemological stance of this study (Locke, 2001).

Key features distinguish grounded theory from other qualitative methodologies. Firstly, grounded theorists advocate a rejection of a priori theorising until the meaning assigned to empirical observations stabilises (e.g., Locke, 2001). Particularly at the early stages of the research process, grounded theorists argue that meaning should be allowed to emerge from the data (a bottom-up process) rather than reading meaning into the data (a top-down process) (Glaser, 1992). Secondly, unlike statistical analysis, where random sampling is dominant, grounded theory analyses adopt both opportunistic and theoretical sampling during data collection. Opportunistic sampling can be implemented through unstructured observation in a setting from whoever is available rather than a predefined participant. This aim is usually to capture distinctive experiences that are not guided by a deductively formulated protocol. In grounded theory, opportunistic sampling is often applied at the early stages of data collection to facilitate serendipity in understanding what goes on in the substantive area of interest. However, purpose-driven theoretical sampling is applied at later stages and thus facilitates the collection of more targeted data relating to specific parts of findings from the initial data collection. Its key benefit is that it allows for a focus on identifying missing data that may enrich the researcher’s understanding of the patterns in the observed phenomena (Strauss & Corbin, 1990). Thirdly, it is common for researchers, who adopt a grounded theory, to routinely shift between data generation and data analysis. Hence, it is fully acknowledged within this community of practice that going back-and-forth is an integral part of collecting and analysing data (see Miles & Huberman, 1994). As a result, grounded theorists advocate for an explicit representation of the changing phases of the research question and/or objectives as new insights reshape what is considered more important in the data captured (Glaser, 1978, 1992; Locke, 2001; Strauss & Corbin, 1998).
Grounded theory appears a necessary inspiration for this research given that resilience theory is relatively new to safety research and there is still much that needs to be built from the ground up. Correspondingly, this research design embraces the core philosophies of grounded theory: allowing a theory to emerge from data (Glaser & Strauss, 1967) and rejecting *a priori* theorising until the meanings assigned to empirical observations show signs of convergence toward key themes (Locke, 2001). In addition, this thesis presupposes that the literature provides a useful means for identifying how the research findings relate to broader scientific body of knowledge. Nonetheless, the researcher acknowledges that caution must be exercised with regards to defining the stage at which set beliefs should be included and the roles that pre-existing theories should play in a research process.

It is important to note at this point that the method of testing preconceived hypothesis is certainly a legal and acceptable way of conducting scientific investigations. Actually, from a practical standpoint, it is hard to begin a research adventure without a preformed idea about practices in the substantive area of interest. In other words, the application of grounded theory proposed in this study employs prior theories and the researcher’s beliefs as part of a broader means to eliciting data and in determining what to look for within a specific context, rather than using such preconceptions simply as a confirmation for the observed properties in the researched phenomena.

### 4.4 Overview of key methodological considerations

In Section 4.2, a proposition was advanced for elucidating a comprehensive—but perhaps still approximate and incomplete—knowledge of a social phenomenon within a contextualised setting rather than seeking to unearth fundamental ‘*truth*’ in the phenomenon studied. As one of the intentions of study is to shed light on socio-cognitive work activities within the context of airline operations control, the initial design challenge is gaining insights into the intrinsic complexity of transactions and interrelationships across the subgroups involved in daily control of airline operations. Correspondingly, initial research efforts are focused on the challenges those subgroups face when dynamically rescheduling interdependent resources in the aftermath of a significant disruption. The rationale is that investigations of how actors manage complex interdependencies will elucidate the driving forces behind the rules they apply when mobilising cross-functional...
and inter-organisational responses. This thinking contributed to the focusing of the investigation on core operations-control processes, which encompass decision-making, collaboration, negotiation and coordination. Of particular interest are the processes that involve multiple players spanning multiple functions, organisations, expertise and different levels of authority. This broad goal forms the basis for identifying key considerations in the research design. The following subsections outline major considerations that are made in the research design.

4.4.1 Ethics in human research

Qualitative research that investigates people’s experiences, behaviours and relationships often involves significant and complex ethical issues relating to how information will be collected from human participants, and how such information will be used and disposed of at the end of the research project. Ethics in human research is often targeted toward minimising—as far as practicable—potential risks that human participants might be exposed to as a result of their participation in a scientific investigation.

In regards to ethical conduct of human research, key considerations include the information that needs to be disclosed to the people (both corporate organisations and individual participants) who would be recruited for this study. An aspect of this consideration relates to how one can inform potential research participants of their rights to voluntary participation and other matters, and how the data related to them will be disposed of should they choose to withdraw from the research at any point. Also, it is often a requirement from ethics review committees to provide participants with information on what their participation entails including the expected demands on their time as well as demands on their cognitive and other applicable resources. Researchers are, additionally, expected to make explicit how informed consent will be requested and obtained (Faden, Beauchamp & King, 1986).

In this study, an opt-in strategy is applied, as opposed to an opt-out strategy, so as to ensure potential participants make conscious decisions regarding their participation in this research. Furthermore, participants were made aware how the information they were asked to provide will be used and to whom such information will be presented—in particular, whether the information they provide will be made available to company executives, or
published in conference proceedings and journal articles. Both individual participants and airline companies were assured anonymity and confidentiality when reporting abstracted data in publications and conference proceedings. Other ethically significant considerations made in the course of the research design and its execution can be abstracted from a set of ethics approval documents from the Swinburne Human Research Ethics Committee (HREC). Please see attached Appendix A for the ethics approval letter and other ethics-related documents.

4.4.2 Eliciting data

Popular notions on scientific methods of inquiry appears to suggest that socio-cognitive processes, including attitudes, relationships and behaviours, are best understood when situated within their natural settings (Brewer & Hunter, 1989). Given the difficulty in simulating complex and dynamically evolving socio-cognitive processes in rapidly changing work settings, a naturalistic study was chosen for this research design. As a result, ethnographic-style study was applied for data eliciting data. Nevertheless, there remains the challenge as to how one can elicit data from a complex and rapidly changing work setting in a way that is methodologically sound without evoking adverse reactive effects from the participants (Allen, 2010). This consideration is pertinent because the settings of this investigation are natural and very dynamic business environments, and thus require minimally invasive ways of collecting data to mitigate significant distraction to the participants going about their normal businesses.

To effectively shape the condition of observation with minimal disruption to business processes, a mix of ethnographic-style methods, including interviews and observation studies, will be applied for data elicitation purposes (Atkinson et al., 2001). Less intrusive, loosely structured, observational approach will play a key part in the early stages of the study to allow exploration of a wide range of interests. Afterwards, the study will progress to more structured, mainly questioning, approaches so as to elicit more targeted data relating to specific phenomena of interest (Creswell, 1998, 2008; Denzin & Lincoln, 1994, 1998). A core design consideration relating to data elicitation is centred on balancing the need to follow a well-defined research process across the different operations control centres against the ability to adapt investigation processes in light of surprises and changing circumstances in the field (Allen, 2010, p. 360). In addition, researchers have warned
against embedding notions and concepts that are foreign to the people and domain being studied in the framework for eliciting data (Vasilachis de Gialdino, 2011). This consideration is significant as it would enable the research outcome to make sense not only to the researcher and theory experts, but also to the participants whose work practices are studied.

In this study, participant observations, interviews and document analyses were applied for eliciting data. Domain-neutral questions from the resilience analysis grid (Hollnagel, 2011a) along with probes abstracted from the literature review were synthesised into an integrated resilience markers framework. The framework was discussed with a supervisory team that included an aviation expert with over 16 years’ experience as an operations controller in efforts to ensure that the framework captures key elements of the applicable domain. The refined framework was then applied as a starting point for eliciting data as to how changes in demand shape adaptive behaviours in airline operations control. The probes act as a referential base to ensure that comparable information is sought for across the different operations control centres participating in this study. At the same time, the loose structure of the probes allows for swift adaptation of the research plan in response to surprises in the field without leaving the entire process precariously loose. Table 4.1 presents an excerpt from the integrated resilience markers framework. The complete framework is attached as Appendix B.

Table 4.1: A sample integrated markers framework for responding

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
<th>Probes for Concrete Manifestations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. Readiness to respond</td>
<td>A14. Having a clear criteria for activating responses/special functions</td>
<td>A141. What are the criteria for activating responses?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A142. Are there factors or preconditions that can influence the criteria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A143. How are the factors or preconditions assessed?</td>
</tr>
</tbody>
</table>
4.4.3 Recording data

Researchers use various instruments to collect information about the phenomena being studied. The design challenge for data recording was how to create authentic record of events as they occur in spite of rapidly changing situations within an airline’s operations-control system. Electronic recordings and handwritten notes are commonly used to record naturalistic work practices, including communications, information management, and collaborations, as well as to record retrospective experiences as accurately as practicable.

A review of widely used data recording instruments—such as audio and video recording—highlighted some ethical issues around their applications in scientific inquiry. For example, Jordan and Henderson (1995) observe that researchers often use video-recordings to illuminate the dynamics of non-vocal aspects of communication in various workplaces. However, the use of videos in research often proves problematic due to the high reactive effects it generates on the participants and the resultant changes on the processes being investigated (Jordan & Henderson, 1995). As images captured through video recording could unveil practices that pose adverse competitive, legal or regulatory consequences, business managers as well as participants and many ethics committees frequently raise concerns—and often objections—to the idea of video-recording people in their workplaces. In order to minimise the potentiality of observational reactivity and to avoid prolonging the ethics approval process, only audio recordings and textual documentations will be used in this study.

Furthermore, Allen (2010) notes that creating detailed field-notes as events occur is particularly challenging in naturalistic work settings. Drawing from knowledge gained from her field studies in hospitals, Allen (2010) suggests the use of shorthand writing style where audio recording is not allowed. Also, Allen (2010) advises that the interval between making an observation and creating records of it—particularly when demands of the field make verbatim recording of field notes difficult—should be kept as short as practicable. Another interesting suggestion relates to the amount of contextual information to be included in the field notes and audio-recorded dictations. Based on the techniques discussed in Allen (2010, p. 365), a low-inference field notes was adopted to show rather than tell about behaviours. This involves a clear differentiation of the vocal and non-vocal behaviours.
The idea is to make more visible the separation between the researcher’s interpretation of behaviours and concrete observations in the field.

### 4.4.4 Transcribing data

Transcripts form a vital tool that allows recorded data to be analysed. However, the challenges of producing valid transcripts have been emphasised in the literature (Heath & Luff, 1993; Schegloff, 1984). Similar to data recording, the key consideration with transcribing data is the level of detail to be included in the transcript and the interval between recording and developing an official transcript for analysis. Data transcriptions are generally time-consuming; as a result, researchers often advise that some level of selection is paramount in order to balance the need for authenticity and the practicality of completing the field study and analysis within schedule (Allen, 2010). Consequently, a mix of ‘near-verbatim’ and selective transcriptions was deployed to ensure a good balance between fitness for purpose and representation.

A near-verbatim transcription, as used in this study, refers to a process of transcribing audio recordings using exact words of the participants, with a few changes to, perhaps, locations, identifiable names (of persons and corporations) and some highly technical, domain-specific terms. The transcription conventions used in this study closely follows Jefferson’s conventions for transcribing vocal activity (Jefferson, 1984). But, as this process is time-consuming, it was used for transcribing short (30 to 45 minutes) interview recordings only.

By contrast, selective transcription allowed for a strategic focus on recordings that appeared relevant to the evolving themes as they are captured in the field. Given the time required to convert audio-recorded data to textual data, conversational recordings (particularly, multi-party deliberations) captured during observational studies were selectively transcribed with a focus on a selected scenarios of interest. Some scenarios were also recorded textually on paper, thus providing triangulation of data across instruments. Nevertheless, the pitfall of the selective strategy is that some vital information may be missed simply due to a failure to see a link between those observations and the overall research goal. To minimise potential adverse effects of selective transcription, two rules adapted from phenomenological research were applied. The *inclusionary* rule advocates that
all information collected as part of the research must be considered as initially valid, until
there are clear indications that some information are more pertinent than others. The
*equality* rule argues for all experiences to be treated as being equally valid particularly at the
early stages of the research process (Ihde, 1986). It remains a challenge, however, when to
apply selective transcription given that the literature offers no set rule to this regard. All
transcriptions were done by the researcher to maintain a level of consistency across various
transcription schemes applied in representing different forms of data generated in this
research.

4.4.5 **Analysing data and generating theory**

Data analysis constitutes an important link between ‘organic’ data and explanations
developed from the data, and thus takes a number of forms. The necessity to address the
analytical rigours of a doctoral research process inspired a preference toward a more
structured analytical approach. In addition to structured analytical procedures, *in-flight*
analyses of data was considered, as it allows emerging themes to be captured and also helps
to quicken the analytic process. In-flight analyses (Allen, 2010, p. 367) refer to those
serendipitous ideas that are generated through abductive reasoning, as a researcher
documents and reflects on his/her field notes and transcripts. Accordingly, the grounded
theory method was chosen for its broad range of analytic possibilities (Glaser & Strauss,
1967). The grounded theory methods also allow for data generation and analysis to be
undertaken concurrently.

The next challenge was how to move from subjective accounts elicited from the
participants to a substantiated, objective account grounded on the data collected. Thematic
coding was preferred as it is widely used in qualitative research when establishing categories
and dimensions of a phenomenon as embodied in the data. However, some researchers
have warned of possible “violence of interpretation codes” (Vasilachis de Gialdino, 2011):
a situation where theoretical codes (mostly from theoretical discourses) are imposed on the
studied settings. Therefore, in order to avoid imposing codes that are foreign to the
domain being studied, descriptive codes that are captured directly in the data will be
employed in exploring the relationships amongst elements of the data at the earlier stages
of the research process. Conceptual codes developed from the literature would, thereafter,
be applied at the later stages of the analytic process in order to develop a theoretical handle for explaining the findings beyond the specific cases studied.

In addition, three phenomenological rules will be applied in the process of analysing data and generating a theory. First, all preconceived ideas, assumptions and expectations regarding the studied phenomenon must be suspended as far as possible until meaning assigned to primary data stabilises. This is referred to as the rule of *epoche* (bracketing). Whilst the difficulty of achieving complete bracketing as argued by Merleau-Ponty (1962) is duly acknowledged, the researcher concurs to Spinelli’s supposition that the very recognition of preconceived bias or expectation lessens its impact upon our immediate experience (Spinelli, 2005). Second, initial representations of research data should be more descriptive rather than speculative. This is known as the rule of description. Again, there is hardly a description of events that could be said to be totally free from some sort of explanation. Therefore, the design challenge would be ensuring that inferences, which are not direct abstractions from observable events or participant accounts, are kept to the minimum. Third, quick assumptions relating to the significance or importance of the items-to-be-described must be avoided as far as practicable. Rather, all items must first be treated as equally important; of course, with the exception of situations where respondents made such hierarchical judgements themselves. This is referred to as the rule of “*horizontalization*” (or rule of equalization). The underpinning assumption in this thesis is that these three phenomenological rules will mitigate the imposition of preconceived notions and biases upon the items of one’s descriptions before it becomes useful to do so (Spinelli, 2005).

### 4.4.6 Enhancing rigour

With regards to enhancing rigour, researchers often face a challenge relating to how one can dynamically monitor the execution of the research plan to ensure that the assumptions that underpinned the research design are in agreement with actual developments throughout the course of the research. Despite a widespread rejection of the notion of reliability (and to some extent validity) within many qualitative research traditions, it seems reasonable that verification mechanisms be built into the research design to enhance rigour in the research process and, consequentially, the authenticity of study. Qualitative verification, as used in this research, refers to the process of checking, confirming, making sure, and being certain (Morse et al., 2002) with regards to whether a qualitative research
process is going as intended or needs to be adapted as necessary. Of particular interest are
the four criteria proposed by Guba and Lincoln for judging the “trustworthiness” of
qualitative research, which are credibility, dependability, transferability and confirmability
(Guba & Lincoln, 1981; Lincoln & Guba, 1985).

Rather than focusing on the potential for replicability, as is the case with most reliability
and validity measures in quantitative inquiry, these criteria are useful for enhancing the
rigour and trustworthiness of qualitative study. Their collective end-goal is to ensure that
self-correcting mechanisms are integrated during the execution of the research plans
through constant verification of the credibility of data collected, the appropriateness of the
theoretical frameworks and the analytical processes applied, as well as the richness of
theory developed as the research outcome. Consequently, respondent validation (member check),
triangulation and reflexivity were employed in this research to support internal credibility,
dependability and confirmability checks during the conduct of inquiry, while extrapolative
testing was preferred for verifying the transferability of the research outcome to other
contexts.

4.4.6.1 Respondent Validation

Respondent-validation, or what is commonly known as member check, was included in the
research process as a credibility/conformability mechanism to better capture nuances of
the substantive observations from the participant’s eye. Two benefits were identified
during a literature review that provided good justifications for including member check in
the research design. Firstly, member checks allow for accurate validation of observational
notes; particularly, when the focus is on non-verbal behaviour captured during observation
studies (Lincoln & Guba, 1985). Certainly, it is necessary to confirm that descriptions and,
perhaps, interpretations relating to participants’ non-verbal behaviour made sense to the
participant observed. Thus, observations were followed up ideally with questioning—either
immediately or as soon as practicable—so as to confirm the non-verbal cues captured.
Again, verbal responses were corroborated across participants within the same role and,
when necessary, across roles. The rationale is not so much as looking for consistency or
inconsistency than it is capturing diversity in views and, perhaps, the forces that shape such
diverse views.
Correspondingly, an iterative cross-examination technique (based on information provided by a previous respondent within the same subgroup) was deployed; again, not for determining irregularities in participants’ responses, but more for clarifying doubts and crosschecking diversity in perspectives across participants within the same role. In addition, notes made during observations along with drafts of interview transcripts were discussed with the participants concerned mainly through physical meetings, with a few phone conversations and email correspondences. Lastly, a preliminary result was discussed with available participants to validate the meanings abstracted from the data.

4.4.6.2 Triangulation

Triangulation can be applied at multiple levels in order to improve the credibility of the inquiry and to enhance the dependability of its findings (Webb, Campbell, Schwartz & Sechrest, 1966). Various forms of triangulation have been proposed for achieving a credible and accurate research outcome—data triangulation, theory triangulation, environmental triangulation and methodological triangulation (Denzin, 1978). Investigator triangulation was not considered for the fact that this doctoral project must be carried out by the doctoral candidate.

With regards to methodological triangulation, the focus of design consideration was on the drawbacks of individual research methods (e.g., interviews, observations, questionnaires, etc.) regarding their applicability in a natural and dynamic business environment. For instance, the limitations of several qualitative methods—including interviews and observations—in light of examining attitudes and behaviours of actors at airline operations control centres have been highlighted in a prior doctoral study (Bruce, 2008). As a result, the goal of methodological triangulation in this study was simply to maximise the possibility of cancelling out the flaws of each individual method and to enhance their synergistic benefits in enriching the researcher’s understanding of the researched phenomena. The necessity to neutralise the drawbacks of individual methods provided further justification for a multi-method approach; hence, the need to employ a combination of semi-structured interviews, observations and document analyses for data collection purposes.

In this study, data triangulation was employed so as to capture a more detailed and balanced perspective on the researched phenomenon (Altrichter et al., 2008). Participants
with diverse roles and experiences were invited to take part in this study. The rationale was to maximise the diversity of experiences and perspectives on the researched phenomenon. The inclusion of some executive members as participants was informed by findings in the literature of resilience engineering that recommended future research to look into how decisions at the blunt end (i.e., at the senior executive level) impact resilience at the sharp end (i.e., the frontline control process) (Dekker, 2006b).

Environmental triangulation is often considered in relation to the diverse characteristics of the study settings. However, as this research was not initiated in conjunction with any specific partner organisation, decisions regarding the specifics of the field study were opened to opportunism and serendipity—including the number of centres to visit, what participants will be involved, commonalities and differences amongst participating companies, the times of day, and work shifts that are best for data collection. An opportunistic strategy was chosen because it was difficult to make precise plans for such mix of environmental factors, when, in practice, they will very likely be shaped by the level of access or permission that is granted by the participating airline(s).

Finally, theoretical triangulation was employed relative to the mix of theoretical frameworks applied in designing this research as well as to the interpretive framework that will be used for making sense of its findings. A key consideration relating to theoretical triangulation was to contrast as many theoretical perspectives as possible with a view to uncover as many alternative stories as possible about the researched phenomena. Contrasting relevant findings in the literature against substantive observations made in this study may be useful for extending theoretical contributions, strengthening arguments, spotlighting limitations, refuting unfounded generalisations or elucidating pertinent factors that could explain the observed differences. The underpinning rationale of theoretical triangulation in this design is to be able to interpret the research findings from more than one frame-of-reference; thus, accommodating for relativity of social accounts.

4.4.6.3 Reflexivity

Another design challenge regarding credibility-accuracy checks relates to how one can make explicit the “conceptual baggage” (Kirby & McKenna, 1989, p. 32) that a researcher brings to the process of designing and executing a research project. These include the values, interests, concepts, and theoretical perspectives that the researcher brings, which
influences construction of meaning. According to Kirby and McKenna (1989), such conceptual baggage could influence the questions that are investigated, the frame-of-reference that is applied, the ontological and epistemological positions of the researcher, and the group’s experiences that are legitimised and theorised. Reflexivity has been applied in unveiling preconceptions and in increasing researcher awareness of situational dynamics in the process of producing qualitative explanations of a social phenomenon. A review of some qualitative research literature (Anderson, 2008; Finlay, 2002a, 2002b; Johnson & Duberley, 2003) identified three levels at which the practice of reflexivity can be implemented: on the researcher level (introspective reflexivity), on the methods applied (methodological reflexivity), and on the theoretical perspective that underpins the research process (epistemological reflexivity).

Introspective reflexivity involves the processes of maintaining a conscientious awareness of how a researcher’s identity influences the design and process of his work (Anderson, 2008). This form of reflexivity is commonly linked either to deliberate reflection on what one is doing or has done (e.g., Woolgar, 1988, p. 22) or to implicit reflection-in-action according to Schön’s model of action learning in professional practice (Schön, 1983). The literature emphasises that researchers need to be aware how their preconceptions contribute in shaping key research decisions, such as the selection and wording of research questions. Furthermore, some scholars have advised that researchers should remain cognisant of how their relationship with research participants could affect responses to questions, particularly where an outsider-insider relationship dynamics changed over the study period (Allen, 2010).

Methodological reflexivity involved identifying potential issues relating to the methods that are applied in the research process, and how these might influence the research findings. To this end, the researcher was particularly mindful that some interview questions could evoke defensive responses. As a consequence, the researcher made a decision to avoid asking questions that might seem contentious at the early stages of data collection until respondents are comfortable with the researcher or when they begin to see the researcher as an ‘insider-by-association’. Also, Allen (2010) suggested that knowledge of the researched phenomena advances incrementally over the life of a research project. In order to allow for such evolution in knowledge, the study aim was broadly defined at the on-set in line with the grounded theory traditions (Glaser & Strauss, 1967; Strauss & Corbin,
Chapter 4: Research Design and Methodological Considerations

1990). This strategy enabled the researcher to progressively narrow the study focus around more concrete lines of inquiry as these were identified in the field (Allen, 2010).

Epistemological reflexivity involved cross-examining the researchers’ assumptions on scientific ways of producing knowledge, and the extent this research process is influenced by the researcher’s allegiance to specific beliefs. The barrage of advices from scholars within the qualitative tradition appears to buttress Vasilachis de Gialdino’s view that paradigm co-existence is a rule rather than an exception in qualitative research (e.g., Vasilachis de Gialdino, 2011). A way of implementing epistemological reflexivity in this research is to highlight all theoretical orientations that have shaped the research process, including fundamental beliefs and assumptions that are used to justify their applicability to this style of research. Sections 4.2 and 4.3 provide some evidence as to how epistemological reflexivity was implemented in identifying and in clarifying a range of perspectives that underpin this research. Intellectual encounters with experts in the field of Resilience Engineering that encouraged a clearer representation of the researcher’s philosophical allegiance are well documented in Chapter 5.

4.4.7 Evaluating the ‘goodness’ of a theory

Glaser and Strauss (1967) offer two ways of thinking about the goodness of a theory: based on its credibility and its pragmatic usefulness. Interestingly, their idea of credibility in relation to evaluating final research outcome is not very different to the application of credibility in enhancing rigour in a research process. Hence, a number of credibility concerns raised in Glaser and Strauss (1967) regarding the relevance of analytical practices, rhetorical issues in writing a research report, connecting with the readers’ experiences and the researcher’s own beliefs, are believed to have been sufficiently implemented in mechanisms such as triangulation and reflexivity. Besides, the notion of credibility in qualitative research tend to underscore the way a research outcome is conveyed to the readers rather than on the intrinsic values the research findings proffer in terms of influencing practices in the substantive area studied. In some respects, credibility appears more relevant as a means of enhancing rigour and establishing authenticity of a qualitative inquiry, rather than as a means of evaluating the goodness of a theory.

It is, therefore, surmised that the criterion for evaluating the goodness of a theory should be based on how pragmatically useful the developed theoretical framework is in relation to
everyday experiences in the substantive world investigated. In this sense, Glaser and Strauss (1967) argue that a theory should make sense to the people studied and, at the same time, be pragmatically useful for influencing their practice. In this study, the pragmatic usefulness of a theory is operationalized using four concepts proposed by Glaser and Strauss (1967): fit, understandable, general and control. Taken together, these four concepts form the foundation for the two conceptual tests employed in evaluating the goodness of the thesis outcome: test of fitness and test of generality.

4.4.7.1 Test of Fitness

The concept of ‘fit’ is employed in this test to gauge how interpretations or explanations generated about the dynamics of work practices is reflected in everyday occurrences that practitioners experience in their work setting. In conjunction, it is also pertinent to assess how ‘understandable’ the conceptual framework is to the people whose lived experiences are studied. There appears to be a complementary relationship between the notions of ‘fit’ and ‘understandable’, in the sense that interpretations that fit practitioners’ everyday experiences will most likely be understandable to them. The assumption is that the higher the level of fitness a theoretical framework achieves, the greater the chances that practitioners in that domain will relate easily to the patterns captured in the framework. Given the presumed complementary relationship between the level of fitness and the level of understanding that is demonstrated, it is expected that the higher the level of fitness the more understandable the phenomena captured in the conceptual categories would become to the practitioners whose practices were studied.

Therefore, in relation to test of fitness, the value of a theory will be measured by the extent the patterns captured in the conceptual categories make sense to practitioners in that field.

4.4.7.2 Test of Generality

With regards to generalizability of findings, researchers have pointed to the difficulty of moving from a narrow abstraction of meaning from a specific case studied to broader abstraction of more general relations captured across different contexts and situations (e.g., Muwaw et al., 2000). The test of generality employed in this study encompasses two dimensions: analytic generalizability, and extrapolative generalizability or what Guba and Lincoln (1981) denoted as transferability of findings.
Analytic generalizability refers to the level of generality that can be deduced from a conceptual category in terms of the diversity of conditions and situations it captures relative to a substantive problem area (Locke, 2001). Similar to the relationship between level of fitness and level of understanding, it is posited that the concepts of generality shares a degree of complementary relationship with the notion of ‘control’. The assumption that underpins this thesis is that the wider the scope of conditions and situations a conceptual category caters for, the greater the degree of control it affords to practitioners in the field. For example, a theoretical framework that captures a wide range of dynamic relationships under diverse conditions would be useful for developing predictive and monitoring indicators.

By contrast, extrapolative generalizability relates to the extent to which conceptual categories developed in one substantive problem area can be transferred to other practice settings. It should be noted that the notion of extrapolative generalizability is still highly contested in qualitative inquiry particularly when talking about transferring findings obtained from one domain to other work settings (Vasilachis de Gialdino, 2011). Extrapolative generalizability typically occurs at a high level representation of a formal theory. It largely takes the form of comparative analysis between the dynamics of a social phenomenon across the domains and theories generated to explain any observed differences in the phenomenon studied (Lincoln & Guba, 1985). Therefore, it is hypothesized that findings can be extrapolated to other domains so long as the descriptions of the research context and underpinning assumptions are clearly highlighted in a way that enables the person making the transfer to judge how the proposed framework maps into the new domain.

Overall, the test of generality can be measured from two angles: from a practical standpoint and from a conceptual standpoint. From a practical standpoint, the value of a theory will be judged by the extent it enables practitioners to develop measures or indications for predicting changing relationships specific to their practice domain. Conceptually, the value of a theory will be determined by the extent the framework proves useful for explaining similarities and differences observed in other substantive problem areas.


4.4.8 General discussions on the research design

The application of triangulation in this study has nothing to do with comparing across different forms of data. On the contrary, it has more to do with enhancing the credibility of the research process and the authenticity of the research account. The different forms of data produced using different research methods (such as interviews, observations, surveys, etc.) proffer very different and unique insights into the investigation and, therefore, cannot be legitimately compared as competing views. Thus, the goal of triangulation in this study is to appropriate the complementary nature of different data sources in developing a more credible and balanced picture of the experiences investigated, as opposed to simply comparing and contrasting data obtained using different methods.

Furthermore, the collective mechanisms embedded in the research design should be useful for enhancing rigour and for improving the authenticity of the final research outcome. With regards to the debate on verification and validation of qualitative inquiry, the researcher shares the view that the widespread outcry against validity testing by most qualitative researchers is indeed a crisis of confidence in response to threats from mainstream quantitative criticisms (Morse et al., 2002). Whilst it is totally understandable that reliability and validity as they apply to quantitative research cannot be imposed directly to qualitative research, it is still proposed that every scientific inquiry should maintain rigorous methods for assessing the overall goodness of its conduct of inquiry as well as its final outcome. In a sense, applying reflexivity (or other mechanisms that can only be deployed toward the later stages of investigation), as a way of proving the goodness of a research account, is grossly ineffective in providing proactive adaption necessary to steer a scientific investigation in a fast changing environment. Such last minute approaches are limited in the extent they can support effective, self-correcting means of adapting a qualitative inquiry as and when needed. Chapter 5 highlights how more proactive mechanisms like triangulation, member checks and expert validation provided serendipitous opportunities to refine, reprioritise, and adapt the research focus and objectives.
4.5 Conclusion

Clearly, the diversity of philosophical worldviews and methodological styles that underpin this research design when combined form a constellation of assumptions that must be carefully untangled in the execution of the research design. Nonetheless, this pluralistic position allows for more appropriate frameworks to be applied where they work best. One important implication is that diverse reasoning techniques including inductive, deductive and abduction reasoning can be employed at different stages of the research process in constructing explanations relative to the phenomena captured in this study. With regards to the research process, investigating activities that involve multiple players spanning multiple functions, organisations, expertise and different levels of authority provides diversity in experiences and further helps in gaining a more detailed and balanced view of the practice under investigation. This broad idea forms the basis for identifying key considerations in the research design. Nevertheless, there remain some practical dilemmas that must be addressed during design execution, including: how to balance between constraining findings and leaving it precariously loose; defining the stage of inclusion and the role of hypotheses and pre-existing theories in the inquiry; defining when and how selective transcription would be applied to not violate the rules of equalization and “horizontalization”; and final, defining the stop rule in terms of data collection and analysis?
CHAPTER 5

FIELD STUDY, DATA ANALYSIS AND FINDINGS

There is no black and white, there’s no right and wrong, and there are no set rules. You can have same problems today and exactly same problems tomorrow and do it differently: same flight, same time.

Anonymous respondent (2012), on the Appropriateness of Situated Responses

You explain to me by cancelling a flight or delaying a flight, how many passengers you’re going to lose and how many will get back the next time they fly. Work that out and put a price on it.

Anonymous respondent (2012), on the Economics of Situated Decision Making

On the day of ops, the unexpected always happens.

Anonymous respondent (2012), on the Dynamics of Demand Situations

OVERVIEW: The trend towards more integrated operations in the airline industry has made it easier to locate distinctive experiences relating to how autonomous functions collectively manage variability in demands. This chapter discusses the research process, including presentations of the analytical processes and discussions on the research findings. The research process encompasses iterative completion of the research design, which came about as the researcher gained more insight into the challenges that airline controllers face and as the researcher’s theoretical sensitivity to applicable conceptual frameworks improved. The research process details the field investigations, the significant milestones attained, as well as the major challenges encountered in the course of implementing the research design. It also captures an overview of the data collection processes. The data analysis protocol serves as a framework for showing how theoretical constructs were generated. The focused coding process, in particular, provided an avenue for reconnecting the substantive observations made in this study with several theoretical discourses in the literature. Overall, this chapter addresses the third objective by shedding light on how controllers adapt their behaviours in response to the relentless fluctuations in demands. It further addresses the fourth objective by delineating links between the thesis findings and several theoretical discourses abstracted from studies conducted in comparable domains (objective 4).
5.1 Description of study components

The key study components include the airline operations control (AOC) system as the unit of analysis, the airline companies, the functional groups that make up the AOC system and the individual participants who took part in this study. Table 5.1 and Table 5.2 capture only a summary of generic characteristics and profiles of the airline companies and the individual participants. The rationale is to protect (as much as possible) the identities of study participants in accordance with their respective conditions of consent. The descriptions focus on elucidating the distinctive characteristics of the practices observed at the various operations control centres and the participants and on clarifying nuances in the observed patterns of responses. Therefore, detailed information of participants—including the names and personal identifiers of both the companies and the individual participants—are not included in the following descriptions.

5.1.1 Profile of Airlines

The four airlines that participated in this study were visited at different stages in the research. The initial exploratory inquiries at each participating control centre were generally focused on understanding the study environment and the dynamics of operation at that particular operations control centre. Such initial inquiries provided information relating to the various operational characteristics across the four airlines, the control units involved in airline operations control, their roles and how they interact when responding to both routine and extreme variances in demand. In one airline that was visited later in the research, initial exploratory study was quickly followed by more focused investigation, given the level of theoretical awareness that has been developed about the researched phenomena as at the time of the visits.

5.1.1.1 Airline companies

Four airline companies were visited for field study purposes. Two of the airlines (designated as Company A and Company B) are considered premium airlines, in the sense that their competitiveness is contingent on their broad range of services. Each of companies A and B operates over 250 aircraft across expansive networks spanning over 30 countries. Both companies also operate extensive long distance, international services, as well as domestic services. The third airline (Company C) operates a medium-sized international, point-to-point network with extensive domestic and feeder services for its
affiliated partners in other countries. The fourth airline (Company D) operates extensive
domestic and regional networks and code-shares some regional and domestic services with
its parent company. Companies C and D are considered low-cost carriers or budget airlines.
All four airlines are based within the Asia-Pacific and the Middle East regions.

5.1.1.2 Network configuration

Most airlines typically operate either a hub-and-spoke network or a point-to-point network
configuration. Airlines that operate point-to-point networks provide direct flights between
two destinations, with the possibility of little or no connecting flights. Budget airlines, for
instance, commonly operate a point-to-point network structure. Company A’s operations is
more akin to a point-to-point network, although some of its long distance flights operate
from three major airports. However, the network configuration for companies C and D
can best be described as point-to-point networks.

In contrast, airlines that operate a hub-and-spoke network use large and often busy
airports, the hubs, as central nodes connecting several smaller, regional airports, the spokes.
Based on a hub-and-spoke metaphor akin to a bicycle wheel, passenger traffic flows from
several spoke-airports into a single hub, thereby creating opportunities at the hub for
connecting passengers and crew to a vast number of destinations. Company B operates a
hub-and-spoke network and, as a result, rarely provide direct flights between two spoke
airports without a connection through its hub station. Responses relating to network
configurations touched on the implications of geographic location on an airline’s choice of
network structure. But more importantly, respondents shed light on how different network
structures both support and sometimes impede controllers’ ability to respond to variability
in demand. These responses are discussed in later sections.

*Table 5.1: Profile of the airline companies*

<table>
<thead>
<tr>
<th>Airline company</th>
<th>Business model</th>
<th>Estimated Fleet size</th>
<th>Network configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
<td>Premium</td>
<td>250-350 aircraft</td>
<td>Point-to-point</td>
</tr>
<tr>
<td>Company B</td>
<td>Premium</td>
<td>250-350 aircraft</td>
<td>Hub-and-spoke</td>
</tr>
<tr>
<td>Company C</td>
<td>Budget</td>
<td>150-250 aircraft</td>
<td>Point-to-point</td>
</tr>
<tr>
<td>Company D</td>
<td>Budget</td>
<td>75-120 aircraft</td>
<td>Point-to-point</td>
</tr>
</tbody>
</table>
5.1.2 Profile of participants

In this study, there was an eclectic mix of expertise, experience levels, leadership methods, frontline organisational culture, and general operative outlook. The participants include duty managers and frontline controllers responsible for various aspects of the frontline operations at the control centres visited. Their length of service in the airline industry range from two to thirty-eight years and span a wide array of functions within the airline industry. Table 5.2 presents a summary of participant characteristics.

*Table 5.2: Demographic profile of participants*

<table>
<thead>
<tr>
<th>Code-name</th>
<th>Duty Managers</th>
<th>Operations Controllers</th>
<th>Crewing Officers</th>
<th>Maintenance</th>
<th>Passenger Liaison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age range (Years)</td>
<td>45 - 65</td>
<td>25 - 70</td>
<td>20 - 50</td>
<td>30 - 55</td>
<td>20 - 65</td>
</tr>
<tr>
<td>GENDER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>LENGTH OF SERVICE IN AIRLINE INDUSTRY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum (Years)</td>
<td>34</td>
<td>38</td>
<td>21</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Minimum (Years)</td>
<td>19</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>LENGTH OF SERVICE IN AIRLINE OPERATIONS CONTROL CENTRE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum (Years)</td>
<td>28</td>
<td>18</td>
<td>9</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Minimum (Years)</td>
<td>12</td>
<td>Less than 1</td>
<td>2</td>
<td>2</td>
<td>Less than 1</td>
</tr>
<tr>
<td>LENGTH OF SERVICE IN CURRENT ROLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum (Years)</td>
<td>16</td>
<td>14</td>
<td>9</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Minimum (Years)</td>
<td>4</td>
<td>Less than 1</td>
<td>2</td>
<td>2</td>
<td>Less than 1</td>
</tr>
</tbody>
</table>

Two senior management personnel also participated in this study. While their roles are higher up in hierarchy than most duty managers studied, for some reasons, their workspaces are inside the operations control room like many other duty managers. Also,
there appears to be significant interceptions in their responsibilities and those of the other
duty managers studied in the other control centres. Consequently, for classification
purposes, the two senior management personnel are grouped in the duty manager category.

A total of 39 airline staff participated in this study. Sixteen participants took part in the
exploratory study. A total of 27 participants took part in the later stages of study, inclusive
of four participants who took part in both the exploratory and the later stages of study. All
sixteen participants who took part in the exploratory study made themselves available for
brief exploratory discussions and questioning, followed up with non-intrusive observations
of controllers’ work at three operations control centres. Hence, all were both observed and
questioned. Table 5.3 provides a summary statistics of the participants and their method of
participation.

Table 5.3: A summary of participants and their method of participation

<table>
<thead>
<tr>
<th>STAGE ONE (16 Participants)</th>
<th>Method of participation</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observation with questioning</td>
<td>All 16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STAGE TWO (15 Participants)</th>
<th>Method of participation</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interviews (only)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Interviews (with observation)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>INTERVIEWS (TOTAL)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Observations (only)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Observations (with questioning)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>OBSERVATIONS (TOTAL)</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STAGE THREE (12 Participants)</th>
<th>Method of participation</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interviews (only)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Interviews (with observation)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>INTERVIEWS (TOTAL)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Observations (only)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Observations (with questioning)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>OBSERVATIONS (TOTAL)</td>
<td>9</td>
</tr>
</tbody>
</table>
In the second and third stages, a total of 27 participants took part in the study across four control centres. Twelve of the 27 participants were formally interviewed in-depth. Ten of the 12 interviewed were also observed same day following their respective interview sessions. Six participants were observed and questioned informally based on issues that emerged from the observation. Nine were observed but could not be questioned, some due to the prevailing workload at the time, and two participants, because they simply want to participate passively. Overall, the sample of controllers who were either interviewed, or observed, or questioned, constitutes a fair representation of the core functions in a typical airline operations control centre. Table 5.4 presents a representation of participants according to their roles and company affiliation.

### Table 5.4: Participants according to roles and company affiliation

<table>
<thead>
<tr>
<th>Company</th>
<th>DM</th>
<th>OPC</th>
<th>CRW</th>
<th>MOC</th>
<th>PAL</th>
<th>Total per company</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total per role</strong></td>
<td><strong>7</strong></td>
<td><strong>12</strong></td>
<td><strong>8</strong></td>
<td><strong>4</strong></td>
<td><strong>6</strong></td>
<td><strong>GRAND TOTAL = 39</strong></td>
</tr>
</tbody>
</table>

#### 5.1.3 Airline operations control system as the unit of analysis

From a joint-cognitive systems perspective, the airline operations control (AOC) system is investigated as a system that comprises human decision-makers, large computerized and networked artefacts used for communication and control purposes, as well as myriad human and inanimate resources that are essential in facilitating the execution of daily schedule of airline services. Control activities within this system are undertaken mainly from a centralised location that houses multiple autonomous subgroups. Activities at those centralised locations are often characterised by goals that are dynamically changing or locally adapted within compartmentalised control centres. Collaborations at the centres are in most cases mediated by some form of technological artefacts. Controllers at the operations control centres are often required to make quick and fiscally sound negotiations with other organisations and sub-functions in remote locations, which might also share very different sets of goals and priorities.
Chapter 5: Field Study, Data Analysis and Findings

5.1.3.1 Operations control (Aircraft control)

The airline Operations Controller (Controller for short) is the principal actor in the operations control process at the control centres. As the focal point of the operations control process, the Controller receives information from various support functions and uses that information to coordinate flow of resources (aircraft, crew) and passengers across the airline’s network, as well as initiating pre-emptive efforts toward recovery when a potential threat is sighted. The role of the Controller appears to be similar across the airlines that participated in this study (relative to managing tactical control operations), but the level of authority exercised seems to vary with reference to the observed transactions between the controllers and their duty managers. However, an in-depth examination into the dynamics at play in an AOC work domain reveals that there is more to the nuances observed. Such observations are the backbone of the discussions presented in the later sections.

The exact duties of each Controller differ across the airlines. In Companies C and D, the duties of a Controller are typically shared between two persons and attended to on a shift basis. One Controller has oversight for domestic flights, while the other Controller is responsible for long distance, international flights. By contrast, Company A also has two shift-based Controllers, but their duties are distributed along a time horizon rather than divided by nature of operation. That is, one Controller is responsible for the day of operations, while the other Controller is responsible for changes to planned schedules over four to seven days leading up to the day of operations. However, the Controllers’ responsibilities in Company B are distributed relative to geographic locations. Owing to the expansive nature of Company B’s hub-and-spoke network, one Controller is in charge of hub operations at the base airport, while the others Controllers are responsible for flights operating from different geographic regions. There are instances of overlap, particularly with company B’s operations, where the control of a flight is transferred from one Controller to another as a natural consequence of the flight’s origin-destination plan.

5.1.3.2 Crew control (Crewing)

The Crewing unit is responsible for tracking individual members of both flight and cabin crew as they traverse an airline network. They are largely responsible for managing and updating crew rosters as plans are adapted in response to the actualities of their operations, and for calling in reserve crew as required. Companies C and D—with fewer variations in aircraft fleet—have two crewing personnel; one tracks and coordinates schedules for cabin
crew, while the other attends to the flight crew schedules. In contrast, companies A and B—with more varied fleet types—appear to share crewing responsibilities relative to fleet type. It was observed that Crewing personnel in all four airlines were in constant interaction with the Controllers. The constant communication and negotiation between Controllers and Crewing are attributed to disruptions to resource schedules usually having immediate detrimental effects on crew schedules—especially on crew flying/duty hours and, in turn, on the crewing units’ ability to find replacements who have the required qualifications (e.g., to fly a specific type of aircraft).

5.1.3.3 Engineering (Aircraft maintenance)

The trend towards a more integrated operations centre in the airline industry has further necessitated that one or more maintenance representative(s) are often co-located with other support units at the operations control centres. Engineering (aircraft maintenance) personnel provide Controllers with real-time information regarding the state of scheduled maintenance services on aircraft and when serviced aircraft become available. Engineering maintenance also plays troubleshooting as well as advisory roles to the operations controllers in times of technical problems with an aircraft. They are also involved in negotiating potential swaps and diversions of aircraft in order to minimise impact on routine maintenance schedules. Similar to crewing, these responsibilities are typically shared across a number of maintenance controllers, who are placed in charge of specific types of fleet in larger organisations, such as companies A and B. Companies with less varied fleet types (e.g., Companies C and D), however, tend to have only one maintenance controller present at the operations control centre.

5.1.3.4 Customer service personnel (Customer liaison officer)

The Customer liaison unit provides the Controller with a ‘passenger perspective’ regarding the impact of changes and recovery options on passenger mobility across the network. More specifically, customer liaison provides information on the category of passengers on board—for example, their frequent flyer status, membership level, and seat class. Passenger characteristics are often a key determinant in the Controller’s decisions as to which flight to delay or cancel, particularly when an airline thrives on premium services.
5.1.3.5  Duty Manager

One or more duty manager(s) are assigned to oversee the overall coordination of operations. The responsibilities of a duty manager often include providing a leadership presence in the centre, ensuring that the representatives of the various airline functions work together during schedule execution, coordinating decision-making, resolving conflicts between groups, and ensuring that all groups act as one team and strive towards common objectives.

5.1.3.6  Other supporting functions

These aforementioned roles are typically supported by several other functions, such as station operations, despatch, and load control. Larger airlines may also have dedicated weather bureau officers, slot controllers, media watch personnel, and air traffic control (ATC) coordinators. Successful control of airline operations depends on coordinated actions of all key actors, including the supporting functions outside the operations control centre (e.g., station managers in charge of station resources, such as gates, catering, ramp handling and passenger handling facilities.

5.2  The research process

The central part of the study corresponds to ethnographic-styled investigations conducted at four airline operations control centres—three in the Asia-Pacific region and one in the Middle East. The field visits are discussed as a three-stage process embedded within a four-phase research process. A four-phase research process is used to highlight the key milestones, along with significant leaps in insight and shifts in the research goals and direction. However, the researcher has made a deliberate decision not to include detailed analytical processes and specific themes emerging from any specific phase in the research process. It became apparent that themes continued to evolve even towards the end of field investigations, requiring fresh open coding of organic data whenever significant ideas emerged. It would indeed be extremely pretentious to make representations that in any way suggest a definitive mapping between the various phases in the research process and the various stages of analysis. Far from such presumptions, the analytical process evolved organically through first insights and, occasionally, abductive reasoning. There were also systematic inductive cross-matchings, along with deductive theoretical substantiation, all of
which contributed in identifying and establishing links between substantive findings, abstract categories and theoretical discourses in the literature.

But, regardless of how ideas emerged, there was always a compulsive need to look back and re-assess links developed earlier in the analysis, as new conceptual categories came to light. The field study and analytical presentations in this section, therefore, represent an attempt to simplify exposition without diluting interpretation. This is achieved by focusing primarily on the significant activities in each phase along with outcomes that provided a foundation for the subsequent phase, and by avoiding the urge to present all recallable back-and-forth steps that occurred during the data analysis and verification processes.

With the approval of the participating companies, emails were sent to the staff in charge of key roles of interest at the operations control centres to solicit their participation in this research. An informed consent and a plain language document detailing the purpose of study were administered prior to the commencement of the observation and interviewing processes. Participants received a written brief before the inquiry began, informing them of the objectives of study as well as what would be required of those that would volunteer to participate. A written instruction was used rather than verbal instructions, so as to ensure consistency in the information presented to the participants.

### 5.2.1 Phase 1: Exploratory fieldwork

The first-stage visits served as briefing sessions to enable the researcher get acquainted with the study environment, the participants and the state-of-practice at the operations control centres. Three operations control centres were visited in the Asia-Pacific region in March 2012. A total of sixteen airline staff briefed the researcher on the *modus operandi* of their respective control centres. Most participants who took part in the preliminary study were line managers, operations controllers and crewing officers. The visits lasted approximately three to four hours for each site studied. Some control centres were visited more than once. The agenda at this stage of study was to draw on the participants’ years of service and expertise in airline operations control in order to capture context-specific variables at play at the respective operations control centres.

#### 5.2.1.1 Data collection

The participants provided insight into their roles and how their roles fit in the broader scheme of things, particularly with other control units in the centre. The discussions were
largely exploratory in nature, with some questioning sessions, and most of them took place at the respective desks of line managers and controllers who were on duty during the visits. In addition, observations were conducted at the workstations of the operations controllers (controllers), crewing and dispatch personnel. Studying participants at their workstations was particularly important as it enabled the researcher to capture events as they unfolded within their natural settings. As the exploration evolved, the participants shed more light on how they interact with other functional units in the operations control processes. During low-tempo periods and periods of minor perturbations, controllers and shift managers verbalised their recovery options and the rationale behind their choices. Deliberate measures were taken not to interrupt the controllers during periods of high workload by not asking questions or requesting clarifications except on a few occasions where some participants talked to the researcher through major disruptive events. Data was collected primarily using an iPhone 4 audio recording device where allowed and notes were taken where permission to audio record was denied.

5.2.1.2 Preliminary data analysis

Ideas gained from prior discussions were discussed with other controllers on the same day, in some instances, and during the second stage of study. Discussions were based on the relevance of the events to the roles and expertise of each controller to ensure that the documented observations and discussions reflect accurately the meanings that are held by experts within that aspect of airline operations control. The outcome of the preliminary study is discussed later in this chapter. The preliminary study provided insights and useful hints on ‘what to look for’ in the subsequent visits.

5.2.2 Phase 2: Protocol design and pilot exercise

5.2.2.1 Formulating the integrated resilience markers’ framework

Themes from the resilience engineering research were collated and applied in developing an integrated resilience markers framework. The integrated markers’ framework aims to extend current resilience markers’ framework (Furniss et al., 2011) to include the four cornerstones of resilience. Resilience markers represent a set of enablers (skills, competencies, abilities, etc.) that highlight the degree of resilience or brittleness of a system relative to specified system conditions and/or design envelope (Furniss et al., 2011, pp. 5-6). The goal of incorporating the four cornerstones of resilience into the resilience markers’ framework is to help make explicit the relationships between themes linked to the four
cornerstones of resilience (monitoring, responding, anticipating and learning) and the evidence that would be collected in the main study. Consequently, preliminary analysis was conducted to identify links between resilience markers, sets of strategies that have been identified in the same or comparable domains and sets of focused questions that are designed to provide answers with which to ground the markers and the strategies to concrete evidence in the field. A sample of such integrated markers’ framework was illustrated with Table 4.1 (Chapter 4). The marker-strategy-evidence sets were then linked to the four cornerstones in order to depict the relationship between each set and the components of the cornerstone framework. As mentioned in Chapter 4, most questions were adapted from probes presented in the resilience analysis grid (RAG) (Hollnagel, 2011a), and then supplemented by questions derived from the resilience engineering literature and the results of the preliminary study. Appendix C shows a comprehensive summary of resilience markers, strategies and tentative questions that acted as pointers in this investigation.

5.2.2.2 Drafting and validating the study protocols

The strategy adopted in developing the resilience markers’ framework can be argued to be largely deductive in nature. Nonetheless, it is important to note that the framework basically served as a guide for what to look for rather than a fixed set of themes or hypotheses that must be validated. Thus, the integrated markers framework only served as a starting point for identifying processes and events of interest during the observational and interview studies. Consequently, flexibility was allowed for in the probing process so as to follow up on emergent themes and interesting events that were not captured in the framework. As illustrated in (Appendix D), the short, focused questions in the framework were adapted in the interview protocol to ensure the questions were expansive enough. The expansive form of the questions opened an opportunity to explore varied directions and to locate distinctive experiences that enriched the data set. They further afforded possibilities for storytelling and narratives that enabled the researcher to explore nuances in the perspectives of the participants.

An initial version of the interview protocol was discussed with two airline operations control experts, who also participated in the preliminary study. Meetings were arranged individually to discuss the suitability of the protocol to the specifics of airline operations control, given that majority of the themes were developed in other complex work domains,
which do not necessarily share exact dynamics with airline operations. Concurrently, the protocol was also discussed with the three doctoral research supervisors to ensure that the interview questions were unambiguous, fit for purpose, and could elicit responses with sufficient variability. In addition, pilot exercises were conducted with two doctoral colleagues who had also applied interview protocols in their research projects. The pilot exercises focused more on the timing and consistency of information provided to the participants at different stages of the interview process. It is worth noting that pilot testing was not conducted using actual participants who work in airline operations control because it was considered that testing actual participants would exhaust the participant pool for the main study. Nevertheless, the pilot exercises provided insight on how one can adapt questions on the spot so as to follow up on emerging themes of interest. As a result, the protocol was adapted on the basis of lessons gained from the pilot exercises and the feedback received from both research advisors and domain experts. The ethics review processes further helped to refine the questions thereby improving the overall clarity of the protocol design and administration.

Critical operational points of interest were also identified during this phase of study. Formal interviews were arranged with available participants in charge of key roles of interest to further explore the emerging research themes. The collated field-notes were used in conjunction with deductively derived themes from the literature to design both observational and interview probes for the next stage of study.

### 5.2.3 Phase 3: Structured fieldwork

The second-stage fieldwork involved company visits at which in-depth exploration of themes were conducted through several 45-minute interviews and two-hour observational sessions. The central idea was to obtain as much information as possible regarding ways in which actors at the operations control centres collaboratively anticipate and monitor fluctuations in demand. It was also the objective of study to gain understanding into the distinctive mechanisms that support actors to respond readily to novel and extreme disruptions in the AOC work setting.

#### 5.2.3.1 Administering the interview protocol

Theme-focused interviews were employed for eliciting subjective views as held by the participants. During the interviews, participants were invited to describe the range of
demand situations they had witnessed as well as the state-of-practice in dealing with a wide range of demand variability they identified. The goal was to capture what makes the AOC work particularly challenging. Consequently, the researcher drew on the participants’ years of service and expertise in airline operations control in identifying context-specific variables at play at the operations control centres.

At this stage, in-depth interviews were undertaken in Company D’s operations control centre. This control centre was chosen for a pilot study because of its proximity to the university, which allowed easy access should further clarifications be needed. The interviews lasted approximately 18-hours per week over five weeks between August and December 2012. Although efforts were made to maintain consistency in the interviewing process, there were substantial variations in the actual questions directed at each participant for a number of reasons. First, the participants occupy different roles in the centre and therefore possess only a particular aspect of the knowledge required. Second, emerging issues were accommodated, as they provided new insights and direction to the research. Third, it was practically impossible to achieve quality discussion on all the questions drafted in the interview protocol within the one-hour timeframe. Hence, questions had to be tailored in accordance to the level of knowledge the researcher has acquired as at the time of the interview and the available time for the interview.

Before the start of each session, the researcher rehearsed the interview questions to facilitate a naturalistic style of questioning. A conversational approach was then adopted to ensure that the way the questions are framed would neither inhibit free-flowing discussions nor constrain responses. This strategy enabled the researcher to phrase interview questions in rapport talks, which in turn elicited more storytelling and narratives rather than short direct answers. Further, the free-style discussions encouraged spontaneity and responsiveness necessary for an in-depth examination of complex and rapidly changing processes. As a result, participants talked freely about their work and experiences and other issues that were of interest to them. But, at the same time, the researcher was mindful that measures needed to be taken to avoid drifting precariously from the research goal. Hence, participants were called upon periodically to address specific themes that are of interest to this research. In addition, a checklist of issues that needed to be addressed was applied periodically to refocus the direction of conversation. More specifically, the researcher applied discretion in requesting two-minute breaks periodically in order to perform a
checklist of issues that have been addressed and others that still beg for answers. Nevertheless, caution was applied not to overdo the checklist activity.

The interviews were recorded using an Apple iPhone 4 to capture the entire conversation. In addition, handwritten notes were used to capture emerging themes that could be explored further. Six sessions were arranged each week to allow for preliminary analyses of data collected in-between visits (all data were later subjected to rigorous analysis). Such preliminary analyses improved the researcher’s sensitivity to possible conceptual relations that exist across the emerging research themes. As a result, field memos (research journal) were developed through abductive reasoning through reflection on the findings, which in turn facilitated the incorporation of themes that have emerged into subsequent interview sessions. The interview study was considered complete when successive interviews and preliminary analyses started returning responses and data that were converging around same core concepts and drivers, a phenomenon referred to as ‘theoretical saturation’ by the grounded theory tradition (Glaser & Strauss, 1967).

5.2.3.2 Observational studies

Observational studies were conducted in-between interview sessions primarily to follow up on emerging themes. Data collected through the observations that followed after the interview sessions were particularly useful in clarifying the participants’ responses through situated actions. In other words, a more insightful knowledge was produced by observing the participants’ actions than from their explanations. However, such insights might not have been as obvious as it appeared in hindsight if those issues were not discussed during the interview. As neither the company nor Swinburne ethics committee approved video recording, data collection was restricted to note taking and audio recording, subject to each participant’s approval.

Given the integrated layout of the operations control centres, it was sometimes necessary to record interactions between a participant and another staff member, who had not signed an informed consent for this study, which initially presented a challenge that needed to be addressed before commencing a full-scale observational study. This was resolved by informing such non-participating staff members of the intention of the researcher and by focusing only on participants who had given their approval to be observed. All participants were observed and/or interviewed at their respective workstations. Nevertheless, observations of collaborative deliberations and other forms of cooperative interactions
(e.g., when members of two or more units convened to discuss potential solutions) also provided rich data for this study. Data collected and lessons learned at this stage of study proved useful for refining the observation procedure and for conducting comparative analyses between practices and processes in this particular control centre against the other centres participating in this study.

5.2.4 Phase 4: Focused study and scholarly reflections

5.2.4.1 Focusing the study

The third-stage fieldwork involved more focused observation sessions and informal discussions. At this stage, a fourth operations control centre in the Middle East was visited, thereby extending both the regional mix and operating cultures across participating airlines. The main agenda was to compare practices and processes across the operations control centres participating in this research so as to make sense of the variances in strategies adopted in dealing with similar situations. The structured observation framework was particularly useful in focusing the research on similar recovery processes and events across the control centres and in ensuring that issues identified during the previous visits were explored in greater depth.

Nevertheless, the study duration requested was not granted in full because of the timing of study. Besides, the company management approved only non-intrusive observational studies, with very few opportunities for questioning, inside the operations control room. Also, audio recording was restricted inside the control room, and was only allowed during brief questioning and interviews with three approved staff members, who were in supervisory roles. The third-stage fieldwork was completed in December 2012 and further clarifications were sought from individual participants via telephone and electronic communications.

Note taking was mostly used during the focused observation stage. Another constraint during observations springs from the fact that conversations at the operations control centres often involve other functions that are not actually located in the same room, such as ground controllers and station managers. However, despite the constraints imposed on data collection, many participants were generous and patient enough to wait for notes to be taken during discussions. One setback though was that the only two participants responded to follow up messages for further clarifications as promised.
Overall, the requirement to minimise the use of electronic device for data collection during this stage is largely compensated for by the methodological triangulation techniques applied to abstract information from more diversified sources (including interviews, observations and document analyses). Further, the variety and range of expertise—including, senior managers, middle-managers and frontline controllers—allowed for an appropriate mix of characteristics, ideas, views and doctrines. Besides, the researcher considered that the effect of such restrictions on data elicitation would be minimal to this study because the data collected at this stage were used mainly to focus and enrich the data set obtained from the first and second fieldwork. Although the risks of having restrictions on data collection methods were anticipated, the decision as to how to collect data from participants was not the researcher’s alone, as the participants had to agree to the method proposed before such protocols were deployed. The effect of not using an audio recording device is easily noticeable in the difference in reporting style chosen for data collected through handwritten notes—the use of case scenarios to paraphrase or summarise stories. Concerns around this reporting style are documented as part of the limitations of the study in Chapter 6.

### 5.3 Data analysis and report of findings

This section provides an overview of the analytical approach followed and the theoretical constructs generated in the process. In many respects, the analysis of data closely follows the grounded theory traditions. For example, there were significant first insights and preliminary analyses of data during the data collection processes. One notable benefit of concurrent generation and analysis of data as employed in this research is that it hastened the emergence of relationships across the categories and further facilitated quick identification of relevant constructs. Conversely, it could also be argued that such quick emergence might have inadvertently led to a quickened focusing process, which might in turn restrict a wider exploration of possibilities. Also, drafting a memorandum of emerging ideas played a significant role in this study. In the study, writing memorandum of reflections became not only an essential process but also a critical tool for concurrent data collection, reflection and analysis, especially during observational studies and when audio recordings were not permitted.
5.3.1 The dynamics of demands in airline operations control

The first stage of the analytical process was targeted toward understanding the dynamics of demands in airline operations control. The open coding process started with identifying responses to a common question. The sample responses shown in Table 5.5 were provided by two operations controllers (OPC-01 and OPC-04) and two supervisors/duty managers (DM-01 and DM-06). This initial coding produced a diverse, rich set of responses on views held by these two key functions at the operations control centres. In addition to controllers’ direct responses, notes from the researcher’s observations and from conversational scripts amongst frontline controllers were employed to enrich the researcher’s understanding of how controllers respond to a disruptive event.

Table 5.5: A sample list of responses to a common question

<table>
<thead>
<tr>
<th>Interviewer: Describe how you respond to disruptive events?</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Acquiring requisite knowledge for dealing with an event</td>
</tr>
<tr>
<td>= Escalating problems to where expertise resides</td>
</tr>
<tr>
<td>= Addressing a problem and communicating decisions</td>
</tr>
</tbody>
</table>

**Respondent (OPC-01):** It depends on what the event is really; there is always a particular department I can seek advice from. Like if it’s a security issue, I’ll contact the airline security straight away. If it is something that relates to the aircraft, I’ll do a conference call with maintenance watch and the duty captain. If it’s something that I feel we don’t have a procedure for, I’ll deal with the issue first and then do a follow up later on with an email to a manager or whoever highlighting the fact that we don’t have a procedure or something in our manual that covers that event.

**Respondent (OPC-04):** Usually, information regarding some form of issue comes into the ops control area and we basically start to handle it from there. Once we know what the issue is, we’ll escalate it to the necessary areas. If it is a maintenance issue, we will talk to our maintenance controller, and let him know. We will then liaise with the engineer in the relevant port or he will speak directly on the HF or the set-phone to the pilot with the issue. Once we’ve ascertained the issue and we know it’s going to cause us some problems, we will then speak with crewing to check the crew hours, to make sure they are not breaching any of their hours. Once all of that has come together in the operations control centre; once we’ve ascertained all those issues, we (the ops controllers) will then go back to the ports and advise them of our plan. The port will then implement the plan.

**Respondent (DM-01):** When somebody rings us or tells us that there’s an issue, we’ve got this trigger list as guidance for our [Crisis Management] triggers. So we have a look at that, and if we feel that it needs to be escalated, then we will do a [Crisis Management] meeting. The meeting is basically ringing these people up here (names on the board), getting them on a conference call, telling them what the event is, and we take it from there. But, if we feel that something is a normal day-to-day stuff (event), we will handle it, like cancellations and whatever, and we SMS out. So there are numerous people on this list that we SMS out to, so everybody knows what’s going on. We’ve got parameters around that; a good thing is, I may SMS something because I don’t think it needs to be escalated, it’s SMS that because it is under our requirement to do that, that also goes to senior management, etc. So if they felt that I should have escalated further, then they can contact me, I mean, I suppose that’s a backup way there.

**Respondent (DM-06):** If I got a call, or the ops controller got a call, or the maintenance got a call, to advise that there was a smell in the cabin, or a haze or fume of any description, I would immediately call a [Crisis Management] meeting. I will get the details. And that’ll all be discussed. It’ll be checked [to see] has it had a prior.... has this occurred before, had there been any issue with this aircraft, and all sort of things will all be looked into. And then, providing if it was all ticked off, the [Crisis Management] team would then liaise with engineering before that aircraft can fly again.

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The first categories of abstraction were generated by classifying responses and notes according to some commonalities in themes and perceptions, as captured in the data set. Table 5.5 captures a sample list of responses to a common question. The first coding process (from this sample data set) highlighted three processes that help to understand how controllers manage disruptions—how controllers acquire knowledge for addressing a problem, how they determine and escalate problems that require specialist or broad expertise, and how they coordinate the process of decision-making and communication.

### Table 5.6: Abstracting codes from the second-stage open coding process

<table>
<thead>
<tr>
<th>Interviewer: Describe how you respond to disruptive events?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquiring requisite knowledge for dealing with an event:</strong></td>
</tr>
<tr>
<td>There is always a particular department I can seek advice from. Like if it's a security issue, I'll contact the airline security straight away. [OPC-01]</td>
</tr>
<tr>
<td>We've got this [a trigger list] as guidance for our [Crisis Management] triggers. [DM-01]</td>
</tr>
<tr>
<td><strong>Escalating problems to where expertise resides:</strong></td>
</tr>
<tr>
<td>I'll do a conference call with maintenance watch and the duty captain [OPC-01]</td>
</tr>
<tr>
<td>Once we know what the issue is, we'll escalate it to the necessary areas. If it is a maintenance issue, we will talk to our maintenance controller, and let him know. We will then liaise with the engineer in the relevant port or he will speak directly on the HF or the set-phone to the pilot with the issue. Once we've ascertained the issue and we know it's going to cause us some problems, we will then speak with the crew to check the crew hours, to make sure they are not breaching any of their hours. [OPC-04]</td>
</tr>
<tr>
<td>So we have a look at that, and if we feel that it needs to be escalated, then we will do a [Crisis Management] meeting. The meeting is basically ringing these people up here [names on the board], getting them on a conference call, telling them what the event is, and we take it from there. [DM-01]</td>
</tr>
<tr>
<td>I will immediately call a [Crisis Management] meeting. I will get the details... [DM-06]</td>
</tr>
<tr>
<td><strong>Addressing a problem and communicating decisions:</strong></td>
</tr>
<tr>
<td>I'll deal with the issue first and then do a follow up later on with an email to a manager or whoever highlighting the fact that we don't have a procedure or something in our manual that covers that event. [OPC-01]</td>
</tr>
<tr>
<td>Once all of that has come together in the operations control centre; once we've ascertained all those issues, we (the ops controllers) will then go back to the ports and advise them of our plan. The port will then implement the plan. [OPC-04]</td>
</tr>
<tr>
<td>But, if we feel that something [is a] normal day-to-day stuff (event), we will handle it, like cancellations and whatever, and we SMS out. So there are numerous people on this list that we SMS out to; so everybody knows what's going on. We've got parameters around that; a good thing is, I may SMS something because I don't think it needs to be escalated, I'll SMS that because it is under our requirement to do that, that [also] goes to senior management, etc. So if they felt that I should have escalated further, then they can contact me. I mean, I suppose that's a backup way there. [DM-01]</td>
</tr>
<tr>
<td>That'll all be discussed. It'll be checked to see has it had a prior..., has this occurred before, had there been any issue with this aircraft, and all sort of things will all be looked into. And then, providing it was all ticked off, the [Crisis Management] team would then liaise with engineering before that aircraft can fly again. [DM-06]</td>
</tr>
<tr>
<td><strong>Seeking expert advice</strong></td>
</tr>
<tr>
<td>Using pre-defined protocol</td>
</tr>
<tr>
<td>Engaging specific functions</td>
</tr>
<tr>
<td>Engaging specific functions</td>
</tr>
<tr>
<td>Engaging a committee with broader skill-set</td>
</tr>
<tr>
<td>Engaging a committee with broader skill-set</td>
</tr>
<tr>
<td>Address the problem before sending out an FYI</td>
</tr>
<tr>
<td>Work out plans and then advise affected units to implement</td>
</tr>
<tr>
<td>Address the problem before sending out an FYI</td>
</tr>
<tr>
<td>Involve higher authority in solving the problem</td>
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</tbody>
</table>
The second stage of the open coding process involved cross-checking responses within the same category to identify commonalities and subtle differences within a given category. This process produced a list of sub-categories and provides insight into the diversity and richness of the phenomena in each category. For example, analysis of the escalation responses in the second row of ision-making and communication.

Table 5.6 suggests that there are two distinct strategies that controllers employ when engaging other functions in solving a problem. From first insight, it appears controllers engage either specific functions where specialist expertise resides or generalists committees that have broader skill-sets.

Table 5.7: Identifying conceptual codes in each category
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Problems considered routine control practices:

...if we feel that something is a normal day-to-day stuff, we will handle it, like cancellations and whatever, and we SMS out. (DM-01)

That section [on the board] is just a bit of a helping hand for our ops people here, so it's just giving us performance restrictions right at the top...For example, we know in [an airport] we haven't got a ground power unit, so we don't send aircraft that uses auxiliary power units there because we won't be able to start the aircraft. So if maintenance said to us an aircraft has got a USAPU [unserviceable issues with the Auxiliary Power Unit] and it's going to [that airport], then we have to make an immediate switch because the ground power unit there is unserviceable. Our ops people can handle this on their own because it's got a well-defined rule. (DM-01)

When we are switching an aircraft, we have to be very careful, [because] an aircraft may not be able to go to a certain port because it may have what we call a "MEL" [Minimum Equipment Listing] defect, which means it can fly but it can't or may not be able to go to a certain port, or might have some sort of restrictions... For example, there may be a minimum equipment listing (MEL) that precludes an aircraft from flying into 30m runways. So that means, we can't put that aircraft flying into [an airport], because that's a 30m runway. So we need to check that before we switch an aircraft; and we know that by the MELs sitting up there [on a notice board]. So before we switch an aircraft, we will always look at the MELs [on the board] to make sure. (OPC-01)

Problems needing escalation:

When an issue surfaces...you sort of go through these things [the crisis trigger list], and if there is any security threat or anything that you think could hit media, immediately we call a [crisis management team meeting]. (DM-02)

We take seriously any infringements on our safety practices here, especially with regards to maintenance control, fatigue management and pilot training...I personally don't like the same error, violation or whatever you'd like to call it, to slide through more than once. It doesn't always look good from [the regulator's] perspective. (DM-07)

You know [a regulatory body] suspended [an airline] last year because they had a series of safety issues regarding their operations. That's why we involve some members of the senior management in a [crisis meeting]. Our procedure here is that certain members of the senior management must be made aware of certain events, especially if it has happened before. (DM-03)

Yes, we had an incident with our booking system, and lots of passengers were stranded, lots of media interest exaggerating the enormity of the problem...so senior management requested for a full crisis escalation and a number of senior executives were placed on conference calls over three days until the backlog was finally resolved. No one likes bad publicity. (OPC-06)

An examination of the second-level category codes and their links to OPCs and DMs will quickly suggest that OPCs lean towards specialised functions, while DMs tend to favour broader crisis management committees. However, the researcher had much more diverse data set that enabled him to resist making such quick correlations. The data set presented in Table 5.7 begins to clarify why and when controllers engage either a specialist function or a generalist committee, the composition of such generalist committees, and why DMs appear to be the ones that make the call to engage a crisis management committee. This distinction provides a rich context for making sense of controllers’ adaptive behaviour in the face of specific types of demands, in the sense that it provides concrete situations
where routine protocols are followed and situations that require the involvement of blunt-end managers in frontline decision-making. Table 5.7 provides some responses regarding demand situations and codes abstracted from those responses.

Analysis of a more comprehensive data set—comprising the interview responses and observational notes collected in this study—suggest that specialist functions are usually called upon when the nature of the disturbance and the skill-set it requires are well understood. That is, controllers engage specific functions directly when a disruption is part of normal operational routine, such as engineering maintenance or crew sickness. The data also show (e.g., DM-01’s response in decision-making and communication. Table 5.6 and Table 5.7) that no escalation to higher authority or a crisis committee is required if there is no significant threat to life, serious breach of air transport regulations, or damage to company image/business continuity. In contrast, a developing problem will immediately be escalated to higher authority if there is any perceived threat to life or any significant economic implication.

In regards to how they manage dynamic decision-making and communication of events, the results (in decision-making and communication. Table 5.6) suggest three possible strategies. First, controllers can address the problem without consulting higher authorities and then send out a notification to inform everyone of what had happened. Second, controllers can formulate ways to address a global problem, and then advise specific functions on how to go about solving their aspect of the problem. Third, controllers can quickly involve higher authority to help work out a solution to a problem. Again, the reasons why the respondents decided on a specific strategy could easily be abstracted from their respective responses in decision-making and communication.

Table 5.6—for example, when there is no procedure for a problem (OPC-01), when the problem can be promptly ascertained (OPC-04), simply following a pre-defined protocol (DM-01), or if a problem is serious enough to warrant attention from higher authorities (DM-06). Based on first insights, it appears there is a link between the two categories (escalating problems to where expertise resides and managing dynamic decision-making/communication). The next stage of analysis focuses on establishing such links
more empirically, including identifying more obvious connections and less conspicuous dynamical relationships.

### 5.3.2 Identifying spheres of influence

The intermediate stages of the coding process were targeted towards eliciting spheres of influence that drive adaptation in airline operations control. The conceptual framework developed during the open coding process seems to suggest that there is a link between demand situations and the kind of responses they elicit. Therefore, the focus of study at this stage of coding was to gain insight into the forces that shape the kind of responses and the control architectures that are employed to handle such demand situations. In regards to the dynamics of demands in airline operations control, the participants’ descriptions of demand situations appear to suggest three distinct scenarios: a well-understood problem that requires a well-defined protocol/rule, a novel scenario that may or may not be serious enough to warrant escalation, and a severe scenario that can significantly impact the company in a number of ways—safety, media, socio-political, etc.

To aid exposition, participant responses are presented as two broad subsections relating to their emphasis on safety/security and operational considerations. At this stage, effort has been made to rely more on concepts expressed in the participants’ comments or taken from the practitioners’ way of representing their work for naming categories and sub-categories. Again, participants’ responses were largely corroborated by formally documented processes for crisis escalation in two of the four airlines, where such formal operational documents were made available for the purposes of this study.

#### 5.3.2.1 Safety and security considerations

Discussions on crisis escalation practices tend to emphasise precursors that determine whether to escalate perceived safety or security threats to a crisis management team. As captured in the first row of Figure 5.1, the participants reported that the severity of an incident (as documented in the formalised procedures), along with its unique characteristics, determines who they call upon for crisis management deliberations.
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If there was a fire, including smoke fumes and explosions, that means the blue code (a colour code on the crisis trigger list). I’ll have to set up a conference call involving the executive duty manager, duty captain, maintenance person, safety department and also the management controller. I’ll conference them all over the phone, have a discussion to work out the problems, and will also send out an SMS on the crisis to a list of experts. If anyone thought, ‘well, this needs to be escalated further’, it could be picked up. (DM-02)

If I got a call, or the ops controller got a call, or the maintenance got a call, to advise that there was a smell in the cabin, or a haze or fume of any description, I will immediately call a crisis management team meeting (DM-06)

If someone informs us of a mechanical problem or breakdown with an aircraft, we try to get relevant experts to talk about what happened. That way, hopefully, we get everything covered off in there; and from there, they will decide whether the problem needs to be escalated further to a full crisis or whatever. (OPC-5)

You sort of go through these things (the crisis trigger list), and if there is any security threat or anything that you think could hit media, immediately we call a crisis management team meeting. (DM-02)

We take seriously any infringements on our safety practices here, especially with regards to maintenance control, fatigue management and pilot training… I personally don’t like same error, violation or whatever you’d like to call it, to slide through more than once. (DM-07)

When we call a crisis team meeting, the group might suggest we let the CEO know about the problem, or public relations (PR), or safety department, etc. In that way, if it makes media, you won’t have the CEO and everybody sort of ringing asking, ‘what’s all these about?’, as they’ll already know. (DM-01)

You know (a regulatory body) suspended (an airline) last year because they had a series of safety issues regarding their operations. That’s why we involve some members of the senior management in a crisis meeting. (OPC-11)

Yes, in different countries, like in the EU zone, there is a requirement on airlines to move people within a specific time or provide temp accommodation for them. I think we’ve got a rule of thumb that says we have to attempt to move people within 24 hours… [so] in domestic operations, we’ve got [name of airline] as partners, so that helps. They can usually help us out if need be to move people. So, you can say it’s our social responsibility to our passengers. (OPC-08)

A number of security initiatives were launched after 9/11. There was a program where armed security in casual clothes are stationed in almost every international flight. It is actually more of a political thing, you won’t be allowed to fly to certain countries at the time without having such security measures in place. So, we often get into caught in diplomatic squabbles and we have to play along to remain in their [national governments and regulatory bodies] good books. (DM-06)

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**Figure 5.1: Grouped responses relating to influencers of safety and security considerations**
Likewise, discussions on how airlines ensure the security and safety of their passengers also yielded interesting triggers that shape how frontline controllers respond to an event. The snippets from their narratives in the second row of Figure 5.1 illustrate how a range of regulatory, diplomatic and socio-political factors that could colour a controller's perception of the seriousness of an event and the level of escalation that might be required. An abstraction from their narratives is that both senior management and regulators frown upon safety lapses that seem repetitive—as captured in DM-07’s comments in the second row of Table 5.7 and first row of Figure 5.1. Both DM-07’s comments and DM-03’s comment in row 2 of Table 5.7 also suggest that reoccurrence of similar class of safety incidents within a relatively short period of time would very likely require an escalation and a more diverse composition of a crisis team. Also, it appears the sort of triggers encoded in the first row of Figure 5.1 could easily be appropriated against an airline. Consequently, it seems more likely that events that involve such triggers will generate a lot of interest across the governing boards of companies; and therefore, would most certainly involve many senior management personnel.

5.3.2.2 Operational considerations

On the topic of maintaining the feasibility of flights and resource schedules, snippets from the first row of Figure 5.2 appears to converge on a need to restrict the number of disrupted variables, including aircraft, crew, passengers, and baggage. The snippets, again, suggest that engaging resources from more flights mean that more resources would need to be replanned and, as a matter of consequence, would require more aggressive strategies so as to regain control. The impact of the 2011 volcanic eruptions in Iceland and Chile on airline operations was also referenced by the participants in their tales of large-scale challenges they had experienced recently (OPC-09’s comment on first row, and CRW-02’s comment on second row of Figure 5.2).

Again, in the second row of Figure 5.2, participants made clear distinction between knock-on reactionary disruptions that started from a singular origin and spread across other airports, and interactional disruptions that emerged as a result of collision of localised adjustments that impacted multiple resources across several airports. Participants’ responses largely touched on the anticipatory challenges posed by the subtlety of concurrent evolution of events and the difficulty in pre-empting how multiple, localised responses might interact globally.
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When massive disruptions happen, there will be cancellations, lots and lots of it...the Iceland volcano for instance lasted for a few days and we had many aircraft and crew trapped in Europe. There were very little options really, you only do what you can to minimise your losses. (OPC-09)

I often base my decisions on which crew member to delay or re-assign on the effect a cancellation or delay will have on other resources, like will it render the rest of the crew illegal? Will it create any reactionary delay? If there are connections, I'll try to work out who's on the flight and whether they will be connecting to an international or domestic flight...so it's basically the impact on other flights that will dictate my options (CRW-01)

There's a rule of thumb I use...keep it simple, don't over-extend the problem to include unaffected ports and flights unless there is a very good reason to do so; and where possible, contain the problem within the ports or rotations where it originated. (OPC-03)

It's always challenging when we have unanticipated problems with crewing occurring at the same time, particularly if the problems occurred at different ports. That means, we have to make series of localised adjustments and sometimes it is hard to see how that plays out across the network in the long run. This sort of problems end up creating bottlenecks down the track, and when that happens, we may only have the option of cancelling flights to regain a bit of control. (CRW-04)

After the Iceland volcanic event, we were left with a huge mess to deal with because our crews were scattered across Europe, and it was tough managing multiple duty re-assignments for both flight and cabin crews stranded at different ports...a lot of variables around their EBA needed to be considered, some were already away from home more than their agreement allowed...It's always a tricky situation dealing with multiple re-assignments across our network (CRW-02)

It depends on where they [flight/cabin crew] got sick, what port they got sick in and it also depends on our coverage, whether we have a crew available on that particular day at that particular time, and also whether we have crew on standby at the airport. So it varies. But if we have crew on standby at home, they have to be at the airport within 90mins. We do have some domestic crew that are on special EBA (Enterprise Bargaining Agreement) and they've got 2 hours to get to the airport. (CRW-04)

If we had a few spare seats on a flight headed for the same port or a spare aircraft when the disruption happened, then we may be able to move our passengers on other flights. But our flights normally operate at full capacity, so a routine disruption could quickly degenerate to a long messy operation if we don't have the required resources available at the port or time where it happened. (OPC-03)

<table>
<thead>
<tr>
<th>Influencers of scale</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapped resources</td>
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<tr>
<td>Impact on other resources</td>
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<tr>
<td>Containing the problem</td>
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<tr>
<td>Collision of localised adjustments</td>
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<tr>
<td>Dealing with multiple and reactionary disruptions</td>
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<tr>
<td>Unavailability of requisite resources</td>
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<td>Unavailability of standby crew</td>
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<td>Unavailability of spare aircraft</td>
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<td>Unavailability of spare seats</td>
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</tbody>
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**Figure 5.2: Grouped responses relating to influencers of scale**
Further, both CRW-04 and OPC-03 commented that the unavailability of requisite resources might change the landscape of a demanding situation, in the sense that a disruption that started small might get out of control if the required resources were not available for addressing such escalations at the onset. The third row of Figure 5.2 provides snippets that capture insights into this form of challenge in the AOC work domain.

The time needed to replan and respond to a challenging event was also identified in the participants’ narratives. The choice of words used, along with the illustrations provided by six participants (three crewing officers and three operations controllers) suggest that many frontline controllers view their daily routine as more anticipatory “problem solving”, and less “reactive” control as suggested by their work designations. Participants seem acutely aware that schedules are hardly executed as planned, and that there is usually not enough time to respond, given the pace of activities across the network. It is, therefore, routine for units to “…have their eyes and ears open…” for potential and actual threats (and opportunities) to their operational goals. The art of “keeping one’s eyes and ears open” is vividly captured in some participants’ remarks shown below and in the first row of Figure 5.3.

Yea, I can pick up on issues if flights are running late, or if I am pushing curfews on different lines. So yea, I can forward-think. If an aircraft broke in Auckland, that can affect all the other ones in the network, and I have to work out how that can have a follow on effect on the network. (OPC-07)

We definitely rely on all the different departments to let us know what’s happening in the network. We are not in the airport, so we can’t see some things. We are the first point of call for the airports and everyone in here to let us know if there are issues with the operations. But we don’t always wait to be notified of problems; sometimes we pick up on problems by scanning the system. (OPC-02)

Complementally, findings from the observational studies evinced that many of the practitioners across the four operations control centres spend a great deal of time scanning various screens during low-tempo operations and listening in on passive communications across the room. For example, it was almost a ritual for someone to ask a colleague after a phone call or face-to-face conversation “…who called or what did s/he said…” particularly amongst controllers, crewing staff and despatchers. Evidence that this act of eaves dropping is considered normal at the operations control centres and that practitioners are well aware of their actions is depicted in the last two snippets in the second row of Figure 5.3.
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#### Influencers of recovery time

<table>
<thead>
<tr>
<th>Influencers of recovery time</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>We are always on the lookout for possible disruptions. Experience tells us where to look depending on time of day, day of the week, or any special event, or anticipated weather developments provided by (a bureau of meteorology). For example, some cities are prone to disruptive thunderstorms at some times of the year, so we try to factor that in when deploying reserve resources at various airports. (OPC-02)</td>
<td>Anticipating a disruption</td>
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<tr>
<td>My work basically revolves around tracking events in our network to ensure that my flight and cabin crew have sufficient time for their assigned duties. So, any potential illegality (a term used at the IOCC to describe a crew that has gone over his/her allowable flying or working hours) or complication arising from reduced airport capacity, slot request issues, or equipment breakdown needs to be dealt with speedily to minimise reactionary delays to later flights. (CRW-01)</td>
<td>Tracking crew illegality</td>
</tr>
<tr>
<td>We listen in on one another’s conversations to keep track of the state of things across the networks as well as other peripheral developments that might provide a better option than our current plan. But most times, I pick up on situations that could render any of my crew illegal...delays in pushbacks or runway congestion is very common. (CRW-02)</td>
<td>Tracking the state of things</td>
</tr>
<tr>
<td>Yesterday, we had a ground operational issue with one of our baggage loading equipment at [an airport]...I overheard that information from (a controller) conversation with our ground control manager and quickly made contacts with some reserve crew at [some other airports] to step in and cover the remaining flight legs originally assigned to the crew affected by the problem. That early contact saved the day, we were already behind schedule and some of the crew wouldn’t have made it had I waited for the flights to be cancelled before making contacts. (CRW-05)</td>
<td>Proactive engagement of resources</td>
</tr>
<tr>
<td>Our operations are very sensitive that even a 30-mins downtime could cost us a whole day. For instance, there was a security lapse at terminal 2 of [an airport, in April 2011]. A ground staff called to let us know there was some sort of power failure and 16 passengers passed through the security checkpoints unscreened. For security reasons, [the airport authority] stopped all flights waiting to take off and ordered a rescreening for all passengers at the terminal including those that have already boarded...it was a massive chaos, I think we had a backlog of well over 2000 passengers and I had to cancel about 15 flights when delays kept extending over six hours. It was obvious implementing delays wasn’t helping to placate already aggrieved passengers. We finally resorted to cancellations especially for our international flights, and the remaining passengers were checked into nearby hotels. That small incident took us almost two days to get back on schedule. (OPC-06)</td>
<td>Sensitivity to downtime</td>
</tr>
<tr>
<td>The unexpected always happens too on the day. You can get crew that goes sick mid-duty. So, they are on a four sector day, they may do one sector and not feel well. They may go sick and it may be in a port that’s not our crew base, so we have to adjust and work around all of those things. (DM-01)</td>
<td>Sudden/Unexpected event</td>
</tr>
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</table>

**Time window for replanning and response**

**Figure 5.3: Grouped responses relating to influencers of recovery time**
The six respondents seem to share a view that “forward-thinking” is particularly crucial in the AOC business because ‘sudden’ events—that is, unplanned-for events that have immediate impact—are highly detrimental to their operations. Two instances were shared relating to the impact of, and strategies employed to deal with, sudden events in the form of system breakdowns. The two instances involved mechanical breakdown of an online booking reservation system, and a security screening system at an airport. In both instances, there were large scale cancellation of flights that lasted for days and cascading effects that continued for weeks long after the incidents. Again, row two of Figure 5.3 captures narratives of the two events.

Also, there were instances of protracted and slowly evolving events that left reasonable window of opportunity for replanning and response. Two duty managers shared how their control centres progressively monitor and adapt operations during protracted events (also see the last snippets in row two of Figure 5.3):

A good example of it was the ash cloud (Chile volcanic eruption of June 2011). We had regular [crisis management] meetings, like every morning, sometimes 6 hours, because the problem kept evolving. Ordinarily, a phone hook-up would be conducted and decisions made right there: like, what are we going to do, is the problem dealt with? If not, maybe we need to reconvene in the next 5 hours or 10 hours. (DM-05)

It depends on the problem, if the problem can be dealt with in the first phone call, closed and that’s it, we’re done, we’ve got our answers and here’s what we are going to do! But, if the problem is evolving, we might have regular [crisis management] meetings all the time. (DM-02)

Lastly, the degree of novelty of a demand was another recurrent theme across participants’ responses. As shown in Figure 5.4, participants often described their experiences based on whether they had personally experienced a similar situation before, and how their relative experience with a similar situation can influence their choice of strategies. To some, the degree of novelty was described relative to whether their particular operations control centre as a unit has responded to a similar situation, or whether there is a procedure for dealing with such situations in their company. For some events, two participants extended their boundaries for describing ‘novel events’ to the commercial air transportation industry as a whole. An interesting aspect of this global depiction of novelty is that it focuses on the scale of a disruptive situation, as one participant in particular (DM-07) raised objections that
there is hardly anything “new” about events the industry have witnessed other than their scales and resultant effects. The argument about the September 11 terrorist attacks on the World Trade Centre and a story of how a company had to transport a human organ in a cabin were some examples that the participants used to discuss varied degrees of novelty.

<table>
<thead>
<tr>
<th>Influencers of anticipatory response measures</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 9/11 there has been series of hijacking, some successful, some not...so that wasn’t really a novel event as many would like to think, we [aviation industry] have always had a procedure for dealing with plane hijacking prior to 9/11. But, some might look at 9/11 as significantly novel because it caused a massive overhaul of airport security systems, impacted heavily on passenger traffic worldwide, and we [airlines] are still paying for the increased operating costs through several security programs launched after the 9/11 attacks (DM-07)</td>
<td>Novelty as a function of impact and change in operative landscape</td>
</tr>
<tr>
<td>From time to time, we continuously come across things we can improve on. An example of that would be a couple of years ago we had a carriage of human organs transported in the cabin. We had a situation in Perth where we needed to transport human organs to Melbourne and we didn’t have a procedure for that. So what happened is that the freighting company that is normally used don’t have enough time to get them across and wanted us to carry them in the cabin. So, we had to actually ask the captain for advise since we basically don’t have a procedure in the manual for transporting human organs. (OPC-01)</td>
<td>Novelty as a function of failure of foresight</td>
</tr>
</tbody>
</table>

Figure 5.4: Grouped responses relating to influencers of anticipatory response measures

5.3.2.3 Summary of the axial coding process

The axial coding process started with a supposition that there is a link between demanding situations and response strategies, as abstracted from the preceding open coding process. Figure 5.5 captures a simplistic mapping of demanding scenarios against various response strategies, as captured in the participants’ responses. This simplistic map provided a framework for reasoning about possible combination of the elements. For example, what will happen when a seemingly routine or severe event has no procedure; how do controllers address problems that are severe but well-understood or problems that are severe and not well-understood, and the like? A more elaborate discussion on the products of such reasoning and the combinations observed at the operations control centres are well captured in the discussions of how airlines negotiate decision authority.
Further, almost all participants emphasised that priority is given to safety- and security-related events. The descriptions in pre-specified guidance tend to highlight the appropriate response for a given scenario. However, controllers tend to focus more on the severity levels or the consequence aspect of demands when describing or classifying safety and security demands. Their descriptions of safety- and security-related demanding situations—along with the resulting responses they require—appears to revolve around control practices and escalation protocols they adapt to manage different forms of demands.

In contrast, the participants’ narratives regarding operational considerations seem to converge on six key themes: restricting the number of variables that needed to be controlled, dealing with multiple and/or reactionary disruptions, unavailability of requisite resources to meet escalating demand, pre-empting a problem before it makes landfall, making the most of the time window available for replanning or responding to a challenge event, and the degree of novelty of the situations encountered. Collectively, the two trajectories of considerations provide a framework for articulating the advanced, focused coding exercise. Figure 5.6 captures the relationship between the open codes and the two-stage axial abstractions.
Chapter 5: Field Study, Data Analysis and Findings

**Challenges to managing demand variability**

- Trapped resources
- Impact on other resources
- Containing the problem

- Collision of localised adjustments
- Reactionary disruptions from same source

- Unavailability of standby crew
- Unavailability of spare seats
- Unavailability of spare aircraft

- Anticipating a disruption
- Tracking crew illegality
- Tracking the state of things
- Proactive engagement of resources

- Sensitivity to downtime
- Sudden/unexpected event
- Gradual evolving event

- Novelty as a function of impact and change in operative landscape
- Novelty as a function of failure of foresight

- Smoke, fumes and explosions
- Mechanical breakdowns
- Crew fatigue
- Security threats

- Media interests
- Regulatory forces
- Social requirements and responsibility
- Political and diplomatic interests

**Second-stage abstractions**

- Restricting the number of disrupted variables
- Dealing with multiple and reactionary disruptions
- Unavailability of requisite resources
- Pre-empting problems before they eventuate
- Adequate time window for replanning and response
- Degree of novelty of a demanding situation
- High safety and security risks
- Regulatory, socio-political and diplomatic interests

**Figure 5.6: Relationship between open codes and the two-stage axial abstractions**
5.4 From substantive findings to formal theory generation

The focused coding processes involved selective elicitation of constructs in order to saturate or rather complete some emerging core categories. It focuses on how the factors identified relative to demand situations and operational strategies interact to shape how frontline controllers coordinate their respective control activities. Similar to the two preceding processes, the abstractions in the focusing stage are largely grounded on concrete observations and through the instrumentality of stories relating to how some respondents have handled specific events they deemed relevant to the questions posed. Some socio-cognitive behaviour (on individual and inter-personnel level) were identified and linked to specific challenge factors, as captured in Figure 5.6.

At this stage in the analysis process, themes from the literature were adopted for explaining certain phenomena that were captured from the findings. Also, some of the abstractions were becoming harder to articulate organically and, therefore, required themes from the literature to help identify relevant theories that would be useful for discussing the substantive findings. The increasing difficulty led to a shift from interpretation codes driven by substantively findings toward more formalised interpretations linked to theoretical discourses. This provided a starting point toward building links between observed practices and established theories. As a result, abstract concepts were derived from existing theories and applied as interpretive frameworks for making sense of those observations captured in the field. This section, in essence, captures the flight from substantive descriptions of inter-relations amongst AOC personnel and subgroups toward more formalised theorising of the dynamic response of an AOC system to a wide range of fluctuations in demand.

5.4.1 Interactions across airline functions

Strategies employ by individual actors and autonomous functions have been applied extensively in discourses relating to resilient modes of reorganisation (Cook, 2006; Cook & Rasmussen, 2005), management of risks and abnormal situations (Malakis, Kontogiannis & Kirwan, 2010; Woods & Wreathall, 2003; Reasons, 2008), and basic trade-offs in human adaptive systems (Hoffman & Woods, 2011; Woods & Branlat, 2011). Stephen, Woods Branlat and Wears (2011) discusses a set of strategies—cooperative, defensive and autonomous—use by units in regulating horizontal interactions across multiple centres of
control. Their discussions triggered the researcher’s interest in gaining insight into how such locally adapted strategies play out in an AOC work domain.

The goal of this comparative study was to understand how the different control units interrelate amongst themselves in light of the dynamics of demands and their operating strategies. One assumption that inspired this line of investigation was that regulating interactions across multiple centres of control is particularly challenging because each centre possesses partial authority, partial autonomy and partial responsibility for different aspects of the operations. Thus, gaining insight into how controllers manage such interdependencies, often under severe economic pressure and time restrictions, became the central focus of analysis during the focusing stages.

5.4.1.1 Mutual beliefs, shared intentions and interdependent resources

The differential level of coupling between resources controlled by different subgroups largely engenders distinctive forms of cognitive relationships among individual personnel and subgroups involved in the control process. For instance, in the observations made relative to interactions among three subgroups at the operations control centres (namely the operations control unit, the crewing unit and the maintenance watch), the operations controllers and crewing personnel engaged in constant dialogue and negotiations in efforts to resolve mismatches between flight plans and crew availability or legality issues. Evidently, their constant interaction reflects the tight coupling between the resources controlled by the two units—that is, aircraft and crew. A focused analysis of the interrelationship between the two subgroups revealed that both units often take a more cooperative, dialogic stance before actions are implemented, as depicted in Figure 5.7.

**Observation: Scenario 1**

A crewing officer (CRW-03) requested a 35-minutes delay so a reserve crew could be flown to another port to replace a sick crew. The controller (OPC-02) obliged without hesitation in spite of the obvious negative effect the request would have on current flight’s punctuality performance. The reasoning, as described by OPC-02, was based on the belief that the borrowed margin was for the greater good of the system rather than for own benefits. By cooperating with the CRW-03, OPC-02 was able to avert cancellation of two flight legs and potential cascade of cancellations.

*Figure 5.7: Frontline collaborations between crewing and operations control units*

Similarly, dialogues and negotiations were observed between controllers and engineering maintenance. However, these occur at a much lower frequency and sometimes appear
more autonomous than the observed interactions between controllers and crewing personnel. The interactions between controllers and engineering maintenance largely involve information exchange for the most part; for example, requesting for specific information relating to airworthiness of an aircraft or confirming status of aircraft under maintenance. Although some elements of cooperation were observed between the two subgroups, their inter-relationship is more akin to autonomous interactions. By contrast, no direct interaction was observed between crewing personnel and maintenance watch, as a controller mediated most conversations regarding availability of flight crew against available aircraft type.

…it will depend on what maintenance tells us. We’ve had a couple of issues this morning; first, maintenance advised that we are not going to see [an aircraft] until lunch and we had to cancel one flight. Then they’ve come around and said we are not going to see it for the rest of the day. If I can move all of the people within a period of time, then I’ll cancel those flights and they will be moved onto other flights. But if I can’t, then I can squeeze up the operation a bit and not lose crew and all of that, and then I might delay the flight.

(OPC-01)

A few abstractions are made relative to the socio-cognitive behaviours that are elicited by the level of coupling between resources controlled by the different units. First, it appears autonomous units tend to show willingness to cooperate when there is tight coupling between their activities or between resources controlled by the units than when their activities are loosely coupled. Based on participants’ responses, controllers at the control centres broadly agree that it is rather a rule than an exception for units that control interdependent resources to sacrifice their local margin for an anticipated better global outcome. During the concluding stages of discussions, two respondents linked this consensus to the belief that it is hard to extricate the performance of one centre from the system’s global outcome. Second, there appears to be some mutually-held beliefs amongst staff within specific operations control centres relating to how work is performed in their company. The respondents believe they develop mutual understanding of situations through formal trainings on how specific subgroups should inter-relate, through informal routines that have proven successful over time, and through explicitly shared intentions during negotiations. While internal beliefs are hard to capture in most cases, evidence suggests that the participants gained understanding of each other’s beliefs through shared intentions.
In airline operations, tight coupling of system resources leads to a high level of interdependent operational activities. A direct consequence of this tight interaction is that the resulting web of activities makes it difficult to extricate one centre’s performance from the others. Therefore, this thesis surmises that a high level of interdependency between resources will encourage individuals within and across autonomous control units to develop mutual beliefs and to share intentions. The excerpts from the interview and discussion transcripts along with case scenario one, in many respects, captures the interplay between interdependent resources, shared intentions and mutual beliefs.

5.4.1.2 Trust, reciprocity and affective consciousness

Besides the contributions of interdependency between resources, there appears to be some personal dimension to the observed relationships between subgroups. As captured in some participants’ responses, there is a high level of affective consciousness that comes to play during negotiations between controllers collocated in the same centre, as opposed to negotiations with other personnel outside the control centre. This view is most vividly captured in some participants’ remarks:

Wouldn’t it be good to just step back and look at problems more objectively, but we are often chasing time, so I need to assess which course of action saves me more work. Having [a customer liaison officer] and his team in the centre makes it a little more complicated than I would have liked, because I’m kind of compelled into paying attention to their views more than I would have done otherwise…that takes time, and time is one scarce commodity around here. (DM-06)

The fact that I have developed friendship with most of the people here [at the operations control centre] makes me relate to their perspectives of the problem. This would definitely be different if I was to engage with them over the phone, as I may have felt a little detached from their perspectives of the problem. (OPC-08)

Evidence from AOC practice further suggests that a history of inter-personal transactions with a particular staff makes a huge difference during horizontal (frontline) negotiations. In particular, it appears that controllers would more readily accommodate a request (even over the telephone) if it was made by someone they know personally or by someone they have transacted with in the past, which left some positive impression of the staff in question. This phenomenon is assumed to be widespread across the operations control centres.
Based on the demographic data supplied (Table 5.2), it appears that all the controllers that participated in this study had worked in some other business areas outside the operations control centres, as the total length of service in the airline industry for each participant is at least a year more than their time at the operations control centre. Thus, controllers appear to approach negotiations with a unit where they had worked in the past more cooperatively. The supposition of this research is that this may be because those controllers are well informed about the units’ capability to assist under a given circumstance. However, a more concrete observation relates to the difference in the formality of negotiations when the parties involved address themselves by their first name, as opposed to when official designations are used. A particular scenario is captured in Figure 5.8.

**Observation: Scenario 2**

A particular over-the-phone negotiation was witnessed between a controller (OPC-04) and a station manager at an airport. OPC-04 addressed the other staff by his first name. Their conversation seemed pretty amiable, more informal, and ended with “…cheers mate, I owe you one”. This instance sharply contrasts with previously observed dialogues between OPC-04 and some other callers, in which the callers were referred to by their official designations and conversations appear more formal than this particular scenario.

*Figure 5.8: Frontline negotiations between an operations controller and a station manager*

There are other interesting responses that capture the inter-relationship amongst collocation effects, inter-personal transactions and approaches to negotiation. Of particular interest is the idea that respondents can pre-empt what other controllers are up to and then adapt their own work accordingly. There seems to be convincing evidence in case scenario three (Figure 5.9) to assert that Schelling’s notion of *tacit bargaining* (Schelling, 1960) is alive and well at the centres observed. The fact that a crewing officer was able to pre-empt what the controller was considering and the fact that both shared the same awareness of impact (both operational and affective implications) without explicit communication suggest that they could have executed those changes without explicit consultations, if only the anticipated outcome was not considered adverse to crewing schedule. The interaction depicted in case scenario three goes to show that operators with a history of interpersonal transactions could, over time, develop the ability to pre-empt each other’s intentions under familiar situations and, consequentially, achieve coordination in such situations without explicit negotiation.
Observation: Scenario 3

During one of the briefing sessions, a controller (OPC-05) unintentionally published a change he initiated while tutoring the researcher on how flights are cancelled or delayed and the possible implications of certain changes on other units’ functioning. A crewing staff (CRW-07) in the process of confirming the controller’s intentions expressed concerns on the implication of those changes. Interestingly, her concerns and tone of frustration corresponded precisely to the controller’s assessment regarding the operational impact of the move on other units’ functioning, as well as the affective reactions that sort of change would elicit amongst other units.

Figure 5.9: Joint predictability of familiar scenario

Overall, it appears that positive interpersonal transactions between colleagues engender trust, and in turn foster reciprocal interactivity. Reciprocity appears to be more widespread among teams collocated in one geographic location than between teams that are placed at different geographic locations. Moreover, the willingness to cooperate appears to be linked to one’s interpretation of and trust in other’s reputation, intentions and beliefs. A worker or work style that has positive affect on colleagues will most likely endear them to cooperate, whereas a work style that is viewed as “self-absorbed” will negatively impact cooperation.

I approach my work differently if it is with someone I have worked with for a number of times, and the person has proved to be dependable. I’ve worked with some controllers, who can be very self-absorbed in their opinions and hardly agrees to suggestions. (CRW-07)

My approach in such situations [when there is personality clash] is to make sure I follow up with changes and get as much flights covered as possible…I don’t even bother to ask, nor expect any favour. But working with people I view as friends does help in airing my views; otherwise I just do my job. But I can tell you it would be really tough if one cannot get the kind of support needed to do this job. (OPC-04)

Correspondingly, this thesis posits that trust and positive affect promotes reciprocity, which in turn encourage autonomous functions to adopt cooperative strategies. It follows from this premise that operators that are collocated in the same facility and share a positive history of interpersonal transactions are more likely to develop joint predictability skills, particularly if the information architecture allows them to share the same views of information regarding a developing situation.
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5.4.1.3 Shared referents, sense-making and common grounds

Governance at the operations control centres is typically distributed across autonomous functions that possess specialised expertise in dealing with specific aspects of the operation. As a result, controllers had to source for the most current operational information across diverse functions in order to make sense of developing situations. During low tempo periods, controllers habitually made several calls to follow up on issues that were reported earlier in the day so as to maintain situational awareness of the state of the system. Earlier depictions of how operators eavesdrop on colleagues’ conversations also buttress their conscious efforts to maintain an up-to-the-minute awareness of situations.

Nonetheless, it appears autonomous units need more than just a means of sharing information to be able to cope amidst severe escalation of demand. To guarantee readiness to respond as new information surfaces, autonomous functions need a common referent and clearly defined basis for negotiating and adapting plans (Hollnagel, 2011a, pp. 284-287). This premise has also been captured in the framework of generic competencies for handling complex and escalating events (Bergström et al., 2011). More empirically, controllers across functions were observed using explicitly defined criteria to create mutual understanding or common ground. In one control centre, updates were periodically displayed on a whiteboard as a way of managing dynamic goals or requesting all units to work towards a common goal. Themes that were displayed include “protect OTP” (on-time performance), “maximise slot allocations”, and “passengers first”. The other centres use similar strategy but more modern technology to achieve goal coordination purposes.

As you can see we’ve got a little graph there (on the board), ‘protect OTP’. So the pendulum is swinging towards protecting OTP as opposed to preventing cancellations because our OTP is not good for the month, it’s down so they wanted us to protect that. So if I could cancel a flight and protect four sectors from being delayed and I could move these people within a reasonable time, then I’ll do that.

(DM-01)

The need to have a common set of evidence as a basis for revising plans is also evident in the findings of the study that examine inter-organisational collaboration during a Swedish railway tunnel projects (Cedergren, 2011). Therefore, this thesis postulates that sharing
common and explicitly defined referents fosters the creation of *common ground* and a shift towards more *cooperative* strategies.

### 5.4.1.4 Window of opportunity and the dynamic nature of airline operations

Airlines operate in a highly *fluid* and competitive business environment, which necessitates that fast and fiscally-sound decisions must be deployed within a reasonable time. A delayed decision may no longer be feasible at the time of implementation because the relationships between resources are constantly changing over time and space. Therefore, decision-making must be quick, pragmatic, responsive to change, and above all amenable to myriad conflicting constraints. Consequently, *satisficing* decisions, which could be easily iterated over time and space, are often preferred over “one-off” optimised decisions at the operations control centre. While reflecting on the dilemma posed by the interplay between time criticality and the dynamic relationship between airline system resources, a duty manager used the term *command-and-control* to describe his authority to commit to a particular course of action regardless whether there is a unified agreement amongst different units involved in the decision-making process. This duty manager argued that command-and-control “…*gets the job done*…” when there are too many variables to negotiate, particularly when time is critical.

> I often use command-and-control because it helps to speed up discussions, especially when it is hard to reach a unanimous decision. Some may see it as dictatorial but it makes my work a lot easier…people don’t always respond well to it but it does get the job done. We don’t always have the luxury to indulge in long deliberations when we are faced with a major disruption. (DM-06)

All participants did not explicitly share this position, particularly the frontline controllers. However, there seems to be an implicit agreement, based on their reflections, that command-and-control does allow for quick, approximate solutions to be deployed, which are later iterated. Specifically, the more experienced controllers tend to support the idea that command-and-control expedites decision-making processes. An elderly controller with long years of service in one control centre, in particular, argued that command-and-control is probably a more attractive strategy to adopt during high-risk events or when a decision of ‘high importance’ is to be made within critical timeframe. Thus, this thesis posits that the interplay between complex decision variables, time criticality, and the dynamic
relationships between resources often influence higher-echelon governance to initiate a command-and-control procedure for horizontal adaptations.

5.4.1.5 Awareness of risks and commitment to safety

Internal safety regulation was also found to be one of the driving forces that shape the choice of adaptive strategy across functions at the operations control centres. The role of engineering maintenance as guardian of aircraft maintenance schedules necessitates a fully autonomous unit that has full authority to initiate and implement aircraft maintenance decisions and activities. As depicted in the participants’ responses in the preceding sections, a crisis management team are typically consulted when safety issues arise. This team always comprise engineering maintenance staff, if the event involves a mechanical problem with an aircraft, regardless of how trivial the situation might seem. On the topic of the needs to maintain a constant sense of unease, and to remain sensitive to the possibility of failure in safety-critical systems, a maintenance engineer (MOC-01) argued, “…it is indeed criminal for engineering maintenance to base safety decisions on uncontested assumptions or be unduly influenced by other considerations”. Other maintenance personnel shared similar view when responding to the role of autonomy in engineering maintenance as a way of ensuring high safety standards.

We’ve had a situation where there’s been a smoke-like smell in the cabin, and passengers have smelled the smell also. If we [engineering maintenance] were advised when the aircraft was on ground, that aircraft will not fly until it was thoroughly checked…normally, we will run a check, and not until a maintenance controller has cleared that aircraft would it fly again. (MOC-02)

With this understanding, the engineering maintenance departments see themselves as internal regulators or “watchdogs” when balancing trade-off between safety and many other pressures at the operations control centres. This viewpoint is corroborated by a story shared by a senior staff (DM-05) at one of the control centres visited (Figure 5.10).
DM-05 further noted that issues of unplanned maintenance checks require an independent assessment of the risks involved with minimal influence from the units that shoulder other responsibilities in addition to safety. In parallel, a maintenance engineer (at a different airline) highlights that maintenance units typically coordinate scheduled aircraft maintenance with strategic planning and operations control units. However, this participant emphasised that an engineering maintenance unit reserves the rights to ground an aircraft as long as is necessary until the aircraft is deemed fit for duty again.

There was a (maintenance) paper work on board that had some issues, so we've grounded the aircraft and one of my colleagues is having a look to know what's happened. (MOC-03)

The common denominator in the accounts narrated by these participants is that maintenance units largely exercise autonomy in their assessment of risks to safe aircraft operations. These accounts further lend support to earlier depictions of inter-relationships between controllers and maintenance personnel. This thesis, therefore, asserts that the need to regulate risky behaviours would often compel functions that hold safety regulatory authority to lean toward more autonomous forms of adaptation.

5.4.1.6 Pressure to sustain the economic viability of operations

In efforts to remain competitive, airlines have devised a number of strategies for relating with competitors and other organisations within the broader air transport system, including partnerships, alliances, etc. Given that the basic resources and equipment needed for day-to-day operations are very expensive, airlines customarily resort to pooling of resources and reciprocal sharing of resources for mutual benefit. For example, airlines largely cooperate
with other carriers for key services at out-station airports, including catering, check-in, maintenance, and ground service operations. Also, as has been captured in earlier descriptions of airline operational strategies in Chapter 2, it is not uncommon for airlines to engage the services of other carriers during major disruptions to recover their crew and passenger schedules.

### Case Scenario 5

An event was recounted by DM-06 that depicts how a committee that reviews business strategies during critical incidents influenced an operational decision to continue flight operations into a region that has lost economic attractiveness at the peak of a political upheaval. Beyond imminent financial losses due to reduced passenger traffic, the committee identified potential risks to business relationship with the government. Also, the committee was compelled to void a controller’s decision to cancel flights heading into the region because of the broader impact a damaged business relationship could have on the airline reputation in that region.

Figure 5.11: Socio-political influences on airline’s operational decision making

However, the pressure to survive the extremely competitive landscape of the airline business often pushes companies to adopt more defensive strategies. This is typically reflected in practices, such as hoarding landing/take-off slots and initiating policies and practices that favour local airlines over non-local carriers at home ports. Evidence suggests that during critical incidents, airlines often give priority to variables that have the most potential to damage their reputation, whether they relate to safety, political or economic factors (Figure 5.11). In most cases, sacrificing decisions are made where necessary to protect a company’s reputation.

In contrast, protective strategy is frequently evident in the way airlines offer generous reimbursements and compensations in efforts to save face after major incidents, such as computer glitches, reservation system failures, union strikes, etc. In resilience engineering parlance, a protective approach represents a situation where priority is given to chronic goals (e.g., safety, security, customer goodwill) over acute goals or short-term gains (e.g., on-time-performance, least cost). Therefore, it is surmised that the pressure to sustain competitive advantage amidst high operating costs and myriad socio-political influences often trigger a shift toward more defensive and protective strategies.
5.4.2 Dynamic renegotiation of decision authority

In a study of international disaster relief (IDR), Dekker and Suparamaniam (2007) postulate that coordination is difficult in disaster relief work, because it is more a renegotiation of authority than mere re-assignment of resources or re-allocation of expertise and manpower. Grounded on this insight, the goal in the later stages of analysis became understanding why and how authority migrates at the sharp-end in the context of airline operations control. The thesis findings begin to clarify that frontline controllers, often unconsciously, assess their authority to make certain decisions based on the severity of the developing problem and its potential scope of impact. Evidence was found from the findings of this study to suggest that these two factors are pivotal in shaping the dynamics of a renegotiation process and in colouring the perceptions of controllers involved in the process.

Furthermore, the formulation in this section has been extended to include not only horizontal collaborations amongst frontline controllers, but also vertical escalation of control along with the inter-relationships that develop between frontline controllers and senior executives during major events. This extension was necessitated by the data collected in this study and, thus, provided a comprehensive framework for interpreting empirical findings captured in this study. Again, it is important to note that this section is framed largely as a discussion of results obtained in the earlier sections. Hence, the discussions draw from the synthesis of results, whilst providing some concrete scenarios to link claims and empirical observations.

5.4.2.1 A mapping problem

From the outset, it was clear that there are nuances in the structure and dynamics of operations between IDR work domain and airline operations control that needed to be addressed before any meaning mapping can be done across the domains. Firstly, international disaster relief work largely involves inter-organisational collaboration, each with their governance style and chain-of-command. By contrast, airline operations control mostly involves subgroups that are within the same airline company (that is, intra-organisational collaboration); therefore, the reporting structure tends to converge at some point towards the same vertical chain-of-command. Secondly, IDR organisations typically have different agenda, goal-sets, diplomatic ties with home country where the disaster occurred, local knowledge of problems-to-be-solved, as well as procedures and resources
to carry out the required tasks. In contrast, airline subgroups often share same referents for deploying actions, work towards the same high-level goals (although sometimes conflicting), responsible for well-defined aspects of the operations and, very crucially, they share same norm and professional indoctrination. Thirdly, Dekker and Suparamaniam (2007) found that plans are usually over-specified in the IDR work environment and that training rarely touches on the possibility of conflict between demands for local action and global interests held by stakeholders further up in hierarchies. By contrast, airline operations controllers’ training takes into account the possibility that flights are hardly executed as planned and therefore makes reasonable effort to incorporate local initiatives during renegotiations. Fourthly, IDR workers, in most cases, work with people they have had no prior experience, people that may speak different languages or have different professional or cultural backgrounds. Airline controllers, on the other hand, enjoy the benefit of working with colleagues that share the same professional doctrine and background, and perhaps work in a collocated centre. Collectively, these differences provided a basis for elucidating why some of the behaviours captured in this study may differ from findings abstracted from the IDR work domain.

5.4.2.2 On representation and discussions

According to Dekker and Suparamaniam, processes of renegotiation can be illustrated using two-dimensional construct—the level of gracefulness and the degree of mutuality associated with the renegotiation, as depicted in Figure 5.12. Gracefulness or the lack thereof is judged by the parties involved as a function of whether ‘feelings were hurt or not’ in the renegotiation process (Dekker & Suparamaniam, 2007, p. 238). The degree of mutuality, on the other hand, is judged as a function of the extent that the party that is required to relinquish authority is involved in the renegotiation process. The degree of mutuality could range from an asserted authority to a mutually agreed renegotiation, with renegotiations perceived as within the first quadrant (Q1) the most desirable. The discussion in this section, therefore, focuses on the forces that shape controllers’ perception of the level of gracefulness and the degree of mutuality associated with renegotiation processes in their respective operations control centres.
Figure 5.12: Two independent dimensions along which frontline workers renegotiate authority

(Dekker & Suparamaniam, 2007, p. 238)

Figure 5.13 extends the original framework by including a renegotiation sphere. A renegotiation sphere is a useful tool for capturing the collective perception of frontline controllers regarding how renegotiations are executed in their operations control centre. The arrows represent some critical forces that influence the dynamics of a renegotiation process—such as, the severity of a problem and its scope of impact. The impacts of such forces are appropriated in the discussions to show how the dynamics of a demand situation colour controllers’ perceptions and feelings about a renegotiation process. It is important to note that the renegotiation sphere is dynamic and should not be mistaken as a static result of a renegotiation process. Furthermore, the locations of a renegotiation sphere in the illustrations in this section are not drawn to scale and largely reflect some specific controllers’ subjective perceptions. However, adding a renegotiation sphere can still be useful for capturing more measurable representations of renegotiation processes across a wide range of human adaptive systems. Hence, a renegotiation sphere when applied to the original framework proffers a tool for understanding controllers’ perceptions of renegotiation practices within a given control centre or operational setting.
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The thesis findings further suggest that even though the two dimensions in Figure 5.12 and Figure 5.13 are represented as independent dimensions, they are not necessarily mutually exclusive. In other words, one can still influence the other even though that may not always be the case. For example, the following discussions highlight that controllers often judge a renegotiation process as asserted when it appears to lack grace.

5.4.2.3 Renegotiating authority during a Low Severity Localised Event

Generally, control systems for airline operations are modelled as polycentric control architecture: a complex network of interdependency among resources that are controlled by multiple subgroups. Evidence from the AOC practice (as captured in this study) suggests that knowledge and authority to act largely co-exist within an airline’s operations control centre. The thesis results show that some controllers do exercise a sense of authority to act, even in the face of situations that demand “outside-the-textbook” protocols. They first implement such initiatives and then provide justifications afterwards. However, it appears such authority is largely manifested when the criticality of an event is low and the span localised. Besides, there is a common understanding that feasibility trumps optimality when faced with perturbations. As a result, controllers’ training acknowledges local initiatives and dynamic negotiation skills.

Based on the findings abstracted from the AOC work domain, this thesis posits that under low severity, localised situations, migration of authority is generally mutual and graceful.
This notion is largely influenced by the supposition that negotiations under low severity, localised events often follow textbook prescriptions because there is little to no need to make drastic changes to the original schedule. As such, controllers usually reach explicit or tacit agreement on changes to be made. It is also the case that socio-cognitive behaviours, such as reciprocity and tacit bargaining, will appear more prominent strategies for negotiation. Of course, behaviours like reciprocity and tacit bargaining will very likely be shaped by other socio-cognitive factors, including historical records of interpersonal relationships and affective disposition between the controllers and/or units concerned.

Also, as long as there is no identifiable threat to life or business continuity, frontline controllers will lean toward collaborative stances that suit their functions when renegotiating plans or when coordinating flow of resources across the network. A gravitational pull toward more comfortable collaborative stances will more likely elicit more autonomous or cooperative forms of adaptation. Again, based on earlier results, the specific form of collaborative relationship will very likely be contingent on resource interdependency and on the specific demand.

![Figure 5.14: Renegotiating authority during a Low Severity Localised Event](image)

Figure 5.14: Renegotiating authority during a Low Severity Localised Event
Overall, negotiations during low severity, localised events can be represented along the
gracefulness- and mutuality-axis as a function that stabilises dynamically on the balance of
forces depicted in Figure 5.14. As downward forces dominate, controllers will more likely
perceive negotiations as becoming less graceful and more asserted. On the other hand, if
upward forces are predominant, controllers will more likely perceive negotiations as
becoming more graceful and mutual. There is also the possibility of side forces pushing the
system toward more ungraceful negotiations, even when there is no explicit assertion of
authority. A typical example would be where a crewing staff or an operations controller
decides to apply a local unit rule, which in turn constrains the options controllers in the
other units have regarding potential solutions they can apply.

5.4.2.4 Renegotiating authority during a Low Severity Global Event

But, as demands escalate across the network, the dynamics of collaboration quickly changes
to tighter and more complex cross-unit interactions. As some responses suggest, airlines
usually have a policy that requires controllers to, at the least, inform certain members of
higher-echelon governance when there are novel or large-scale demand variability that
could require an ‘outside-the-textbook’ protocol. Threats of a network-wide impact may, in
some occasion, necessitate a horizontal command-and-control (C2) being initiated by an
operations-controller, a duty manager or a senior executive that was notified of the
incident. Under a horizontal command-and-control structure, negotiations are largely
asserted given that complex network of interdependencies often need to be reconsidered
within a critical timeframe.

Evidence suggests that the degree of gracefulness attributed to a horizontal C2
renegotiation process (under low severity, global-impact situation) is a function of frontline
controllers’ perception of ‘being in control’. Controllers appears to have differing views on
their perception of changing demands, with some more operationally focused while others
consider broader implications of decisions beyond immediate operational concerns.
Controllers that are heavily focused on the operational details of a developing problem
tend to have stronger illusion of control than those who often look for implications outside
of core operations. Not surprisingly, experience seems to play a role in their perception of
changing demands. Controllers that had worked through situations that attracted bad
publicity tend to involve higher-echelon governance more readily in certain decisions than
those who may not have been exposed to such experience. This suggests that experience plays a crucial role in knowing when to flag a developing problem as a full-blown threat.

Paradoxically, it turns out that some controllers that identified themselves as confident in their skill-set also reported falling victim of holding tenaciously onto an illusion of control. Two controllers hinted that they have had situations earlier in their career, where they failed to involve higher-echelon governance as quickly as a situation demanded. These hints do clarify why the more experienced controllers are particularly cautious of situations that are notoriously linked to bad publicity and loss of goodwill. They appear reluctant to make certain decisions, despite the number of times they had experienced similar situations in the past. The less experienced controllers, on the other hand, tend to exhibit exuberant confidence toward most situations discussed.

As captured in Figure 5.15, frontline controllers may perceive negotiations during low severity, global events as asserted but not necessarily ungraceful, especially when there are obvious adverse socio-economic and socio-political implications. Experience with a specific event together with openness to broader considerations will likely engender more cooperative adaptations; hence, a perception of mutual agreement by frontline controllers.

![Figure 5.15: Renegotiating authority during a Low Severity Global Event](image_url)
By contrast, non-transparent instructions from higher echelon governance could easily generate a sense of asserted authority, particularly when frontline controllers feel strongly they are in control of a situation or where a controller places more priority on operational considerations. A combination of illusion of control and operationally focused control strategy will very likely shape the arena for asserted and ungraceful negotiations. In general, this thesis postulates that, under low severity global events, controllers with a strong sense of being-in-control are less likely to escalate problems willingly than those who would rather not entertain an illusion of control.

5.4.2.5 Renegotiating Authority during a High Severity Global Event

In view of high severity, global problems, the results suggest that controllers are acutely mindful of their perception of control, and would rather not entertain a false sense of control. Examples of this claim abound in the responses, wherein respondents emphasised they will “immediately” (DM-06, Table 5.5) or “straight away” (OPC-01, Table 5.5) call a crisis management meeting. Interestingly, controllers seem more eager to escalate control—by way of surrendering authority to higher-echelon governance—if a demanding event has readily identifiable impact on business survival, or any adverse safety, security, socio-political or regulatory implication. Particularly when safety or diplomatic relations are at stake, frontline controllers tend to readily relinquish authority to an ad hoc committee comprising senior executives and technical experts, who have the authority to make decisions regarding such matters on behalf of the company.

Figure 5.16 depicts the dynamics that are likely to emerge in a negotiation process during a high-severity global event. It seems that more critical situations elicit a perception of gracefulness, as controllers tend to readily relinquish control to higher-echelon governance. The downward push toward an ‘asserted-but-more-graceful’ dynamics is likely driven by the ‘damage control’ or protective stance commonly taken by the local units and higher-echelon governance under critical situations that pose severe safety, security or diplomatic threats. However, the upward push toward ‘mutually-agreed-and-graceful’ dynamics highlights the fact that many frontline controllers would rather not risk the consequences of making localised, operational decisions that could complicate an already bad situation. Correspondingly, frontline controllers are “…more than willing to dodge the bullet and allow senior executives address critical decisions that could attract heavy penalties” (OPC-10). Senior management,
for their part, seem willing to participate in such deliberations in an effort to protect high-level corporate values and goals that are being threatened.

The resulting control architecture is a vertically driven command-and-control (C2) structure, where the executive and managerial levels make the critical and hard decisions, and then push those decisions down to frontline controllers to execute. In airline operations control, this control structure is typically facilitated by a duty manager. Duty managers bridge the authority-responsibility chasm between the blunt-end managers with a broader perspective on the problem-to-be-solved and the authority to veto actions, and the sharp-end controllers that possess clearer understanding of specific solutions that are operationally feasible at any given time. Many frontline controllers appear to relate to some measure of gracefulness involved in the vertical transfer of control under high severity global situations. The positive measure of gracefulness attributed to the vertical migration of authority under critical situations is more likely a reflection of the protection it confers on frontline controllers, in the sense that controllers are protected from shouldering responsibilities relating to any adverse consequence that arises from such high-stake decisions. In a way, relinquishing authority to higher-echelon governance shields frontline controllers from possible authority-responsibility double bind and from making high-stake decisions that are, in most cases, “very hard and sensitive calls to make” (OPC-10).
5.4.2.6 Renegotiating authority during a High Severity Localised Event

When responding to high severity but localised problems, most airlines adopt (for lack of a better term) a parallel control strategy, where frontline controllers continue to execute most of the resource schedule as originally planned, while coordinating their actions with an ad hoc committee setup to address the localised problem. Parallel control can also emerge in the other three cases, but appears more prominent during a high severity but highly localised event. Again, the duty manager acts as the coordinative mechanism between the committee and the frontline controllers by ensuring that decisions made by the committee consider the most up-to-date operational situation across the network. Interestingly, the demarcation between authority and responsibility during parallel control appears to be more blurry than in the other control architectures. The fuzziness often lead to divergent perspectives on what part of work should be renegotiated and what part should run as planned. There is also the possibility of contradictory perception of control where frontline controllers think they have things under control, whereas higher-echelon governance thinks otherwise. In many respects, the contradictory perceptions and general lack of clarity relating to authority-responsibility double bind appears to reflect the difficulty in managing renegotiations in domains where demand situations hardly share same parameters relative to prior experiences. A previous study have suggested that uniqueness of problem encountered in airline operations often require creative solutions (e.g., Bruce, 2011, p. 98); however, very little is known on how different parties judge the appropriateness of the process of generating such creative solutions.

Figure 5.17 captures the likely dynamics of negotiations under high-severity localised situations, as shaped by a number of forces. As parallel control requires coordination of operational activities in order to match decisions pushed by the committee to other routine demands, horizontal collaboration quickly takes a military-style command-and-control structure, particularly when vertical renegotiations are asserted and when action is required within a critical timeframe. The degree of gracefulness attributed to the renegotiation between frontline controllers and the committee appears to be contingent on how controllers perceive the committee’s openness toward their view of the problem-to-be-solved (that is, the operational side of things). Some controllers commonly use “we” in their descriptions of the escalation protocol, where they are suggesting ownership or at least a conscious acceptance of the need to renegotiate operational strategies, whether initiated by the controllers or the committee.
By contrast, three frontline controllers could not relate to a reasonable measure of gracefulness during parallel control, particularly when operational goals are to be sacrificed for some high-level goals that were not readily disclosed. In many respects, it appears that gracefulness is attributed when frontline controllers judged reasons for sacrifices and renegotiation of authority as transparent and fairly communicated than when it is viewed as largely dictatorial and asserted with very little input from the sharp-end. Overall, renegotiation tends to be judged as ‘ungraceful’ when controllers feel their inputs or, perhaps, their desire to minimise unnecessary work were “sidelined” in the final decisions reached.

Figure 5.17: Renegotiating authority during a High Severity Localised Event
Chapter 5: Field Study, Data Analysis and Findings

5.4.3 Revisiting the antecedent logics for actions

Scholars who have investigated the psychology of action-regulation in complex adaptive systems (e.g., Dörner, 1996; Hollnagel, 1983; Rasmussen, 1983a) have long established that the lack of congruence often seen between outcome of actions and the intentions of the agents is hardly accidental. In his theorising of the logic of failure, Dörner sponsored a number of underpinning rationales for actions and illustrated that human actions are largely grounded on anticipatory and consequentialist thinking (Dörner, 1996). The logic-of-failure perspective upholds that the logic of action is contingent on an agent’s ability to anticipate the unexpected and to pre-empt its consequences (Dörner, 1990, p. 463). In contrast, March and Olsen (2008) advanced a contention that actions of individuals and institutions are driven by rules of appropriate or exemplary behaviour and, in principle, are not primarily tuned to anticipation of future consequences (e.g., March & Olsen, 2008, p. 690). Following their investigations of formally organised political institutions, March and Olsen (2008) argue that appropriate rules are followed simply because they are seen as “natural, rightful, expected, and legitimate” (p. 689). Their discussions resulted in coining what they believe to be two distinct logics: the logic of appropriateness and the logic of consequentiality (March & Olsen, 2008, pp. 701-705).

5.4.3.1 March and Olsen’s perspectives on the logics of action

March and Olsen (2008) present the logic of appropriateness as a perspective on how human action is to be interpreted. This perspective conjures an idea of actors going about their everyday routines following some internalised prescriptions of what is socially defined as true, right or good, regardless what the expected consequences could be. According to March and Olsen (2008), “to act appropriately is to proceed according to the institutionalised practices of a collectivity, based on mutual, and often tacit, understandings of what is true, reasonable, natural, right and good” (March & Olsen, 2008, p. 690). The authors, however, emphasised that defining a rule as appropriate does not necessarily guarantee its technical efficiency or moral acceptability. By contrast, the logic of consequentiality implies treating possible rules and interpretations as alternatives in a rational choice problem (March & Olsen, 2008, p. 691). It also conjures the notion of self-interested, rationally calculating actors.
To support efforts towards advancing knowledge on the possible relationships that may exist between the two logics of action, March and Olsen advanced a number of propositions and future directions for research. Following March and Olsen’s propositions and suggested directions, the focusing stages of this study sought to gain insight into the logics that underpin actions in the AOC work domain. This effort particularly aims to clarify whether the logic of appropriateness and the logic of consequentiality are in fact observable, and how the specific dynamics of the AOC work domain could shape their applicability and evolution. The focused analysis, as a consequence, became centred on examining the processes of reasoning that govern how practitioners go about fitting work prescriptions to actual work performance. The intention was to abstract the aspects of controllers’ reasoning—in fitting work-as-prescribed to work-as-tenable—that relate to the arguments raised by scholars that subscribe to the logic-of-appropriateness and the logic-of-consequentiality perspectives. In the spirit of cross-fertilization of ideas, the substantive judgments and the processes of reasoning that were observed at the operations control centres are reviewed in light of March and Olsen’s suggested directions. The overall goal is to provide empirical grounds for elucidating the antecedent logics of action as they relate to the specifics of airline operations control and safety-critical operations at large.

### 5.4.3.2 On the vocabulary for rule prescription, interpretation and selection

In support of March and Olsen’s propositions, the empirical observations evinced that rules for actions are hardly prescribed in the language of consequentiality, but in terms of their appropriateness to specific situations. However, the prescription of appropriate actions at the control centres observed appears to be contingent on the typology of situations for which a set of actions are considered appropriate. The classification of typologies—as captured in the trigger lists shared with the researcher—are unapologetically framed according to degree of severity of events. The fact that even rules of appropriateness are underpinned by consequentialist ideals may explain why the processes of reasoning and interpretation of rules in airline operations control are heavily tuned to exploration of immediate and future consequences of actions. More empirically, the standard response for managing variations in airline operations control appears to follow sequential actions to determine the impact of a situation on the aircraft, the crew, the passengers and other resources. Participants’ responses clearly show that frontline controllers largely explore the impact of various recovery options on the flow balance of key resources (aircraft and crew) and passengers across the network.
There are a number of things we have to keep in mind, like OTP (on-time performance). We need to ask if I cancel this flight, where am I going to move these people? Also, if I delay this flight, how many other people are going to be delayed for the rest of the day, particularly if that aircraft is doing eight sectors for the day? If there are curfews at the end of the day and if it is going to make the crew hours too long, then are we going to lose some crew members because crewing can’t crew the flight? Is the crew going to refuse to do the duty because we have delayed it over an hour? Again, there may be a fog forecast somewhere at a certain time. If I run these flights late, will I be running them into a possible fog period? So, all of those things have to be taken into account. So we look at all of that, and based on that, we will then make a decision whether to delay or to cancel a flight. (OPC-03)

If we are going to delay a flight or cancel a flight, we’ll need to speak to our customer recovery team to ensure how we’re going to manage the passengers, and how we’re going to organise the recovery. We may have to re-crew a flight, so we may need to find out whether there is sufficient crew to re-crew the flight. We might also look at whether we can switch an aircraft to cover some legs. (DM-05)

Thus, in most instances, it is evident that controllers generate recovery options simply based on the impact of those options on the resources they control. Nevertheless, it is reasonable to think that in some instances controllers will explore both the consequences and the appropriateness of decision options within their sphere of influence before initiating cross-unit negotiations to identify the most appropriate outcome globally. Afterwards, the options may be subjected to further debate to determine the most appropriate course of action. Hence, whilst the prescriptions for actions are typically written in the language of appropriateness, frontline practitioners apply consequentialist thinking more broadly than they give thoughts to the appropriateness of actions. Appropriateness appears to be relevant only when negotiating across functions and across echelons, and mostly in situations that could have adverse regulatory or legal implications.

### 5.4.3.3 On the criteria of similarity and congruence

March and Olsen (2008, p. 690) suggest that actors will more likely use criteria of similarity and congruence in their processes of reasoning than likelihood and value. But, cracks began to emerge as the explanatory prowess of this argument was tested in light of concrete observations in the AOC work domain. In agreement to their postulation, controllers do use criteria of similarity and congruence to assess the typology of a developing problem, by drawing on experiences and events that in the past have involved
similar set of resources, airports, or the initiating event. However, after a developing problem has been identified and/or categorised, controllers tend to focus on minimising potential impact of the problem across the network. Under escalating situations, controllers would often extrapolate the consequences of disruptions on resource connections to gain better clarity on how its impact might affect the general balance of flow across the network. Actions are thus deployed that minimise both immediate and future impact on the AOC system; nevertheless, within the bounds stipulated by the systems-of-rules that govern what is regarded as acceptable or appropriate set of responses for a given situation. Overall, it appears that the criteria of similarity and congruence are more useful for making sense of a developing problem, rather than for dictating actions that should be taken to correct or recover from a situation.

5.4.3.4 On the interaction of logics of action

Observations captured in this study suggest that logic of consequentiality appears more dominant in individual-reasoning processes, based on the language controllers employ when explaining their reasoning and actions to the researcher. The findings, however, suggest that language of appropriateness appears to be more dominant during collective negotiation processes across functions and, particularly, in negotiations between the sharp-end decision-makers and the blunt-end executives. Even though negotiations with higher echelons are commonly framed in terms of what is appropriate (as this is usually the alternative viewpoint that is widely believed blunt-end managers bring to sharp-end deliberations), there is still a persistent undertone of consequentialist thinking in the rationalisations of what is considered appropriate in specific situations. For example, discussions of what is socially or legally acceptable are often expressed, understandably, in terms of repercussions that may befall the organisation or the individual should a set of actions fail to meet public expectations or certain legal or regulatory requirements.

The battle for dominance between the two logics—logic of consequentiality and logic of appropriateness—is not limited to airline operations control. The crash of Swiss Air Flight 111 (SWR111) near St Margarets Bay Nova Scotia is a reminder that following rules as prescribed can sometimes lead to disastrous consequences, especially during rapidly escalating situations. Following their detection of smoke smell in the cockpit, Captain Urs Zimmermann and First officer Stephan Löw decided to make a quick landing. However, the flight crew seem to have misjudged the threat of the situation by the fact that they
made a “Pan Pan” call which only signifies an urgent problem, rather than a “Mayday” call which signifies a full blown emergency. The flight crew also made two critical decisions that would later raise many controversies as to their sense of urgency and their awareness of the imminent danger. The first is their choice to deploy a 20-minute checklist and the second is their choice to dump fuel before attempting to land the plane. Both of these decisions are in fact required in the standard operating procedure; in a sense, the flight crew was just following what they considered appropriate at the time. Although such decisions ordinarily would be considered ‘appropriate’ routines, the Transportation Safety Board of Canada’s report pointed to the decision to delay landing in order to apply checklist and to dump fuel as contributors to the escalation of the fire that caused the eventual crash of Swiss Air Flight 111.

In contrast, the heavily investigated crash-landing of US Airways Flight 1549 into Hudson River points to an instance in which an unpopular improvisation provided impetus for resilience. In recounting the event and why he did not follow the ATC recommendation to fly back to LaGuardia airport, Captain Sullenberger claimed he considered, amongst other things, the consequences of failure to make safe landing in a busy airport against meeting the same fate in Hudson River. According to widely televised interviews, Captain Sullenberger and First officer Jeffrey Skiles independently suggested that their decision to ditch the plane was based on the consideration that the casualties would at least be limited to only those on board should the attempted ditching failed (also reported in Pariès, 2011, p. 18). In essence, what the flight crew considered an appropriate action for the situation was based on choosing an option with lesser consequences.

Herein lies the difficulty with attributing appropriateness in safety critical missions and operations. Given their high risk nature, problems can escalate very quickly leaving little time for transitioning from complex to chaotic mode of control. Besides, it is not always clear to the actors what would be considered appropriate actions after-the-fact because slight changes in parameter can easily render a normative, standard rule inappropriate. Taken together, the two cases echo the dilemma relating to how actions considered appropriate can sometimes lead to bad consequences, whereas actions considered “rule violation” can turn out to be a source of resilience. The two cases also highlight the

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\(^5\) Information relating to the cases of Swiss Air Flight 111 and US Airways Flight 1549 were abstracted from the Transportation Safety Board (TSB) Canada and the National Transportation Safety Board (NTSB) US respectively.
difficulty in “matching a changing and ambiguous set of contingent rules to a changing and ambiguous set of situations” (March & Olsen, 2008, p. 693), especially in safety-critical and rapidly escalating situations.

The inference that can be drawn from this discussion is that the rules of appropriateness and the rules of consequentiality can in some situations support each other while in other situations counteract each other. But, in view of the empirical findings gathered in this study, it is reasonable to think that the rules on whether action is appropriate and the rules of expected consequences are not all that distinct in the AOC work domain. This supposition is premised on the notion that appropriate actions are so determined because they are in most cases economically viable and at the same time do not violate safety or regulatory recommendations.

5.4.3.5 Reflections on the formulation of consequentiality and appropriateness

Dörner’s logic of failure illustrates how experimental subjects, in their bid to improve the lives of the Moro people, deployed actions that later resulted in a catastrophe. In the short term, the actions improved different aspects of the Moro region, but the interaction of system variables led to a later degradation of the conditions of the Moro people (Dörner, 1990, pp. 463-466). This formulation presents neutral processes of reasoning that sometimes lead to long-term successful outcome and in other times lead to degradation of the system condition. An interesting abstraction made by Dörner is that the successful subjects adapted their thinking to the situation, whereas the unsuccessful subjects did not display sufficient fit between their process of reasoning and the situation (Dörner, 1990, p. 472). In all, Dörner made no value judgement regarding the perspective on how human action is to be interpreted.

Although March and Olsen alluded to the need to match a changing and ambiguous set of contingent rules to a changing and ambiguous set of situations, their formulation is heavily biased toward the logic of appropriateness, as a perspective on how human action is to be interpreted. In defence of appropriateness, March and Olsen presented a view of consequentialist thinking as “self-interested” and “utility calculating actors” who are motivated by incentives and personal gains (March & Olsen, 2008, p. 691 footnote), and made little to no effort to identify specific instances where following a consequentialist reasoning would lead to a globally acceptable outcome. The thesis that falls out from their
argument is that the logic of appropriateness should be the basis for prescribing and interpreting rules and for selecting actions.

However, there is a fundamental problem with arguing for the distinctiveness of the two logics (e.g., March & Olsen, 2008, p. 703). Such arguments appear to follow a view of decision making as a sum rather than a lump. As Hollnagel have argued (Hollnagel, 2007), decisions are not typically reached through purely rationally defined processes, but rather through dynamic processes of making trade-offs as choices present themselves. This dynamic process of decision making is vividly capture both in Dörner’s experiments and in the substantive stories gathered in this research. As evidence from Dörner’s experiments suggests, there is hardly a single decision that was made conclusively just on the basis of appropriateness alone, without due consideration of the possible consequences, even when the goal is improving the lives of the Moro people. This then raises a question whether it actually makes sense to assume that the logics of reasoning are so distinctive that they can be identified as separate processes of reasoning.

The conclusion drawn from this argument is that the idea of unequivocally defined rules that can be represented to follow appropriateness- or the consequentiality-dimensions more distinctively is not tenable in the context of human actions in complex sociotechnical work systems. Both rules appear to co-exist in many of the processes of reasoning and rationalisations provided by the participants. Again, the assumption that rational choice only manifests in consequentialist thinking fails to consider the potentiality that even rules of appropriateness can sometimes be ambiguous, ridden with dilemmas, unknowable risks, and conflicting goals to which one must make a choice based on a rationalisation of ‘appropriateness’ in that specific context. Overall, only time shall tell the relevance and the contributions of March and Olsen’s perspective on appropriateness to the study of resilience in high-risk organisations. With the continuing extension of this perspective to corporate businesses and to safety-critical operations, it will become clearer over time the aspects of its core premises that proffer useful insights for understanding bounds on practitioners’ actions and the ones that are becoming increasingly obsolete in the context of safety critical missions and operations. In this research, at least, March and Olsen’s propositions have provoked a need to revisit one fundamental question that is often taken for granted: how practitioners consider the appropriateness of actions and the factors that shape their disposition to the mix of rules and actions they employ.
5.5 Conclusion

This chapter has elucidated the driving forces behind a unit’s choice of adaptive strategies, with particular focus on how internal constraints (e.g., interdependent resources, time criticality and dynamic relationship amongst resources) and external drivers (e.g., regulatory, economic and political forces) shape the adoption of specific strategies. Evidence for the forces at play when regulating both inter-organisational and intra-organisational interactions are clearly captured in the stories shared, the specific events observed and the unique dynamics of airline operations control.

In many aspects, the findings reiterate that human adaptive systems need a cooperative culture and structure in order to adapt formalised procedures across functions; particularly, in the face of myriad internal constraints and external pressures. The tight coupling of system resources underscores a key motivation that compels functions to cooperate, in that it is hard to extricate one unit’s performance from the performance of other units. Cooperative adaptation is more likely in units that share symbiotic relationships, where individual actors share mutual beliefs of one’s positive affect towards the other, and perhaps, shared intentions to cooperate as well. On the contrary, units that share only unidirectional (one-way) interaction may likely lean toward autonomous or defensive strategies. Nevertheless, having highly interdependent resources alone may not be enough to yield satisfactory results when teams cooperate toward a common goal. The need for quick reorganisation not only necessitates easily accessible means of acquiring, communicating and validating information (Bergström et al., 2011), but also a clearly defined referent in order to guarantee readiness to adapt plans across functions in the face of surprises. Thus, our results give support to the postulation that cooperating functions need a common referent and clearly defined basis for activating responses.

In a rather interesting twist, evidence was found to suggest that cooperative adaptation is not always preferred when managing trade-offs in the AOC work domain. This twist reflects the necessity to implement a course of action under severe time constraints (Hollnagel & Woods, 2006, p. 355), particularly, when managing complex network of interdependencies relating to resources and performance variables controlled by different units. More specifically, command-and-control has been found to expedite decision-making processes, when there are too many variables to negotiate; when time is critical; or
when safety, regulatory or political issues are involved. It is also interesting to note that command-and-control strategy is mainly deployed during extreme or high risks negotiations between specialised units and traditional functions than during routine, horizontal resource regulations across traditional functions.

Likewise, autonomous adaptation appears particularly significant in airline operations control. Evidence suggests that autonomous modes of adaptation are well suited for internal safety-regulation purposes. Units deploy autonomous regulation to checkmate a system-wide risk taking behaviours, particularly when there is a need to ensure a system is not drifting precariously towards its boundary of safe operation. Given the need to remain sensitive to the possibility of failure in aviation (Hollnagel, Nemeth & Dekker, 2008), having an internal regulation mechanism or unit will likely improve a system’s ability to monitor its position in relation to its boundary of acceptable performance. The structural relationship between safety-regulatory units and other units parallels what is obtainable in the financial world, where some agencies are set up to regulate transactions within the financial market.

Table 5.8 summarises the researcher’s understanding of the inter-relations that exist among the theoretical variables applied to the substantive findings. It highlights the various perceptions of mutuality and gracefulfulness, as well as the likely architectures and locally adapted strategies that various combinations of severity and scope can elicit.

Table 5.8: Summary of inter-relations across theoretical attributes

<table>
<thead>
<tr>
<th>Severity of demand</th>
<th>Scope of demand</th>
<th>Control architecture</th>
<th>Degree of mutuality</th>
<th>Degree of gracefulfulness</th>
<th>Collaborative strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Global</td>
<td>Predominantly Command-and-control</td>
<td>Mostly judged as asserted</td>
<td>Mostly judged as graceful</td>
<td>More protective</td>
</tr>
<tr>
<td>High</td>
<td>Localised</td>
<td>Predominantly Parallel control</td>
<td>More asserted, Can be mutual</td>
<td>More graceful Can be ungraceful</td>
<td>More cooperative Can be protective</td>
</tr>
<tr>
<td>Low</td>
<td>Global</td>
<td>Predominantly Cross-unit collaboration</td>
<td>More mutual, Can be asserted</td>
<td>More graceful Can be ungraceful</td>
<td>More cooperative Can be autonomous or protective</td>
</tr>
<tr>
<td>Low</td>
<td>Localised</td>
<td>Predominantly Polycentric</td>
<td>More mutual, Can be asserted</td>
<td>More graceful Can be ungraceful</td>
<td>More autonomous Can be cooperative or defensive</td>
</tr>
</tbody>
</table>
CHAPTER 6
Conclusion, Significance and Outlook

The goal of science is to make the wonderful and complex understandable and simple—but not less wonderful.

Herbert A. Simon (1969), Sciences of the Artificial

The process of scientific discovery is, in effect, a continual flight from wonder.

Albert Einstein (1879-1955), Autobiographical Notes

6.1 Addressing the research objectives

This section provides insight into how the objectives were addressed, in terms of specific actions taken, relevant discussions and arguments made, and the particular chapters where the actions/discussions/arguments are documented.

Objective 1: To observe and describe a perspective of the AOC practice from a social and cognitive perspective

Concepts adapted from the fields of organisational sociology, cognitive psychology and resilience engineering were explored (in Chapters 2 and 3) to provide a sense of direction on the state-of-the-discourse around performance, as captured in various safety-critical work domains. The discussions uncovered not only the factors that contribute to successful performance, but also how the path to performance degradation—and an eventual catastrophic failure—is staged almost imperceptibly, as organisations normalise deviances and as they fail to notice how processes that yielded successful outcomes in the past are becoming less effective in view of the changing shape of vulnerabilities in their world. The knowledge gained was utilised in the development of a framework for eliciting data through observations and interviews (in Chapters 4 and 5) and, also, proved crucial for interpreting the practices that were captured in the field.
Objective 2: To share insights on the pragmatic steps taken to overcome limits to authenticity relative to observing work in context.

In Chapter 4, considerations were identified and prioritized relative to their respective contributions toward shaping the conditions for eliciting and analysing data, enhancing rigour in the research process, and ensuring the overall authenticity of the research outcome. The goal of study was broadly defined at the onset to allow for a progressive narrowing of focus as themes emerged in the course of study. Less intrusive, observational strategies were first applied to mitigate potential reactive effects on the people whose work practices were investigated. The questioning protocols were flexibly structured so as to balance between following a well-defined research process and being responsive and adaptive to emerging themes and other surprises. This strategy was particularly helpful in eliciting narratives that later became crucial to the research, such as those relating to escalation of problems, anticipatory response to problems, and the centrality of safety considerations in AOC decision making.

Furthermore, triangulation was applied across multiple levels throughout the research process. The mix of airlines and participant characteristics provided a diverse and thorough laboratory for capturing distinctive response scenarios that span business models, size of companies, geographic locations, and cultural orientations. The variety and range of expertise allowed for an appropriate blend of ideas for identifying nuances in the AOC operating landscape, along with the forces that shape various styles of decision-making in the context of AOC practice. Methodological triangulation was also deployed using a combination of questioning techniques, observational studies and document analyses. The observational studies later became a critical technique that facilitated capturing normal, everyday functioning of the AOC processes, even when the research focus was at the time tuned toward novel, extreme events. This opportunity would have been lost if only questioning techniques were employed for data elicitation purposes.

For verification purposes, respondent validation was employed using member checks and expert validation. The practice of introspective reflexivity further necessitated heedful consideration of ways the researcher’s inclination and sensitivity toward certain theoretical, methodological, and philosophical orientations could influence both the research process and the interpretation of the research findings. Collectively, these mechanisms provided
opportunities for proactive refinement, reprioritisation, and iterative adaption of the research focus and its objectives.

Objective 3: To delineate how the various parties in the AOC processes adapt their behaviours in response to the endless variety and uniqueness of demands.

The overarching thesis of this research is that anticipatory adjustments are required to make up for gaps in assessments relative to specific threats expected. Successful adaptation depends on how responsive a system is when dealing with variations in demand that differ widely from the planned-for situations. The results lend support to the argument that responsiveness not only applies to the planned contingencies, but also to the processes by which the escalating situation is managed—such as strategic flexibility in thinking (Dörner, 1990, p. 471), adaptive leadership styles (Uhl-Bien et al., 2007), and shifts in decision-making protocols (Snowden & Boone, 2007). Another significant abstraction is that adapting prescribed rules to fit prevailing situations will require not only a leeway in interpreting prescriptions of appropriateness, but also some degree of ingenuity in “matching a changing and ambiguous set of contingent rules to a changing and ambiguous set of situations” (March & Olsen, 2008, p. 693). Being responsive also demands that both the goals-to-be-accomplished and the understanding of prevailing situations be periodically reviewed and updated to be able to dynamically counter the gap between the actual and the anticipated.

The four airlines investigated, to varying extent, employ a decision-making architecture akin to command-and-control structure during a significant disruption. This strategy is indicative of the necessity to implement a course of action under severe time constraints, while managing complex network of interdependencies relating to resources and performance variables controlled by different units. Evidence collected from the AOC practice suggests that command-and-control “gets the job done” when there are too many variables to negotiate, particularly when time is critical or when safety, regulatory or political stakes are high. In other words, command-and-control strategy appears especially useful in speeding up decision-making processes in highly distributed but interdependent systems, within a critical timeframe. Whilst the notion of command-and-control in military operations is a well-established form of decision and control strategy, little is known of how this concept plays out in other complex domains such as the airline operations.
control. Therefore, this thesis contributes to knowledge by elucidating the dynamics of command-and-control in various contexts. The discussions of dynamic renegotiations reveal that command-and-control is an essential and well-established strategy that controllers in the AOC domain apply so as to function successfully in the face of significant stressors. But, more significantly, the discussions also shed light on how command-and-control can degrade collaborative deliberations. Perhaps, the findings may potentially contribute to a related discussion on “command-and-control agility” that is currently being reviewed in the defence force and military applications.

In regards to how one can operationalize resilience in practice, practitioners contend that resilience should be contextually determined based on what a company wishes to achieve as their operational goals. Using complex mappings between location, size of operation, company policies, political and cultural orientations, and career experiences in various airline companies, practitioners that took part in this study argued that various airlines have very divergent perspectives regarding what resilience means to their operations. In particular, a senior network-control manager suggested that to understand resilience in context of a specific airline’s operations, one must “dig deep” to unveil not only the economic drivers, but also cultural, political and social driving forces behind the response strategies and escalation protocols that various airline companies deploy. This idea parallels Barry Turner’s work (Turner, 1976, 1978) in the sense that cultural, social and political forces influence the direction of the resilience ‘pendulum’ and how far it swings. Of course, other publications in the complex systems and resilience engineering literature (e.g., Dekker, 2011; Perrow, 1994; Pidgeon, 1997; Sagan, 1993; Vaughan, 1996; Woods, 2003, 2009) have also illustrated how such forces can combine to set up an almost imperceptible drift toward failure. It would be interesting for future research to further shed light on how precisely cultural and political forces influence frontline strategies in airline operations control, and how they may contribute to the resilience or brittleness of the system.

Collectively, the findings contribute toward advancing collegiate understanding in regards to the socio-cognitive behaviours at play in airline operations control. They also shed light on the generic patterns of macro-cognitive behaviours in safety-critical systems. By mapping the dynamics captured in this study against patterns obtained in comparable domains of practice, the abstractions begin to clarify a more generic pattern of socio-cognitive behaviours that are manifested in many work domains where safety, and perhaps
security, is regarded as one of the ultimate mission of the institution (such as in urban and bush fire-fighting, Intelligence Services, nuclear power systems, and healthcare systems). Of particular significance include the ideas that decision-making in these domains of practice follows: (i) consequentialist thinking (e.g., critical situations take priority over routine events); (ii) the need to focus resources on anticipatory response rather than focus only on current problems; and (iii) a continuing struggle to remain ahead of threats, both the anticipated and the unforeseen. Ultimately, the thesis findings lend fresh insights into the act of “dynamic balancing” in airline operations control by elucidating how practitioners actually go about resolving distributed control problems that in most cases have unclear, rapidly evolving, or conflicting goals.

Objective 4: To construct explanations grounded on observations made in this study, and further identify links between findings in this study and findings in comparable domains.

In Chapter 5, several links were identified between findings in this study and theoretical discourses in the literature. However, a detailed comparative study was conducted across three discussions. The first comparative study was conducted between the findings in this thesis and a similar study conducted in a hospital emergency department unit by a resilience engineering group in the United States—Stephen, Woods, Branlat and Wears (2011). In agreement to their views, the thesis findings reiterate that human adaptive systems need a cooperative culture and structure in order to adapt formalised procedures across functions: particularly, in the face of myriad internal constraints and external pressures. In a rather interesting twist, evidence from the AOC practice suggests that cooperative adaptation is not always preferred when managing trade-offs at the operations control centres. Building on the three locally adapted strategies proposed by Stephens and colleagues (2011) – cooperative, defensive and autonomous, a fourth strategy, protective strategy, was uncovered. This comparative study provided insight into trade-off dynamics that are context-specific and the ones that are likely shared across the broader human adaptive systems.

A second comparative study was conducted between this study and a study of international disaster relief by Dekker and Suparamaniam (2007). Relative to the model of renegotiation developed by Dekker & Suparamaniam (2007), a significant abstraction arising from the investigation of dynamic renegotiation strategies in AOC practice is that actors involved in dynamic renegotiations in interactively complex systems would occasionally have problems.
in resolving ambiguities among competing ideas of a situation and in adapting pre-specified guidance in the face of a new situation. The findings also suggest that frontline actors may struggle to determine what their changing roles and responsibilities should be in the renegotiation process, and what such dynamic characteristics in roles and responsibilities imply, with regards to their authority to act amidst ambiguous and changing situations. What is considered familiar or obvious may gradually become murky—and sometimes, conflicting—as lines of authority and responsibility continue to intersect during the renegotiation processes. Nevertheless, these dynamics provide impetus for clearer referents and clearer rules for adapting rules. Despite the challenges of adapting rules on-the-fly, it is the position of this thesis that adapting authority and responsibility according to needs is a more resilient strategy than seeking to take knowledge to the seat of authority in times of need.

A third comparative study was conducted between this study and a study of logic of actions by two leading researchers in public policy and organisational studies—James March and Johan Olsen. In response to their propositions on promising directions for research on the antecedent logics for action, evidence collected from the AOC domain of practice evinced that, although the prescriptions for actions are typically written in the language of appropriateness, the processes of reasoning and interpretation of rules are heavily tuned to exploration of immediate and future consequences of actions. Based on controllers’ explanations of the rules they apply and the procedures in place, it was deduced that frontline practitioners largely apply consequentialist thinking in the process of determining the appropriateness of their actions. This thesis further challenges the supposition that a publicly and widely validated rule can be regarded as a mark of appropriateness. Regardless of how long a rule has been successfully applied, a resilience perspective suggests maintaining a reasonable degree of heedfulness regarding ways such rules might fail and in monitoring the changing shape of vulnerability within an operative landscape. Further discussions regarding the significance of these comparative analyses, as well as the contribution of this thesis to those discussions, are documented in Section 6.2.
Objective 5: To reflect on the significance and implications of study.

The current chapter presents a reflection on the significant contributions of study, the limitations of study, as well as the potential applicability and transferability of study. This chapter concludes by making a case for resilience in airline operations control. In the concluding remarks, the chapter reflects on the potential usefulness of resilience thinking to the study of decision making in airline operations control, with emphasis on how the research findings may contribute towards the development of methods that can incorporate some degree of resilience thinking in airline operations research (airline OR).

6.2 Research Contributions

The findings of this research have strong links to prior studies conducted in a broad range of domains and fields of study. In this sense, it would be incorrect to claim that the thesis discussions and contributions deliver a paradigm shift in a Khunian sense (Kuhn, 1970). However, some significant insights can be claimed based on the fresh perspectives provided by the reformulations, reinterpretations, extensions, and integrations of existing notions, concepts, and theories. The contributions were generated through critical analysis and application of theories developed in other domains and areas of study to the AOC domain of practice.

6.2.1 Contributions to research in airline operations control

This thesis produced two significant reformulations that have several implications for the potential translation of research into practice in the context of airline operations control.

Contribution 1: The reframing of the traditional airline resource-control problem as a ‘socio-cognitive variability control’ problem.

The traditional airline ‘resource-control’ problem was reframed in this thesis as a ‘socio-cognitive variability-control’ problem. The reason for accentuating the socio-cognitive aspect is to better account for human contributions in managing demand variability in airline operations. Clearly, human agents proffer numerous advantages over automated systems in addressing the vagaries of demands. More specifically, human agents provide variability
when it is needed to address surprising variations and restrict variability when it becomes detrimental to the successful coordination of activities (Hollnagel, 2009a). Second, this perspective calls to mind the challenges and the many assumptions that are often taken for granted relative to the ever dynamic and evolving nature of the airline operations' problems; and consequently, the need for highly responsive and adaptable agents armed with plans that have reasonable margin of manoeuvre (Woods & Branlat, 2011b). Third, this perspective acknowledges that whilst robust planning is necessary for resilient execution of schedules amidst surprising variations, maintaining adequate margin-of-manoeuvre goes beyond the use of buffers to absorb variances in operations. The dynamic and evolving nature of the problems-to-be-controlled necessitate flexible adaption of applicable rules-of-action and other systems of rules that govern cross-functional interactions amongst the multiple centres of control involved in the day-to-day execution of airline schedules.

The notion of socio-cognitive variability control can, therefore, be seen as a critical concept for determining the goodness of an airline schedule by considering the exploration space that a set of responses afford during dynamic renegotiations in practice. From a standpoint of multi-criteria decision analysis, a socio-cognitive formulation favours a decision-space framework over a criterion-space framework. In decision-space representations, the priority is on the variety and range of responses that can lead to favourable consequences; whereas in criterion-space representations, the focus is on a set of decision objectives and their pre-defined relevance. Given that goals tend to shift quickly in AOC practice, there is a need for a more flexible and resilient criterion for evaluating the goodness of a response. The operative framework that offers more variety to address variability then becomes a more befitting way of measuring resilience. This thinking is clearly in line with Ashby’s formulation of ‘requisite variety’ (Ashby, 1958), which has also been acknowledged by leading experts in resilience engineering as one of the fundamental laws that govern joint-cognitive systems at work (Woods & Hollnagel, 2006). Overall, the socio-cognitive variability control perspective may provide some possibilities for determining the resilience of an airline operations control protocol; in terms of the level of margin a specific protocol affords, its tolerance to relentless fluctuations, the buffering capacity embedded in the protocol, and the flexibility it can afford in the face of unforeseen surprises (Woods, 2006).
Contribution 2: The reformulation of tactical control operations in AOC as a distributed anomaly response

The reformulation of tactical control problems as a distributed anomaly response is largely motivated by a need to account for the evidence that frontline controllers are not only concerned with dynamic management of resources. In addition to tactical control of resources, frontline controllers are largely involved in dealing with broader issues associated with coordination of responsibilities, renegotiation of authority, and resolution of conflicting stakeholder interests. In a sense, taking a distributed anomaly response perspective reiterates the need to consider the broader duties performed by practitioners in the field in conceptions that aim to improve or to optimise tactical control practices in airline operations. Observations made in the field have also revealed that frontline controllers will very likely favour feasibility over optimality. The concept of distributed anomaly response further captures explicitly the collaborative nature of airline operations control and, implicitly, the potential double binds that often manifest when two or more competing views are presented during cooperative deliberations. Ultimately, this view of tactical control in airline operations better reflects what goes on in practice, compared to an idealized view of omniscient, objective agents who have unlimited knowledge of all aspects of the airline operational processes and make rational decisions unaffected by emotions and social considerations. Perhaps this distributed anomaly response perspective may trigger new ways of thinking about, and new ways of formulating, multi-agent systems in operations research.

6.2.2 Contributions to research in Resilience Engineering (RE) and Naturalistic Decision Making (NDM)

In addition to several cross-disciplinary discourse and analysis that were investigated, this thesis made five significant contributions that have several implications for research in resilience engineering and naturalistic decision making.

Contribution 1: A perspective on the forces that shape how governance architectures evolve

The discussions on ‘interactions across multiple centres of control’ provide a fresh perspective on the driving forces that shape a unit’s choice of adaptive strategies, and how a unit’s governance architecture evolves in the context of regulating interactions across multiple centres of control. The results begin to clarify how severity of an event and its
scope of impact can shape a unit’s choice of adaptive strategies. The findings also point to the significant role that external forces (e.g., safety and security regulations) play in shaping cross-scale (vertical) interactions in frontline operations, and how the resultant cross-scale interactions in turn influence horizontal adaptive behaviours during escalating situations.

By mapping the three strategies suggested by Stephens, Woods, Branlat and Wears (2011) to the specifics of airline operations control (i.e., cooperative, defensive and autonomous), a fourth strategy, protective strategy, has been uncovered. In some sense, protective strategy is possibly a variant of defensive strategy, but it is mainly deployed when there is need to make very tough choices that have broader implications than immediate operational losses. More specifically, protective strategy appears most useful when contriving plans to protect organisational values and interests amidst potentially damning situations. While defensive and protective strategies share a lot in common, protective strategy encompasses both restrictive and sacrificing approaches mainly tuned towards survival of the system in the long term. Perhaps it is more transparent to describe protective strategies as damage control procedures, which are mainly activated when there is need to address critical issues that would otherwise impact negatively on an organisation’s reputation. Defensive strategy, on the other hand, is deployed purely to create monopoly power (Holloway, 2008, pp. 157-161) or competitive advantage by restricting opportunities of others—for example, restricting opportunities of competitors to gain market share (Williams, 1994).

Overall, protective strategy, together with the other three strategies suggested by Stephen and colleagues (cooperative, autonomous and defensive), should be a helpful framework for reasoning about generic patterns of adaptive behaviours that decision makers employ across a broad range of human adaptive systems. The thesis position is that, whilst cooperative structures appear more efficient, the effectiveness of an adaptive strategy is not tied to whether adaptation is defensive, cooperative, protective or autonomous. On the contrary, the effectiveness of an adaptive strategy is contingent on the extent that an adaptive strategy enables decision makers to successfully manage trade-offs to achieve a better overall outcome given prevailing circumstances.

Contribution 2: The extension of the renegotiation of authority model

Based on empirical data collected from the field, this thesis extends the original model of renegotiation developed by Dekker and Suparamaniam (2007) by highlighting, with a
renegotiation sphere in Figure 5.13, how various forces colour the perception of controllers involved in the renegotiation process. In particular, this extended formulation identifies two crucial elements; the severity of demand and the scope of demand, that often shape the context for renegotiations. However, abstractions from the extended model capture much more than the relationship between severity and scope of demands. As depicted in Table 5.8, the abstractions further capture the forms of responses that could be elicited, as well as the governance architectures that are likely to evolve. Collectively, the extended model is a framework for thinking about the likely forms of responses and control architectures that certain combinations of demand severity and scope can elicit during multi-party collaborations in a distributed anomaly response. Severity and scope of events also appear to be useful factors for predicting whether renegotiations would likely be perceived as mutual or asserted, and the level of gracefulness that would likely be associated with a renegotiation process.

From a practical sense, the extended model can support decision makers in making sense of how their adaptive strategies impact on controllers’ perceptions. The location of a renegotiation sphere can indicate how the controllers perceive a renegotiation process globally. Therefore, a renegotiation sphere when applied to the original framework yields a tool for understanding controllers’ perceptions of renegotiation practices within a given control centre or operational setting.

Contribution 3: Theoretical integration of disparate models and frameworks of resilience

The resilience markers framework proposed by Furniss and colleagues (Furniss et al., 2011, pp. 5-6) was extended to include a column for the four essential capabilities of resilience—anticipating, responding, monitoring and learning. Strategies and patterns of resilience that have been observed in various safety-critical operations, as presented in the resilience engineering literature, were further abstracted and categorised in accordance with their respective relevance to anticipating, responding, monitoring and learning. Probes from the resilience analysis grid (RAG) as proposed by Hollnagel (2011a, pp. 284-289) was adapted—in accordance with their relevance to each strategy abstracted from the literature—to elicit concrete manifestations of resilience as observed in the field. The integrated framework (Appendix B) provided a starting point for abstracting exploratory interview questions and further guided what is considered “worth investigating” in the early stages of the field.
observation study. More importantly, it provided a way to articulate clear links between resilience concepts and concrete manifestations of resilience in practice, grounded on their relevance to the four essential capabilities of resilience. This integrated framework proved to be an appropriate starting point for investigating patterns of resilience and the dynamics of resilient repertoires in safety-critical operations. This framework should be useful to practitioners and new researchers who are interested in investigating issues around resilience in safety-critical systems.

In addition, Jen Rasmussen’s model of risk management in a dynamic society (Rasmussen, 1997) was applied in elucidating the interplay amongst some essential attributes of resilience—margin, buffering capacity, flexibility and tolerance—as proposed by Woods (2006, p. 23). In the process of applying Rasmussen’s model to the study of resilience, a vital clarification of one of its core assumptions was made to better reflect the fact that modern sociotechnical systems are largely distributed, with many parts or functions interacting in complex and unforeseeable ways. The revised assumption presupposes that the operating point represents an emergent characteristic of interrelating functions as a whole—the very same property that could yield systemic failure from a series of complex, non-linear combinations—rather than a literal summation of the operating points of each organisational part or function. In a metaphorical sense, it is the complex rhythm or signal that indicates the general health of an organisation as opposed to the summation of the health of its different organs. The significance of this application is primarily that it accentuates the relevance of the dynamic model in resilience research by demonstrating that the model captures adequately the interplay between resilience attributes—margin, tolerance, flexibility and buffering capacity—and can be used as an interpretive framework for resilience dynamics in safety-critical operations.

**Contribution 4: A perspective on the underlying reasoning for actions**

This thesis challenges the assumption that the logic of appropriateness and the logic of consequentiality follow distinct processes of reasoning. By examining what controllers consider and how they frame the rationale for their decision considerations, the results begin to illuminate patterns of relationship that may exist between the two logics. There appears to be a nested relationship in the way both logics are applied in the context of airline operations control. In formal rationalisations, the relationship can be conceived of
as a *concentric* system of rules, with a common point that defines the overall goals-to-be-achieved. In this concentric sense, the rules of appropriateness becomes the outer bounds (the shell or casing) that constrains what can or cannot be done; whereas the rules of consequentiality constitutes the internal mechanisms (the nub) for selecting specific action trajectories and for making trade-offs, all within the bounds of what is considered appropriate (the shell or casing). Often, though, the relationship between the two logics appears to take more of a judicial sentencing structure—to borrow from Hopkins analogy (Hopkins, 1999). From the perspective of a judicial structure, the rules of appropriateness are applied as the *obiter dicta* representing the more visible explanations that are applied when justifying the processes of reasoning to an outsider or to one who was not privy to the deliberations. The rules of consequentiality, on the other hand, are then applied as the *ratio decidendi* signifying the substantive (but tacitly acknowledged) reasons for the actions. Although both analogies seem to suggest a relationship where consequentiality takes precedence over appropriateness, such claims cannot be substantiated more definitively using the current results. Further study is needed to help clarify whether there is precedence or not in the way both rules are applied. The underlying assumption of this thesis, for now, is that both rules hold equal significance to the controllers and the airline organisations.

It therefore follows from these analogies that ‘unequivocally defined rules which can represent either the appropriateness- or the consequentiality-dimensions more distinctively’ is not tenable in the context of human actions in complex sociotechnical work systems. The thesis results evinced that both rules are hardly mutually exclusive. The results further suggest that the underlying reasoning as to whether a rule is appropriate derives from the logic of balance between the impact of a rule on the people it is applied on and its implications for the system that enacted the rule. As March and Olsen suggested (March & Olsen, 2008, p. 702), it seems reasonable to think that applying both perspectives complementally is a more resilient approach. A complementary stance could provide alternative perspectives to a situated action, thereby improving the chances of learning from an experience. Therefore, exploring the complementary dynamics of both logics in a decision-making process is a more beneficial step toward advancing resilience-engineering principles across organisations and domains-of-practice that are constantly faced with the pressure to be both thorough and efficient.
A significant lead that was not investigated, at this stage, is the implication of having a gap between rule prescription and rule interpretation. Future research may seek to uncover how such gaps may shape the way practitioners go about adapting pre-specified guidance, and how such gaps can influence the way practitioners go about ascertaining the appropriateness of their actions. Ultimately, the primary significance of this discussion is that it has yet again reiterated the need to provide frontline controllers with more concrete guidance on how to fill in gaps between rules-as-prescribed and rules-as-tenable.

**Contribution 5: On the antecedent conditions for learning**

Despite emphasis by safety researchers on the demerits of focusing on accidents/incidents as a vehicle for learning, it is still the case that accidents/incidents still drive many initiatives that are targeted toward learning in airline operations. Time constraints and limited access to the field did not allow for a more empirical investigation of the antecedent conditions for learning in this research. Nonetheless, in the spirit of advancing knowledge, abstractions have been made from cross-domain analysis and from recent events within the aviation sphere (such as, the disappearance of Malaysian airline Flight MH370 and then the subsequent shooting-down of Flight MH17 over Ukrainian airspace). The abstractions, in turn, led to the proposition that it is time to rethink what we currently know about the drivers of learning in high-risk, safety-critical systems through a number of questions, such as: what exactly do practitioners think about learning in their work domain? How well do they know about or value current advocacy for a shift in thinking? Why is there still an inclination toward past failure events as vehicles for learning despite clear warnings from various academic research? How can practitioners begin to see what is apparently unthinkable (e.g., that an aircraft can simply vanish)? Is there something practitioners experience that researchers are yet to account for with regards to learning in safety-critical operations? Given that bureaucratic accountability and stakeholder pressures will hardly be assuaged following a disastrous event, how is current knowledge being deployed to ensure practitioners abstract the right lessons from such experiences?

These are open questions that could generate endless debates, and may even be discarded on the grounds that some are mere reiteration of issues that have been addressed in the literature. But the persistence of failure events as vehicles for learning has necessitated a revisit to the roots of current knowledge about organisational learning in safety-critical
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systems. It is hoped that the questions posed will provide some sense of direction for progress and future work in substantiating current assumptions more empirically. A conclusion from this thesis is that it is needful for theoreticians and practitioners to maintain an open mind (as far as practicable) concerning matters relating to learning, so as to be better positioned to call into question current assumptions of what constitutes “effective”.

6.3 Limitations of the study

This section articulates a number of limitations relating to some unplanned-for situations that in some ways constrained either the research methods that could be successfully applied, or the access to information sought throughout the course of the research. It also discusses potential impact of the decisions made with regards to methodological considerations and theoretical perspectives applied in this research.

6.3.1 Methodological limitations

Several limitations were encountered during the implementation of the research design, which necessitated some degree of changes to the original design. The five significant limitations relating to methodological issues include:

1. Access to participants

The sample size of the targeted participants was understandably limited, because this investigation was tailored toward a population of experts that is relatively small: frontline controllers in airline operations control centres. Participant sampling was opportunistic rather than being based on any predetermined metric. This is because controllers were willing to participate in the study if and only if the sessions arranged in collaboration with airline management coincided with their work shift. The result is that some participants could not be reached for further examination or clarification.

Besides, the airline operations control centres can be very busy. This made getting access to controllers’ thoughts quite challenging in practice. In particular, it was hard getting controllers to use think-aloud protocols during busy times, as they often had to deal with a barrage of calls and conversations with other personnel within and outside their operations
control centres. The limited access to controllers directly impacted on the depth of thoughts that could be accessed during critical incidents and, in many instances, limited the research method to less intrusive observation methods.

2. **Access to control centres and critical information**

Access to the operations control centres varied widely as some centres were visited only once due to distance, whereas some centres were visited several times. In all, the visits were just sufficient for contrasting patterns of adaptive behaviours across the four operations control centres. But, despite the immense goodwill shown by the airline organisations to grant access to their standard manuals, access to daily operational reports and documentations of critical events was not granted. As a result, documentations relating to stories of interest were not accessible, and such stories of interests were not corroborated with the official documentations held by the companies.

Again, deliberations on serious matters were conducted over a conference call with the participants on ground sharing their views behind closed doors. Thus, access to information was restricted only to retrospective accounts of what was discussed rather than unmediated access to the entire conversations that transpired. Perhaps being present in those meetings might have afforded access to unspoken communications, such as body language, the tensed or relaxed atmosphere in the room during deliberations, and the like.

3. **Openness to sensitive subjects**

In general, the participants generously responded to the questions posed during the interview and the observation sessions. But, on a few occasions, it felt like some participants intentionally evaded providing information to some questions that involved sensitive subjects, which could be damming to their personal and/or organisational image. This situation might have to do with the fact that the researcher is an outsider to the airline organisations. Again, the fear of revealing information that might have serious political or legal implications to an outsider could have deterred open responses to some of the difficult questions. Perhaps the participants would have been more open with their thoughts if this investigation were conducted by one of their colleagues.
4. **Learning effects**

Given the exploratory nature of this inquiry, the conditions of observations and the focus of study evolved continuously over time as the researcher learned more about the controller’s work and the rules they apply, and as the researcher stumbled across new theoretical concepts that provided more comprehensive insight into earlier observations. The impact of this evolution is that the focus of investigation at the later stages of research differed widely from the focus at the early stages of study. Whilst the exact consequence of this learning effect is not known, it is assumed that more insightful information could have been obtained if the researcher had access to the same level of knowledge in the beginning as he had in the later stages of study.

5. **The scoping problem**

At stated in Chapter 1, the unit of analysis was delimited to focus only on tactical control operations at the operations control centres. But, as the discussions in Chapter 2 have shown, there are clear links between the strategies adopted in the planning and scheduling stages and the strategies that controllers can deploy during schedule execution. Besides, tactical control extends beyond what happens at the centralised control centres. There are many activities that are concurrently going on at various airports: check-in operations, refuelling, catering services, cleaning, embarkation and disembarkation of passengers and so forth; any of which can contribute to a sudden need to vary actions to meet new demands. However, these activities were not considered in detail as it would require having an investigator at each station to be able to capture more precise picture of what is going on. So, whilst this delimitation can be seen to afford a manageable scope for the empirical investigations, it is difficult to assess at this point how the conclusions would have been affected had the planning stages and the other strategic elements been included as part of the unit of analysis for this study.
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6.3.2 Theoretical limitations

Again, the application of theoretical frameworks in this study was not without its problems, including the use of theory for guiding what to investigate and for interpreting findings. The two most prominent issues identified include:

1. Effects of underpinning theories and interpretive frameworks

Woods & Branlat (2011, p. 2) have suggested that perspectives can “simultaneously reveal and obscure aspects of the world”. The perspectives used in this study certainly played a huge role in the conclusions drawn from the observations. For example, many of the conclusions drawn about controllers’ rationale and logics for actions have much to do with their safety considerations, perhaps a result of applying a ‘resilience engineering’ viewpoint which is a perspective that is developed for studying risks to safe operations in high-risk industries. Cross-fertilization of ideas across perspectives is suggested as a way to encourage disambiguation and undue fixation on only one frame of reference.

2. The generalizability of conclusions

The patterns of behaviour captured in this study are grounded on what was observed in only four airlines and, as a matter of consequence, may not be representative of generic patterns of behaviours across airlines in the regions studied and beyond. Although a reasonably good mix of airline organisations was used for this study, airlines have unique protocols and policies, such as protocols on how to balance authority and responsibility, and engaging third party carriers when recovering passengers and crew members. These differences can and often do influence the way controllers act and feel during negotiations. Consequently, the generalizability of the conclusions made in this thesis may be limited as the findings may have been heavily influenced by the unique characteristics of the airlines that participated in this study.

Extensions of the findings to other domains may face challenges as well if those domains do not share critical dynamics with the AOC domain—as seen in the way safety consciousness influences decision options and the rapidly changing relationship between resources across an airline network. The results will most likely vary across domains because some situations and domains may require exact solutions and there may be limited or no opportunity for iterative solution, as evident in airline operations control. But, even
within the AOC domain and other domains that share similar dynamics, it is not a given that the results will be repeated. Rather, it is postulated that these dynamics are likely when the factors and the conditions, as identified, combine interactively. Therefore, caution is advised when re-interpreting or extending the findings, especially when the findings are extended beyond airline operations control.

6.4 Future directions and outlook

The discussions and conclusions drawn from this study could be extended in a number of ways so as to further illuminate how resilience can be supported in both the AOC domain and in human adaptive systems more broadly. First, this work could be extended to other airlines, particularly within the Asia-Pacific region. The extension should be useful for understanding why frontline controllers prefer specific kinds of adaptive behaviours over others. Extension of study to other domains can also elucidate common denominators that managing trade-offs in airline operations control may share with the broader human adaptive systems. Such insights could serve as a foundation for delineating underlying structures, culture and practices that support decision makers to adapt formalised procedures *in-flight*, while managing many-to-many mappings across conflicting goals, roles, and responsibilities.

Second, future research should explore the possibility of using insiders as investigators in order to elicit trust and openness in the way participants share their thoughts on difficult and sensitive subjects. But, even with an insider, attention should be paid to power relations and possible conflict-of-interests that may exist between investigators and participants; as such dynamics can still elicit distrust if not aligned properly.

Third, the findings in this research also captured an interesting interaction between parallel control and the command-and-control governance architectures during cross-scale (vertical) renegotiation of authority. This interaction, particularly, needs extensive investigation to uncover how and what makes such governance dynamics work, along with how breakdown can occur. On a related topic, it would be interesting to examine how mid-level supervisors question their understanding of local pressures and challenges at the
sharp-end, and the extent such understanding goes in adapting the ways they make future plans or reconfigure operating rules.

Fourth, future research also needs to examine how pre-specified protocols address the issue of sacrifice decisions; that is, how current protocols make provisions to ensure some functions do not feel like they are always singled out to sacrifice their subgroup’s goals for the greater good of the system. Future research should investigate how these dynamics play out in airline operations control and in other domains of practice with similar or different operational characteristics, so as to further clarify the cultural and doctrinal contributions of the renegotiation dynamics observed in this study. Such knowledge will enrich collegiate understanding of how and why control migrates in both routine and escalating situations.

Fifth, it would also be promising to find more empirical evidence that could explain how trade-offs between the rules-of-appropriateness and the rules-of-consequentiality—and perhaps other less salient drivers—can influence frontline controllers’ ability to apply cognitive judgement in both routine and novel demand situations. Although some ‘nested relationship’ analogies have been presented in this study, it would be hugely conceiting to make a definitive assertion at this point that these analogies constitute the best explanation for the relationships and forms the two logics could take in an AOC context. Therefore, future research should investigate the relationship between rules-of-appropriateness and rules-of-consequentiality across more diversified scenarios, organisations, and echelons, in order to contribute towards a more definitive architecture that allows the two systems-of-rules to co-exist in a complementary rather than competing fashion.

Against the backdrop of the shooting-down of Malaysian Airline Flight MH17, which in hindsight should have been routed over a safer but less financially-favourable route, future research should aim to uncover how organisations verify the appropriateness of the performance targets they set, as well as the forces that contribute to an organisation’s ability to monitor and regulate its performance targets more successfully. Future research might also investigate how organisations deal with challenges relating to prospective learning, along with how organisations construct and combine lessons from the past, the present, and the future.
Chapter 6: Conclusion, Significance and Outlook

6.5 The case for resilience in airline operations control

The entire thesis has been designed to provide strong evidence as to why resilience should be taken seriously in the studies and practices of airline operations. Research and practice in airline operations decision-making can reap immense benefits by taking a resilience perspective because this perspective makes provision for safety considerations to be investigated alongside productivity challenges. In addition, workers in the field of airline operations research (airline OR) may also see a need to redefine current assumptions on what constitutes good outcomes. The argument regarding a preference for a decision-space framework in multi-criteria decision analysis is a step in the right direction because it provides an avenue through which airline OR studies can engage with the concept of resilience. In addition, the reformulations introduced in this thesis have further ideas on how the mathematical formulation of resilience can be grounded on the logic of balance between margin, buffering capacity, tolerance and flexibility. Taken together, these four attributes can serve as criteria for determining the resilience of a response. The arguments that stem from this study also support the age-long premise that forming an optimal response to a situation requires more than the accurate calculation of the impact on tangible resources. An optimal response should be evaluated by how well a set of responses meets the immediate needs (that cover a broad range of demands) and ensures the feasibility of future adaptations. Perhaps resilience thinking may inspire a new set of methods and algorithms for dealing with multi-criteria decision-making problems. As already discussed, for such methods to be relevant and effective in rapidly changing contexts, they should be tuned towards decision-space measures rather than towards criterion-space measures. This line of thinking holds possibilities for translating research into practice, as it better captures actual dynamics in airline operations control than many formulations oriented towards criterion-space measures.
REFERENCES


Managing Demand Variability in Complex Sociotechnical Systems


APPENDIX A: ETHICS APPROVAL LETTER

Ethics Clearance Letter

To: Dr Peter Higgins, FEIS, Mr Kenneth Igbo

Dear Dr Higgins,


Dr Peter Higgins, FEIS, Mr Kenneth Igbo
Approved Duration: 09/08/2012 to 09/09/2015 [Adjusted]

I refer to the ethical review of the above project protocol undertaken on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by SUHREC Sub-committee (SHESC4) at a meeting held on 22 June 2012. Your responses to the review as e-mailed on 19 and 23 July and 7 August 2012 were reviewed by a SHESC1 delegate.

I am pleased to advise that, as submitted to date, the project has approval to proceed in line with standard on-going ethics clearance conditions here outlined.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

- A duly authorised external or internal audit of the project may be undertaken at any time.
Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the SUHREC project number. Please retain a copy of this clearance email as part of project record-keeping.

Best wishes for the project.

Yours sincerely,

Kaye Goldenberg
Secretary, SHESCI
------------------------------
Kaye Goldenberg
Administrative Officer (Research Ethics)
Swinburne Research (H65)
Swinburne University of Technology
P O Box 218
HAWTHORN VIC 3122
Tel: +61 3 9214 8465
# APPENDIX B: RESILIENCE MARKERS FRAMEWORK

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
<th>Concrete Manifestations of Resilience</th>
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<tbody>
<tr>
<td>A1. Readiness to respond</td>
<td>A11. Maintains relevant contingency plans</td>
<td>A111. Are there standard responses or procedures in place to address most expected and unexpected events?</td>
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<td></td>
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<td>A112. How is it determined that the responses are adequate for the situations they refer to (e.g., empirically, or based on analyses or models)?</td>
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<td>A12. Maintains requisite and readily deployable resources for most expected and unexpected events</td>
<td>A121. Are there adequate resources available to respond? (People, materials, competence, expertise, time, etc.)</td>
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<td></td>
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<td>A122. How many are kept exclusively for the prepared responses?</td>
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<td>A123. How soon can an effective response begin? (e.g., immediately, an hour, etc.)</td>
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<td>A124. How fast can full response capability be established?</td>
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<td>A125. For how long can an effective response be sustained?</td>
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<td>A13. Maintains the capability to engage additional resources and/or expertise in cases of prolonged or escalating demands</td>
<td>A131. Are there key personnel or special functional units that can be called upon to fill in specific roles temporarily in order to recover from a disruption?</td>
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<td>A132. What skill-set or expertise do such personnel or functions bring to the ops control unit?</td>
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<td>A133. How are those skill-sets or expertises different from the ones within the ops control unit?</td>
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<td></td>
<td>A134. How quickly can resources be replenished? (What’s the refractory period?)</td>
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<td></td>
<td>A14. Have clear criteria for activating responses or special functions</td>
<td>A141. What are the criteria for activating responses? (Do the criteria refer to a threshold value or a rate of change; is it clear how the responses have been chosen?)</td>
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<td></td>
<td>A142. Are there factors or conditions that can influence the criteria? (i.e., are the criteria absolute or do they depend on internal/external factors?)</td>
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<td>A143. Are there criteria for returning to a ‘normal’ state of operation after activating a recovery procedure? (How clear is it?)</td>
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<td>Resilience Markers</td>
<td>Strategies</td>
<td>Concrete Manifestations of Resilience</td>
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| A2. Capability for continuous regulation | A21. Adapts resources to match the needs of the prevailing situation without compromising the potentials for future adaptive actions | A211. Is there a defined margin (reserves or buffers) that must be maintained during operations? (i.e., is the readiness to respond maintained?)
A212. How is it determined that margins are adequate for the situations they refer to? (i.e., how and when is the readiness to respond verified?)
A213. Are there strategies to ensure buffers are not depleted beyond a defined margin? (Any examples?) |
| A3. Regulation of interactions across centres of adaptive behaviour | A31. Adjusts forms of coordination | A311. How are interactions with other functional units coordinated? (e.g., defensively, cooperatively, debative)
A312. Does the strategy vary across events (and how, if yes)? (i.e., is it rigidly implemented or adaptable given the prevailing circumstance?)
A313. How is it verified that a strategy is globally acceptable and adequate for the situations for which it is deployed? (e.g., empirically, negotiation with other units, standard procedure?) |
| A32. Adapts authority and initiative across multiple centres | A321. How are initiatives and potential decisions generated? (e.g., from a controller or a unit manager)
A322. Are there defined protocols for authorising actions? (e.g., centralised, decentralised or hierarchical, is there a clear basis for selecting a protocol?)
A323. Does the protocol vary across events (and how, if yes)? (i.e., is it rigidly implemented or adaptable given the prevailing circumstance?)
A324. Are roles adaptable with regards to initiating decisions and authorising potential actions? (e.g., can a controller authorise actions on behalf of a unit manager?)
A325. How often are roles adapted in order to get over a disruption? (e.g., routinely, infrequently, only in time-critical situations) |
### Resilience Markers: Knowing what to expect

<table>
<thead>
<tr>
<th>Resilience Markers</th>
<th>Strategies</th>
<th>Concrete Manifestations of Resilience</th>
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<tbody>
<tr>
<td>B1. Ability to see and evade</td>
<td>B11. Maintains the capability to look into the future</td>
<td>B111. Is there expertise available to look into the future? (Is it in-house or outsourced?)</td>
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<td>B112. How far does the organisation look ahead? (weekly, forth-nightly, monthly, yearly)</td>
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<td>B113. Is there a common time horizon for different parts of the organisation? (e.g., for maintenance, crew rostering and tail assignment)</td>
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<td>B114. How does the time horizon match the nature of the core business process?</td>
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<td>B12. Maintains a recognisable ‘model of the future’</td>
<td>B121. Is there a recognisable model of the future? (What is the assumed nature of the model?)</td>
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<td></td>
<td></td>
<td>B122. How is the model of the future formulated? (i.e., is the model about the future well articulated or based on a ‘folk’ model or general common sense? Is it explicit or implicit)</td>
</tr>
<tr>
<td>B2. A constant sense of unease</td>
<td>B21. Maintains an awareness of potential threats and opportunities</td>
<td>B211. Are there events that are considered potential threats or opportunities in the model of the future? (What are they and how do they develop?)</td>
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<td>B212. How often are future threat and opportunities assessed/re-assessed? (e.g., regularly or whenever the need arises)</td>
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<td>B213. How well are the expectations about future events communicated or shared amongst units involved in the tactical ops control?</td>
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<td>B22. Maintains an explicitly-defined level of risk acceptance</td>
<td>B221. To which extent is risk awareness part of the organisational culture?</td>
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<td>B222. Is there an explicit recognition of risks as acceptable and unacceptable?</td>
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<td>B223. What is the basis for this distinction? (e.g., industry standard, company policy, etc.)</td>
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<td>B224. How is it determined that risk is acceptable or unacceptable? (Is the basis for this distinction clearly expressed)</td>
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<tr>
<td>B23. Anticipates alternative strategies and capacities to address the potential</td>
<td>B231. How often are new strategies explored to address potential disruptions as envisaged in the model of the future?</td>
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<tr>
<td>Resilience Markers</td>
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</table>
| C1. Early detection of signs of decompensation and potential surprise | C11. Maintains the ability to assess ambiguous signals | C111. What are the indicators that are commonly used to assess changes within the flight network and in its environment? (e.g., changes in crew availability, unscheduled maintenances, airport closures, late arrivals, GDPs, etc.; do indicators refer to single or aggregated measurements?)
| | | C112. How have the indicators been defined? (e.g., by analysis, by tradition, by industry consensus, by the regulator, by international standards, etc.)
| | | C113. What is the nature of these indicators? (i.e., are they leading, current, or lagging indicators; how appropriate is the mixture of ‘leading’, ‘current’ and ‘lagging’ indicators)
| | | C114. How is the validity of pre-emptive cues (leading indicators) established? (e.g., are they based on an articulated process model?)
| | | C115. Is there a typical elapsed period for lagging indicators? What is the duration of the lag?
| | | C116. How often is the indicator list revised? On which basis is it revised?
| | | C117. Is someone responsible for maintaining the list?
| | | C118. How often are the measurements made? (Continuously, regularly, now and then?)
| | | C119. Are the effects that are measured transient or permanent? How is this determined?
| | | C120. What is the delay between measurement and analysis/interpretation?
| | | C121. What are the indicators that are commonly used to assess changes within the flight network and in its environment? (e.g., changes in crew availability, unscheduled maintenances, airport closures, late arrivals, GDPs, etc.; do indicators refer to single or aggregated measurements?)
| | | C122. How have the indicators been defined? (e.g., by analysis, by tradition, by industry consensus, by the regulator, by international standards, etc.)
| | | C123. What is the nature of these indicators? (i.e., are they leading, current, or lagging indicators; how appropriate is the mixture of ‘leading’, ‘current’ and ‘lagging’ indicators)
| | | C124. How is the validity of pre-emptive cues (leading indicators) established? (e.g., are they based on an articulated process model?)
| | | C125. Is there a typical elapsed period for lagging indicators? What is the duration of the lag?
| | | C126. How often is the indicator list revised? On which basis is it revised?
| | | C127. Is someone responsible for maintaining the list?
| | | C128. How often are the measurements made? (Continuously, regularly, now and then?)
| | | C129. Are the effects that are measured transient or permanent? How is this determined?
| | | C121. What is the delay between measurement and analysis/interpretation?
| C12. Maintains the ability to assess ambiguous signals | | C120. What are the indicators that are commonly used to assess changes within the flight network and in its environment? (e.g., changes in crew availability, unscheduled maintenances, airport closures, late arrivals, GDPs, etc.; do indicators refer to single or aggregated measurements?)
| | | C122. How have the indicators been defined? (e.g., by analysis, by tradition, by industry consensus, by the regulator, by international standards, etc.)
| | | C123. What is the nature of these indicators? (i.e., are they leading, current, or lagging indicators; how appropriate is the mixture of ‘leading’, ‘current’ and ‘lagging’ indicators)
| | | C124. How is the validity of pre-emptive cues (leading indicators) established? (e.g., are they based on an articulated process model?)
| | | C125. Is there a typical elapsed period for lagging indicators? What is the duration of the lag?
| | | C126. How often is the indicator list revised? On which basis is it revised?
| | | C127. Is someone responsible for maintaining the list?
| | | C128. How often are the measurements made? (Continuously, regularly, now and then?)
| | | C129. Are the effects that are measured transient or permanent? How is this determined?
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<th>Concrete Manifestations of Resilience</th>
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</thead>
<tbody>
<tr>
<td>D1. Having the right basis for learning</td>
<td>D11. Maintains the capability to learn from the right experiences</td>
<td>D111. Is there a clear principle for which events are investigated and which are not?</td>
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<td>D112. Does the selection depend on specific conditions?</td>
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<td>D113. Does the organisation learn from what is common (successes, things that go right) as well as from what is rare (failures, things that go wrong)?</td>
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<tr>
<td>D2. Openness to contrary views and alternative explanations</td>
<td>D21. Maintaining the ability to develop and to question assumptions and interpretations</td>
<td>D211. On which level does the learning take effect (individual, collective, organisational)?</td>
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<td>D212. Is there someone responsible for compiling the experiences and making them ‘learnable’?</td>
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<td>D213. Are there means in place to verify or confirm that the intended learning has taken place?</td>
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<tr>
<td>D3. Capability for continuous learning</td>
<td>D31. Recognising knowledge as a manageable resource</td>
<td>D311. Is there any formal training or organisational support for data collection, analysis and learning?</td>
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<td>D312. Is learning a continuous or discrete (event-driven) activity?</td>
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<td>D313. Are adequate resources allocated to investigation/analysis and to dissemination of results and learning?</td>
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<td>D314. Is the allocation stable or is it made on an ad hoc basis?</td>
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<td>D315. Are there means in place to maintain what has been learned?</td>
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### APPENDIX C: SAMPLE INTERVIEW QUESTIONS

#### Defining the system:

1. How is the boundary of the operations (ops) control unit defined within the IOCC?
2. What are the key roles involved in the ops control unit *(aircraft control, crew control and dispatch)*?
3. Is there a clear separation of functions between those roles?
4. Are those functions also separated along the lines of domestic and international control within the IOCC?
5. Is there any supporting function within the company that normally gets involved in the day-to-day operations control *(ramp, gates, check-in counters, maintenance ops control, etc.)*?

#### Identifying and classifying events:

1. What ‘typical’ events are the ops control unit normally prepared for?
2. Is there a basis for selecting those events *(e.g., regulatory requirements, design basis, experience, expertise, risk assessment, industry standard)*?
3. Are there rules/guidelines for when the list of events should be revised *(e.g., regularly or when necessary)*? On which basis is it revised *(e.g., event statistics, accidents)*?
4. What other events are the control unit usually wary of but not necessarily prepared for?
5. Is there a basis for classifying events *(is it clear enough)*? On which basis are events classified *(e.g., severity, frequency, location)*?
6. Is there a criterion for determining the severity of an event *(e.g., economic, political, environmental or social impact)*?

#### Populating the Resilience framework table

**A1. Readiness to respond:**

1. Are there standard responses or procedures in place to address most expected and unexpected events?
2. How is it determined that the responses are adequate for the situations they refer to *(e.g., empirically, or based on analyses or models)*?
3. Are there adequate resources available to respond (people, materials, competence, expertise, time, etc.)?
4. How many are kept exclusively for the prepared responses?
5. How soon can an effective response begin?
6. How fast can full response capability be established?
7. For how long can an effective response be sustained?
8. How quickly can resources be replenished? What is the ‘refractory’ period?
9. Is there a key personnel or special functional unit that can be called upon to fill in specific roles temporarily in order to recover from a disruption?
10. What skill-set or expertise do such personnel or functions bring to the ops control unit?
11. How are those skill-sets or expertises different from the ones within the ops control unit?
12. What are the criteria for activating responses? *(Do the criteria refer to a threshold value or a rate of change; is it clear how the responses have been chosen)*?
13. Are there factors or conditions that can influence the criteria? *(i.e., are the criteria absolute or do they depend on internal/external factors)*?
14. Are there criteria for returning to a ‘normal’ state of operation after activating a recovery procedure? *(How clear is it)*?

**A2. Capability for continuous regulation:**

1. Is there a defined margin (reserves or buffers) that must be maintained during operations? *(i.e., is the readiness to respond maintained)*?
2. How is it determined that margins are adequate for the situations they refer to? *(i.e., how and when is the readiness to respond verified)*?
3. Are there strategies to ensure buffers are not depleted beyond a defined margin? *(Any examples)*?
LIST OF PUBLICATIONS


