Managing Reliability
Under
Critical Conditions

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MANAGING RELIABILITY UNDER CRITICAL CONDITIONS

BY

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THESIS

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Summary

Critical infrastructure organizations provide essential services to society. Some of these critical infrastructure organizations have proven to perform highly reliable while operating risky technologies. These so called High Reliability Organizations (HROs) have the unique ability to consistently achieve their organizational goals and enhance safety – i.e. failure free performance – despite the high demands for performing highly reliable. The success of HROs in stable operating conditions has been discussed by high reliability theorists through extensive case studies. But whether HROs are able to deal with more critical operating conditions is a question that remains to be answered.

Crisis management literature teaches us that conditions become more critical once uncertainty and time pressure creep into operational processes. Uncertainty and time pressure can be integrated in a framework that distinguishes four performance modes: bureaucratic (certain, slack time), high velocity (certain, time pressured), innovation (uncertain, slack time) and crisis (uncertain, time pressured).

Air Traffic Control the Netherlands (LVNL) is an organization that resembles the ideal-type HRO and operates on occasion in uncertain and/or time pressured conditions. Observatory analysis in the air traffic control room and interviews with air traffic controllers, staff and management has resulted in a number of conclusions.

First of all, the highly reliable performance of LVNL essentially depends on the ability of professional air traffic controllers to adjust their practices to varying conditions. Changing weather conditions, unexpected May Day calls, high traffic loads and the implementation of a new airspace structure are exemplary situations to which air traffic controllers need to adapt. An effective response relies on real time professional decisions such as alerting extra personnel, restricting traffic or even improvising new solutions that go beyond routine based practices.

Secondly, the professional decisions by air traffic controllers display a strong commitment to safety. Safety is closely related to the reliability of service provision. It is regarded as a baseline performance criteria that is not traded off at the margins with other goals. Once the conditions allow for enough certainty and time, safety can be combined with the attainment of other goals, such as efficiency and environmental goals. In critical conditions this proves to be more difficult.

Thirdly, the organizational culture and design of LVNL nurtures, fosters and protects the expertise and discretionary space that these professionals need in order to adapt. Decentralized decision making, managerial protection of operator decisions, resource buffers and extensive training programs are examples of how LVNL invests and relies on operator judgment.

In essence, these three ingredients enable LVNL to perform highly reliably under stable and more critical conditions of uncertainty and time pressure.

For my family and friends

whom I can always turn to in uncertain and stressful times

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Acronyms

ACC	Area Control Centre
AIP	Aeronautical Information Package
APP	Approach Control
ASSIST	Acknowledge, Separate, Silence, Inform, Support, Time
ATM	Air Traffic Management System
CAIB	Columbia Accident Investigation Board
CAISO	California Independent System Operator
CIO	Critical Infrastructure Organization
CDA	Continuous Descent Approach
CTA	Control Area
CTR	Control Zone
DEF	Discrete Emergency Frequency
DutchMil	Dutch military air traffic control
ESARR	EUROCONTROL Safety Regulatory Requirements
FAA	Federal Aviation Administration
FIC	Flight Information Centre
FIR	Flight Information Region Amsterdam
HRO	High Reliability Organization
HRT	High Reliability Theory
IAF	Initial Approach Fix
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
KNMI	Royal Meteorological Institute
LKTS	Core Team Supervisors
LRO	Low Reliability Organization
LVB	Luchthavenverkeersbesluit
LVNL	Air Traffic Control the Netherlands
MAS	Meteorological Advisor Schiphol
MUAC	Maastricht Upper Area Control
NASA	National Aeronautics and Space Administration
NM	Nautical Mile

OE	Operational Expert
OSD	Operational Support & Development
OVV	Dutch Safety Board
SACN	Stichting Airport Coordination Netherlands
SESAR	Single European Sky Air Traffic Management Research
SID	Standard Instrument Departure
SOP	Standard operating procedure
SSE	Safety significant event
STCA	Short Term Conflict Alert system
TMA	Terminal Manoeuvring Area
TWR	Tower Control
UTA	Upper Control Area
VEMER	Safety, Efficiency and Environmental Effect Report
VFR	Visual Flight Rules

True knowledge exists in knowing that you know nothing

Socrates

Introduction

Critical infrastructure organizations are an undeniable feature of modern society. The benefits of such organizations – i.e. electricity networks, transportation providers, public safety organizations, financial institutions, healthcare organization and so on – are numerous and indispensable. They provide fundamental products and services for sustaining our standard of living. Critical infrastructure organizations are therefore required to provide a reliable service provision. Failure is not an option. Yet, at the same time these organizations perform highly complex tasks. The margins of error are tight, and due to risky technologies small failures have the potential of cascading into catastrophic events. Events such as Chernobyl, Three Mile Island, Bhopal, the *Challenger* launch, and more recently the financial crisis, the tragic loss of the *Costa Concordia* and the Fukushima nuclear meltdown demonstrate the fatal consequences of such failures.

But how do we explain that some critical infrastructure organizations have been running smoothly despite the complexities of their operations? How are we able to explain that some critical infrastructure organizations seem to deliver highly reliable services? Why do some critical infrastructure organizations with risky technologies succeed in performing nearly failure free? These questions have motivated scholars from different disciplines to investigate this special class of organizations which has come to be known as "high reliability organizations" (HROs) (La Porte & Consolini, 1991). HRO studies have highlighted and propagated the unusual and remarkable abilities of organizations to perform highly reliable in a risky and complex context. The foundation of HRO theory is based on case studies in the U.S. at a naval nuclear aircraft carrier, a nuclear power plant and air traffic control (La Porte & Consolini, 1991; Roberts K. H., 1990; Rochlin, La Porte, & Roberts, 1987; Weick, 1987). These organizations provide critical services for society – e.g. defence, electricity and transport – and involve potentially catastrophic operations – e.g. nuclear weapon failure, nuclear meltdown, mid-air collision – but were found to perform nearly failure-free.

Yet, many questions about the success of HROs are left open. First of all, it is far from clear what a "high reliability organization" really is (Hopkins, 2007). What does reliability mean? How does reliability differ from safety? When is a technology risky? How can we recognize an HRO? Are we able to differentiate between a high reliability organization and a low reliability organization? The literature on HROs remains particularly ambiguous with regard to these questions. Secondly and more importantly, the investigated high reliability organizations have been analysed under complex, but stable, task conditions. Critics of high reliability theory argue that HRO theorists have hardly paid attention to more dynamic environments (Perrow, 1994). The naval nuclear aircraft carrier was, for instance, studied during peacetime activities (Roberts K. H., 1990; Rochlin, 2011). Whether the aircraft carrier is able to be reliable during extreme wartime conditions remains a pressing question to be answered. Crisis management research shows that such critical conditions involve deep uncertainty and time pressure, posing major challenges for organizations to enhance reliability (Rosenthal & Boin, 2001).

It is the aim of this thesis to examine *if* and *how* a critical infrastructure organization with risky technologies is able to perform reliably under conditions of uncertainty and time pressure. In summary, the central research question of this paper is:

What enables critical infrastructure organizations with risky technologies to perform reliably under conditions of uncertainty and time pressure?

By drawing on theories of high reliability, organizational change, innovation management and crisis management a set of hypotheses is formulated. These hypotheses are explored in the empirical context of Air Traffic Control the Netherlands (LVNL). To provide an answer to the research question, this paper employs a sociological perspective. From a sociological point of view, organizations are not studied as "technical instruments", but rather as entities that are "infused with value" (Selznick, 1957, p. 40). Picturing organizations as sociological entities, means organizations are "shaped in reaction to the characteristics and commitments of participants as well as to influences and constraints from external environment" (Scott, 1987, p. 494). As such, organizations are "products of interaction and adaptation" (Selznick, 1957, pp. 21-22). They adapt to environmental forces and create social structures in order to preserve a stable and reliable organization.

Thesis Structure

The first three chapters provides a theoretical outline for the research. Chapter I defines a high reliability organization and explain its characteristics. Chapter II provides a framework for studying different task conditions based on the dimensions of uncertainty and time pressure. Chapter III provides suggestions from different strands of literature on how critical organizations are able to maintain reliability when challenged by uncertainty and time pressure. Chapter IV is devoted to the research strategy. In this chapter the research design and methodologies are described. In Chapter V the context of air traffic control operations is described providing background information for Chapter IV which discusses the findings of the research. Chapter IIV concludes the thesis by answering the research question and discussing the lessons learned.

Chapter 1
High Reliability Organizations

The origins of High Reliability Theory (HRT) can be traced back to the High Reliability Project at the University of California, Berkeley in the late 1980s. The High Reliability Project was a research group aimed at discovering why some organizations are able to remain nearly error free. They investigated the U.S. Air Traffic Control at the Federal Aviation Administration (FAA), Pacific Gas & Electric company and two naval aircraft carriers of the U.S. Navy, in order to understand the secret of their highly reliable operations. These organization were labelled as High Reliability Organizations (HROs). But what does the HRO precisely mean? How do we distinguish between a high reliability organization and a low reliability organization? How are we able to use the concept for scientific purposes? Literature shows that controversy reigns with regard to these questions (Hopkins, 2007; Marais, Dulac, & Leveson, 2004). In this chapter, I will revisit the HRO literature and its critiques, and suggest a refined definition for HROs. For purposes of this study I define a high reliability organization as:

an ideal-type (a) critical infrastructure organization (b) providing services with risky technologies while (c) performing in a highly reliable manner

Framing an HRO as an ideal-type organization provides the opportunity to assess the extent to which an organization lives up to the three parameters outlined above. Past studies on HROs have focused on assessing whether an organization is an HRO or not, without specifying the indicators for 'critical infrastructure', 'risky technology' and 'reliable performance' (Hopkins, 2007). As a consequence, the HRO concept is used misguidedly by investigative commissions, consultants and marketeers to denote how organizations should be reliable. For instance, the investigation board of the Columbia space shuttle accident (CAIB) concluded that NASA didn't "qualify" as an HRO (CIAB, 2003). Yet, research shows that NASA never was or could be an HRO (Boin & Schulman, 2008). The healthcare system, on the other hand, is deemed as "the newest member of the HRO family" (Bourrier, 2011) while many scholars remain very sceptical to that claim (Bagnara, Parlangeli, & Tartaglia, 2010; Dixon & Shofer, 2006; Tamuz & Harrison, 2006; Singer, et al., 2003). In response to these problems with the original HRO conceptualization, Rochlin (1993), one of the founding fathers of the concept, concluded that the terminology has somewhat been "unfortunate". He argues that the label 'high reliability organizations' infers some "static" and "invariant" meaning of reliability while in fact there is no "widespread consensus" on what reliability really is (Rochlin, 1993, p. 28).

By framing an HRO as an ideal-typical organization I try to break through the controversies. An ideal-type model "is static, and cannot therefore reflect the real world of process and change [but] it has the considerable virtue of being able to provide a stable point against which empirical variation and process can be systematically compared and analysed" (Freidson, 2001). The HRO ideal-type provides a theoretical tool for assessing the extent a 'reliability-seeking organization' *resembles* the 'static' ideal-type high reliability organization (HRO). In addition, the ideal-type definition helps to distinguish between reliability-seeking organizations that closely resemble the ideal-type – i.e. High Reliability Organizations (HRO) – and those that don't – i.e. Low Reliability Organizations (LRO) (Jarman, 2001).

1.1 Critical Infrastructure Organizations

A defining characteristic of the ideal-type HRO is that the organization provides society-critical services. The stakes that are associated with maintaining reliability are particularly high. Examples of such critical infrastructure organizations are electricity companies, banks, transportation companies, water supplies, health care system, telecom organizations and prisons. Combined they comprise society's critical infrastructure. But how do critical infrastructure organizations (CIOs) differ from other organizations?

First of all, the essence of a CIO is that its services are indispensable to society's functioning. It is hard to imagine a modern world in which convicted criminals are not imprisoned, internet is not available, water is contaminated, electricity is down or transport by train, boat or plane is unavailable. These services provide basic core functionalities for governments, businesses and people to conduct their everyday activities. As a consequence, Boin & McConnell (2007) explain, that "a breakdown in one or more of these critical systems has the potential to cause very serious problems" (Boin & McConnell, 2007, p. 50). This means that once an CIO fails to deliver its critical services, "a wide variety of social and economic capacities are affected" (Roe & Schulman, 2008, p. 6).

A second property of critical infrastructure organizations is that their services are generally provided through "networked systems" (Roe & Schulman, 2008, p. 6). On the one hand these services are "the necessary elements for more specific secondary systems and activities", while on the other hand the services are provided by a range of "multiple organizations and varied interdependencies" (Roe & Schulman, 2008, p. 6). In other words, a wide array of activities, services and products depend on the "always-on availability" (Bruijne & van Eeten, 2007, p. 18) of CIOs, whereas CIOs in turn also depend on other organizations to provide their services. It is therefore important to study CIOs in a wider institutional context.

Considering these two characteristics, it becomes apparent that many organizations fall outside the scope of HRO research. We can think of the small bakery at the corner of the street as a 'high reliability organization' providing tasteful breads all year round, but that would overstretch the CIO concept. It is the remarkable ability of an organization to perform reliably under immense societal pressure that distinguishes a high reliability organization form other organizations.

1.2 Risky Technologies

CIOs do not necessarily work with risky technologies. When a telecom company stops functioning it will assuredly harm a nation's economy. However, it has no direct catastrophic consequences for life and property compared to, for instance, a meltdown of a nuclear power plant or a mid-air collision of two planes. Risky technologies are defined as a "characteristic of a production […] such that if it fails significantly the damage to life and property can be very considerable" (La Porte & Consolini, 1991, p. 23). Considering the original HRO studies of the Berkeley research group, the HRO concept is derived from organizations that work with risky technologies– i.e nuclear weapon systems, nuclear power plants, and jumbo jets (La Porte & Consolini, 1991; Boin & Schulman, 2008; Sagan, 1993; Roberts, 1990).

The term risk refers to "the product of the magnitude of harmful consequences and the probability of an event causing them" (La Porte & Consolini, 1991). The risky nature of technologies in HROs is determined by the potentially catastrophic consequences of failures. Failure of these technologies is catastrophic, because "if it does materialize [it] will produce a harm so great and sudden as to seem discontinuous with the flow of events that preceded it" (Posner, 2004, p. 6). Although the possibility of such failure can never be fully avoided, it is precisely the hallmark the of an HRO to reduce the probability of such failures to an absolute minimum. HROs are remarkable in their capability to avoid low probability-high impact events. "They somehow seem to avoid the unavoidable" (Boin & Schulman, 2008).

It is important to distinguish the term 'risky technologies' from 'high-risk technologies' (Perrow, 1984). The terms are regularly used in the same fashion by HRO theorists while they refer to different things (Hopkins, 2007). In this thesis, high-risk technologies are defined as systems that consist of complex interactions – i.e. interactions of unfamiliar, unplanned, unexpected and incomprehensible sequences – and tight coupling – i.e. time-dependent, invariant, and interdependent connections between the different components of the systems (Perrow, 1984). Risky technologies, on the other hand, are not by definition high-risk technologies because they do not have to be complex and tightly coupled. Complexity and tight coupling are system *conditions* that can make it more difficult to operate the technology reliably. Hence, these conditions lead to a higher probability of failure. An HRO does not necessarily hold technologies that are complex and tightly coupled. Recall that it is the hallmark of an HRO to be able to reduce the probability of failure to a minimum. Leveson e.a. (2009), for instance, found that air traffic control "is as safe as it is precisely because the system has been deliberately designed to be loosely coupled in order to increase the safety" (Leveson, Dulac, Marais, & Carroll, 2009, p. 231).

In addition, the term 'risky technology' does not imply that the design of the technology has to be the cause of failure. Perrow argues that the failure of technologies is caused by the very complex and tightly coupled design of the technologies themselves (Perrow, 1984). Yet, technologies are as much prone to human induced failures. Although Perrow (1984) defends the difficult position of an operator in complex and tightly coupled systems, we shouldn't forget that technologies are designed and operated by humans. Also linear and loosely coupled technologies can fail catastrophically once operated improperly (Turner, 1994). As such, the failure of a risky technology can have varying origins (Reason, 1990).

As a last note, not all employed technologies by HROs are risky. In fact, there are many technologies that benefit the safety of organizations. Air traffic control, for instance, warmly welcomed radar systems, computer-generated displays of aircraft positions, distance measuring equipment, high-frequency navigation aids, instrument landing and ground controlled approach systems (La Porte, 1988). The technology (a) provided air traffic controllers with "an independent source of information"; (b) "made the controller task less problematic"; (c) "reduced operational surprise", (d) "enabled the FAA to continue serving a rapidly growing aviation industry"; (e) "increased accuracy of aircraft position images"; and (f) "increased the number of aircraft controllers could handle simultaneously" (La Porte, 1988, pp. 229-235).

In sum, the risky nature of a technology is determined by the potential cost of life and property associated with a failure, and to the extent that such event will be "discontinuous with the flow of events that preceded it" (Posner, 2004, p. 6).

1.3 Highly Reliable Performance

Besides being a critical infrastructure organization operating risky technologies, becoming an HRO depends on the level of reliable organizational performance (La Porte & Consolini, 1991; Rochlin, La Porte, & Roberts, 1987) . But what does reliable organizational performance mean?

The adjective 'reliable' stems from the Scottish word *raliabill* which means 'dependable'. A reliable organization is an organization that can be relied upon because it does what it promises to do. Reliability, therefore, refers to the future performance of an organization. In other words, labelling an organization's performance as reliable or unreliable means inferring a judgment about how well the organization will function tomorrow, next week of next year based on its past and present status. For this reason, achieving highly reliable performance is defined as "the ability [of a critical infrastructure organization with risky technologies] to consistently achieve its organizational goals over time" (Kapur & Pecht, 2014; Roe & Schulman, 2008).

In order to provide a measurement for reliable performance, reliability engineers have framed the level of reliable performance as the absence of failure. By statistically calculating the chance a failure will occur it is possible to determine how reasonable an organizational failure will be in the future. If the probability of failure – i.e risk of failure - is low, we can assume the organization will function as intended, thus being reliable. From this perspective, risk and reliability are two sides of the same coin.

Most HRO theorists have used this engineering perspective to explain the reliable performance of critical infrastructure organizations with risky technologies. HROs have been coined as organizations whose "devotion to a zero rate of error is almost matched by performance" (Rochlin, La Porte, & Roberts, 1987, p. 76). Measuring reliability would require asking the question: how many times could this organization have failed catastrophically while it did not? (Roberts K. H., 1990). High reliability theorists argue that for an organization to be "highly reliable", the answer to that question would need to be "on the order of tens of thousands of times" (Roberts, 1990, p. 160). For example, air traffic control of the Federal Aviation Agency was deemed reliable because in one year "U.S. air traffic controllers handled an aircraft across an airspace 73 million times with no mid-air collisions" (La Porte, 1988, p. 217). The U.S. Navy nuclear aircraft carrier is another example of high reliability because in six months it handles "10.000 arrested landings with no deck accidents" (La Porte & Consolini, 1991, p. 21).

The focus on failure has emphasized the reliability of safety. High reliability theorists, for instance, describe reliability as "a record of high safety over long periods of time" (Roberts, 1990, p. 160). Critics have, however, demonstrated that being safe is not by definition the same as being reliable. An organization can perform very safely and at the same time very unreliable. If, for instance, air traffic control would decide to keep all planes on the ground, it is operating perfectly safe, but at the same time very unreliable since air traffic control cannot maintain an expeditious flow of air traffic. Combining safety with other goals is no easy task. Studies have, for instance, highlighted the trade-offs between enhancing safety and operating efficiently (Heimann, 2005; Hollnagel, 2009; Wildavsky, 1988). Investing in safety can come at the expense of efficiency, and the other way around.

Considering these critics, I argue that a highly reliable performance is based on two notions. First of all, I argue that safety is a precondition for the achievement of other organizational goals. Safety is no 'bargainable commodity' (Boin & Schulman, 2008; Roe & Schulman, 2008). It is "not exchanged or submitted for something else; otherwise those services would not be critical" (Roe & Schulman, 2008, p. 10). Safety is referred to here as the absence of catastrophic failure. The performance record of an ideal-type HRO displays failure-free operations. Since in reality there is always a chance of failure, a critical infrastructure organization with risky technologies resembles the HRO ideal once the chance of catastrophic failure approaches zero.

Secondly, the idea that safety is a precondition doesn't mean that the delivery of organizational services should be stopped at every instance. Critical infrastructural organizations are critical because their products and services are essential to the functioning of society. A reliable performance implies that the critical infrastructure organization manages to provide a constant service delivery process without affecting the safety of the system. Yet, I argue that other organizational goals can be temporarily unattainable in order to warrant societal safety. Such situations may involve short-term problems with regard to service delivery but can prevent catastrophic losses. I can't think of any person who wouldn't accept a delay of his or her flight if it was needed to prevent the plane from crashing down.

Reflecting on the definition of 'highly reliable performance', the ideal-type HRO is highly reliable because it is able to be always safe – i.e. nearly-failure free performance – while consistently delivering its society-critical services – e.g. keeping the lights on, providing an expeditious flow of air traffic, etc..

1.3.1 High Reliability Organization vs. Low Reliability Organization

Based on the definition of highly reliable performance, we can differentiate a 'high reliability organization' (HRO) from a 'low reliability organization' (LRO) (Jarman, 2001). A critical infrastructure organization with risky technologies is regarded as HRO when it manages to enhance organizational safety and maintain a consistent delivery of society-critical services. On the contrary, a critical infrastructure organization resembles an LRO when it doesn't manage to guarantee that safety. Where a HRO manages to remain safe, a LRO fails catastrophically.

It is important to emphasize that the LRO-HRO distinction is a distinction between extremes – a catastrophic organization (worst case) and safe organization (best case). But is it possible for a critical infrastructure organization with risky technology to experience errors that do not inflict catastrophe failure? Errors are "occurrences judged as undesirable and sometimes costly to remedy [which] threaten the viability of the organization in part or whole" (La Porte & Consolini, 1991, p. 23). Of course, the risky technology leaves little margin for error, but, on the other hand, research shows that these organizations are continuously open to interruptions without them failing catastrophically (Weick, 2011). Understanding the level of reliable performance then bears the question of what type of interruptions are tolerable and manageable, and which aren't. These margins constitute the "bandwidths of reliability" (Roe & Schulman, 2008, pp. 116-117). An HRO manages to stay within these bandwidths whereas an LRO does not. Yet, some operating conditions provide greater reliability bandwidths than others. In the next chapter these different operating conditions are discussed.

Chapter 2
From Stable to Crisis Conditions

Maintaining a reliable organization is no easy task, but a stable and predictable task environment does make it easier. Task environment is defined here as “the part of the total environment which is (potentially) relevant to goal setting and goal attainment” (Dill, 1958; Thompson, 1967). In a stable environment, everybody in the organization understands the goal of the organization, knows what is expected of them to do, and possess sufficient resources to make it all happen. Traditional organizational theorists have applied this view of organizations to understand how they work. They believed organizations are closed and rational systems behaving like ´black boxes´ which turn inputs efficiently into preferred outputs (Wilson, 1989).

Contingency theorists have demonstrated that organizational environments are not fixed but rather dynamic and changing. Organizations are “open systems facing the need to adapt to environmental variations” (Rainey, 2009, p. 44). Dynamic task environments make it harder to sustain a highly reliable performance since an organization will need a more extensive repertoire of responses to deal with varying conditions.

Critics of high reliability theory have repeatedly argued that the HRO concept is based on a closed system model. Perrow (1994) wrote: “no great effort is made to theorize environmental effects upon the operating system” (Perrow, 1994, p. 213). Also Sagan’s influential book *The Limits of Safety (1993)* directs attention to the political processes affecting organizational safety which HRT seems to neglect. High reliability theorists do emphasize the importance of an organization’s adaptive ability – i.e. resilience – and flexible organizational processes to adjust to changing circumstances (La Porte & Consolini, 1991; Roberts, 1990; Sutcliffe, 2011). Only recently, however, attempts have been made to understand the relationship between high reliability organizations and task conditions (Jarman, 2001; Roe & Schulman, 2008).

An organization can perform highly reliable in stable conditions, hence nearly achieving the HRO ideal. But will reliability be enhanced once stability makes way for instability, and more risky conditions challenge the ability to sustain safe performance? For analysing highly reliable performance across different task conditions I suggest a performance mode framework. The framework differentiates between four performance modes, which range from stable to crisis conditions. Crisis conditions are extreme events characterized by uncertainty and time pressure (Rosenthal & Boin, 2001). At the other end of the spectrum, stable conditions are favourable conditions characterized by certainty and slack time. To understand the differences between the performance modes, the concepts of ‘uncertainty’ and ‘time pressure’ require further explication.

2.1 Uncertainty

Uncertainty refers to how unsure people in the organization are about their operating tasks. More specifically, uncertainty refers to the *incomprehensibility* and *unpredictability* of tasks due to of a lack of information and knowledge. Will there be sufficient resources to employ organizational activities? Is the existing repertoire of organizational activities effective for achieving organizational goals? Do organizational goals prescribe a clear and consistent course of action? Uncertainty may render such cause-and-effect relationships invisible or non-existent. Uncertainty can manifest itself with regard to environmental circumstances, technology and goals/outcomes of the employed tasks.

If uncertainty results from the *environmental circumstances* we are dealing with volatile or turbulent organizational environment. Volatility means "the degree to which the focal organization [...] faces uncontrollable changes or unpredictable conditions that threaten service reliability" (Roe & Schulman, 2008, p. 43). The organization faces deep uncertainty because there is no understanding of how environmental circumstances will affect their performance. In contrast to the argument of Roe & Schulman, I argue that volatility is strongly related to an organization's option variety – i.e. the amount of resources available to respond to unfolding events. Much of the unpredictability of environmental circumstances lies in not knowing whether the organization will acquire enough resources – e.g. political support, financial aid, personnel, etc. – to attain its goals.

Uncertainty can also be present if *technologies* are not available or not known to be effective (Christensen K. S., 1985). Once there are no 'proven solutions' for how to deal with emerging situations, it will be unsure as to whether the organizational activities will contribute to attaining organizational goals. Technology can also be incomprehensible due to the complex interactions of the system (Perrow, 1984), making operators wander how to control the system and achieve the desired outcomes.

Uncertainty can, thirdly, emerge from disagreement over *organizational goals* and preferred *outcomes* (Christensen K. S., 1985). Multiple, conflicting or ambiguous organizational goals may induce uncertainty about whether the employed tasks are oriented towards the right ends. Vague and ambiguous goals do not provide "a ready basis of task definition" (Wilson, 1989, p. 48). In such uncertainty, the definition of tasks is shaped by "naturally occurring rather than by agency-supplied incentives [like] the imperatives of the situation [and] the expectations of peers [...] over which the organization has relatively little control" (Wilson, 1989, p. 49).

The difficulty with uncertain conditions is that it makes rational reasoning 'bounded' (Simon, 1976) by the limited available knowledge. There is no complete information to assess the costs and benefits and determine the best course of action. Statisticians, economists and other rational school theorists have long argued that uncertain futures can be predicted by assessing the chances and probabilities of specific events. Minimizing uncertainty thus involves careful 'risk management'. Remember that we defined risk as "the product of the magnitude of harmful consequences and the probability of an event causing them" (La Porte & Consolini, 1991, p. 23). When we know the probability of a specific negative outcome, we can bring this prediction of future costs into our cost-benefit calculations and provide a rational outcome.

Tversky & Kahneman have shown that judgment under uncertainty is far from a rational process. They found that people "rely on a limited number of heuristic principles which reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations" (Tversky & Kahneman, 1974, p. 1124). For instance, even though tsunamis in Japan are rare, people tend to overestimate this probability because the associative image of such disaster is very vivid and compelling. The wish to avoid such events is so strong that we tend to overweigh the probability of its actual occurrence: "our expectations about the frequency of events are distorted by the prevalence and emotional intensity of the messages to which we are exposed" (Kahneman, 2012, p. 138). Our mental models provide a different version of the world than what happens in reality. This is where human error occurs. We expect something (not) to happen, but because our expectation is based on a false heuristic things turn out different from what we had expected. A good example of how uncertainty can lead to organizational failure is the accident at Three Mile Island. A testimony of the nuclear plant's supervisor during the President's Commission Hearing illustrates how the uncertainty of the situation rendered a priori assumptions about the situation ineffective in the decision making process.

"I think we knew we were experiencing something different, but I think each time we made a decision it was based on something we knew about. [...]. There was a logic at that time for most of the actions, even though today you can look back and say, well that wasn't the cause of that, or, that shouldn't have been that long." (Perrow, 1984, p. 27)

In conclusion, uncertainty is a risk-inducing task condition because it constrains the ability to rationally determine the safest course of action for a critical infrastructure organization. Given the situation that the organization doesn't know whether its actions of today will provide safety for tomorrow, it creates the opportunity for errors and mistakes.

2.2 Time Pressure

Time pressure refers to the compression of available time for producing the preferred organizational outcomes. Both output and available time can increase time pressure. On the one hand, the organization may need to safely provide an increasing amount of services without being able to lengthen the time frame. The organization will need to do more with the same amount of time. On the other hand, the organization may need to provide the same services but in a shorter time frame. In air traffic control, for example, studies show how operations involve slack times and peak load times (La Porte & Consolini, 1991). During *slack* times, controllers have a minimum amount of load and have abundant time to respond. In *peak load* times controllers are pressured to handle a higher load in the same time frame, pressuring air traffic operations. In extreme cases, such as *emergencies*, the urgency to respond is even more intense. In this condition managing safety becomes a real-time activity. Only a very small time frame is available for response.

Similarly, Roe & Schulman (2007) studied how the deregulated California Independent System Operator (CAISO) managed to perform under increasing time pressure. Control room operators at CAISO explained that efficiency demands and resource constraints forced them "into a corner" describing their operations as "thirty-four balls you get to juggle at one time" (Roe & Schulman, 2008, p. 80). The research shows how time pressure reduces the "bandwidths of reliability" (Roe & Schulman, 2008, pp. 116-117) and brings operators in the organization near the edge of their reliability-enhancing capabilities. A shift manager, for instance, explains that "to master attention to detail is not in the timelines we operate under" (Roe & Schulman, 2008). Missing out on the crucial details in the operation of a hazardous organization can, however, have severe consequences. In addition, the crisis management literature explains how time pressure can lead to high stress levels and even paralysis. Organizations can become "overwhelmed by the pressure of events to such an extent that they are incapable of taking action; the course of action takes its turn by default" ('t Hart, Rosenthal, & Kouzmin, 1993).

Just like uncertainty, time pressure puts boundaries on rational behaviour. Time pressure makes it particularly demanding to analyse and make sense of the situation before organizational response is too late. The time constraints do not allow all relevant information to be processed in time to make a solid rational judgment. This increases the chance of mishaps and errors.

2.3 Performance Modes

Once we integrate uncertainty and time pressure into a matrix, we can distinguish between four different "performance modes" (Roe & Schulman, 2008; Hollnagel, 1998).

In the *bureaucratic* mode an organization faces a relatively certain task environment without time pressure. Circumstances are ordered and predictable, relationships between cause and effect are comprehensible, and there is enough slack time to decide what organizational practice to employ. The organizations comes to resemble the traditional bureaucratic organization in which processes are rationalized and the environment is fixed and foreseeable.

A second mode is labelled as the *high-velocity* mode. The environment remains relatively stable, predictable and comprehensible, but the organization faces high pressure to perform in limited time. Problems need to be solved quickly, creating a very fast-pace and hyper-focused state of organizational activity.

The *innovation* mode is one in which the organization isn't pressured to perform in terms of time, but it does need to cope with highly unpredictable and uncertain conditions. There is no pre-existing knowledge of how to deal with the problems at hand. However, the organization has got enough time to sort out and experiment with what works and what doesn't. Novel practices emerge during organizational activity leading to innovative changes in organizations.

The last performance modes is the *crisis* mode. This is the most extreme condition an organization can be in. This situation is characterized by high uncertainty and high time pressure (Boin, 't Hart, Stern, & Sundelius, 2005). The organization can only react to what happens. Operators are in 'unstudied' and 'unfamiliar' situations. At the same time, the threat must be contained as soon as possible in order to enhance safe operations. The crisis mode is the most threatening condition for a critical infrastructure organization with hazardous technologies. Chances are that uncertainty will lead to decisions with catastrophic consequences. Moreover, the short time period available to come up with an effective response implies the organization will not have much leeway to correct or recover from any ineffective decisions. The organization will not get a second chance to get it right. Very complex tasks need to be conducted in 'real time' at the 'moment of truth'.

Table 1: Performance Mode Framework

		Uncertainty	
		Low	**High**
Time Pressure	**Low**	**Bureaucratic**	**Innovation**
	High	**High velocity**	**Crisis**

So how do these performance modes relate to the ideal-type concept of a HRO? In essence, a critical infrastructure organization with risky technologies can be more LRO or HRO across the different performance modes. In other words, a nuclear power plant or an air traffic control organization can resemble an HRO in the bureaucratic mode, but may perform as an LRO once conditions change to a crisis mode. By means of the performance modes we can try to explain why organizations are able to be highly reliable in one condition and less reliable in another. The bureaucratic mode provides most favorable conditions for enhancing reliability, but once confronted with uncertainty and/or time pressure losing reliability becomes a serious risk. How are organizations able to turn the tide? What enables organizations to move from innovative, high velocity and crisis modes back to the bureaucratic mode?

Chapter 3
Managing High Reliability

The challenge of critical infrastructure organizations with risky technologies is to attune its organizational processes to the performance mode it encounters. The interesting question is why some organizations, more than others, seem to be able to confront these challenges and maintain reliable performance under changing performance modes. Why are some organizations able to enhance safety under high velocity, innovation and crisis conditions whereas others do not have that ability? What capabilities does a critical infrastructure organization need to stay reliable once uncertainty and time pressure creep into operations? HRO research has primarily focused on the characteristics of organizations to enhance reliability in the bureaucratic mode, although it must be noted that some have stressed the importance of adaptability – i.e. resilience – during the high velocity mode as well (La Porte & Consolini, 1991; Roe & Schulman, 2008). The fields of innovation management, crisis management and institutional change provide additional suggestions for how a critical infrastructure organization is able to perform reliably once confronted with uncertainty and time pressure. In this chapter the organization in the bureaucratic mode is first discussed followed by suggestions on how to adapt operations in order to respond to pressure, innovation and crisis modes.

3.1 The Bureaucratic Organization

Under stable conditions critical infrastructure organizations face a consistent, predictable and comprehensive task environment with ample of time to determine the right course of action in response to the operational situation. As long as the situational imperatives are almost fully known, the critical infrastructure organization is able to prepare, program and design operational responses which enhance reliable services. The organization comes to resemble a ‘closed system’ in which stable inputs are transferred through a fixed organizational process into stable and reliable outputs. There is sufficient capability to control environmental variables and function as an independent ‘closed off’ system.

But what does that capability look like? Weber’s classic theory on bureaucracy suggests that such organizations need to follow a rational structure in which rules are formalized, procedures standardized, tasks specialized and authority hierarchically distributed (Rainey, 2009). Like the pinmaker in Charlie Chaplin’s Modern Times, the operator’s occupation is “broken down into separate, limited tasks, each part of a coordinated plan designed to result in the production of pins" (Freidson, 2001, p. 20). The workplace is "governed by an elaborate set of rules [and] effective planning and supervision [to standardize production] so as to assure consumers of reliable products at a reasonable cost" (Freidson, 2001, p. 1). Operators are thoroughly trained experts. Their expertise resides in their knowledge of the rules and the capacity of applying them. The rules function as constraints on human behaviour. The focus is on controlling the front-line workers and minimizing their individual discretion. Decisions are a logic outcome of a calculative process in which the most efficient means are applied to achieve the organizational objectives. Personal motives and preferences are not allowed to creep into decision-making processes. The organizational goals and conduct need to be consistent and precise to maintain a standard production processes – i.e. enhance reliability.

From this perspective, failures in bureaucratic organizations are caused by human error, poor organizational design or poor technology (Reason, 2000; Turner, 1978; Perrow, 1984). Reason (1990) explains that "planned actions may fail to achieve their desired outcome *either* because the actions did not go as planned *or* because the plan itself was deficient" (Reason, 1990, pp. 53-54). Consequently, the bureaucratic organization goes to great length to anticipate and prevent such failures from happening (Wildavsky, 1988). A strategy of anticipation presumes that as long as we make sure that the rules are well designed and practices well executed, the operator is able to predict and prevent unwanted situations. It is the dominant inference pattern for sustaining safe and reliable performance. This is how most safety and risk management is organized: (a) events are assessed by their expected impact and probability, (b) the risks are mitigated by rules and procedures so (c) adverse events are prevented and safety is enhanced.

HRO research shows that many of these bureaucratic characteristics are found in HROs that function in stable conditions. LaPorte & Consolini (1991) argue that "this drive for operational predictability has resulted in relatively stable technical processes that have become quite well understood within each HRO" (La Porte & Consolini, 1991, p. 30). A number of organizational features highlight the bureaucratic nature of the studied HROs in stable conditions.

First of all, the studied HROs were found to exist in an environment with a difficult, yet fixed, requirement "to warrant absolute avoidance of error" (La Porte & Consolini, 1991, p. 19). There is indisputable support from the environment to prioritize safety above all other values. "HROs typically exist in closely regulated environments that force them to take reliability seriously but also shield them from full exposure to the market and other forms of environmental competition" (Boin & Schulman, 2008, p. 1053). With regard to the development of the United States Air Traffic System, LaPorte (1988) explains that safety remained the primary organizational concern even though market demands increased. The U.S. Air Traffic System was deemed as an organization that:

- Is always safe;
- Carries anyone, anywhere, anytime (and is always safe);
- Enables private carriers to make a reasonable profit (while always being safe).

Secondly, HROs “share the goal of avoiding altogether serious operational failures” (La Porte & Consolini, 1991, p. 21). There is great consensus among member of the organization of how safety is defined and what failures are to be avoided. There is a homogenous and fixed organizational preference function in which safety holds the highest benefits because “the consequences and costs associated with major failures […] are greater than the value of the lessons learned from them” (La Porte & Consolini, 1991, p. 21).

Thirdly, the HROs in stable conditions invest heavily in precluding a set of “core events that simply must not happen” (Roe & Schulman, 2008, p. 54). By predicting potentially dangerous situations and analysing weak spots in the system, HROs aver operations “in the area where reliability or safety is being jeopardized” (Roe & Schulman, 2008, p. 54). In other words, HROs try to avoid conditions of certainty and time pressure by anticipating events that can cause such situation to materialize.

Fourthly, the operations of bureaucratic HROs are constrained by a vast amount of rules and procedures covered in thick manuals (La Porte & Consolini, 1991; Roe & Schulman, 2008). At both air traffic control and nuclear carrier operations there was “a great deal of dependence on operator adherence to the formal procedures of operations […] the only decision is which SOP to apply” (La Porte & Consolini, 1991, p. 24).

Fifthly, the operators in HROs are highly technical competent experts who have gone through considerable selection, training and socialization.

Although in HROs there is a strong tendency to avoid uncertainty and time pressure, members of HROs recognize and are aware that no organization is perfectly rational and error-free. “They try to be synoptic while knowing that they can never fully achieve it” (La Porte & Consolini, 1991, p. 29). Two HRO characteristics are routinized in HRO practice to buffer potential errors. First of all, operators in HROs are constantly on the lookout for events that deviate from their prior expectations. They do not take stable conditions for granted. Rather, there is “a widespread shared mindfulness toward conditions that might causally lead to error and failure” (Roe & Schulman, 2008, p. 55). Operators are preoccupied with potential failures and resist simplification of the situation by falsifying their own world views (Weick & Sutcliffe, 2007). They treat past experiences and predetermined solutions with scepticism and suspicion.

Secondly, HRO enjoy considerable amount of resources to invest in extensive redundancies. Redundancy is regarded as the HRO’s “key design feature” (Sagan, 1993, p. 19). Redundancy is the ability of the system to continue operations when the primary unit of the system fails (Rochlin, La

Porte, & Roberts, 1987). Independent back-ups and reserves are built into operations decreasing the chance of operational failures. As such, a fall-out of one component doesn't immediately lead to safety critical situations since a second one can take over.

Both characteristics allow an HRO to detect deviations from the normal production sequence and provide a margin for error. Yet, they do differ somewhat from the traditional bureaucratic ideal. Redundancy and preoccupation with potential failures require an inefficient allocation of organizational resources. From an economic point of view they are "'unconsequent anticipations' i.e., predictions of unsafe events that never come to pass" (Wildavsky, 1988; p. 6). The unconsequent anticipation provide costs but no additional safety benefits. But once unsafe events do come to pass, these anticipations can be lifesaving.

In sum, the characteristics that are argued to enhance high reliability of hazardous organization in routine conditions are (Boin & Schulman, 2008):

1. Indisputable support from the environment to prioritize safety above all other values.
2. Consensus and shared definition among organizational members of safety goals.
3. Organizational efforts aimed at anticipating and precluding a set of core events.
4. Emphasis on operators' compliance with rules and standard operating procedures.
5. Operators are trained and socialized as highly technical competent experts.
6. A culture of scepticism and suspicion.
7. Extensive resources and redundancies.

Despite all efforts of HROs to sustain reliable performance in stable conditions, organizations encounter dynamic environments. In practice external demands for safety have to be balanced by demands for efficiency. Heimann (2005) explains that efficiency requirements become more pressuring once the organization has proven to be operating safely: "[…] because the organization has been successful in preventing a major accident, political leaders discount the potential for such failure and thus do not see how this requirement for greater efficiency may conflict with the organization's ability to maintain safety" (Heimann, 2005, pp. 113-114).

The conflict between safety and other organizational goals, such as efficiency, is at the heart of many critical infrastructure organizations (Wilson, 1989). The California Electricity Crisis is a good example of how efficiency demands eroded the capacity of the California Independent System Operator (CAISO) to function reliably. Roe & Schulman (2008) found that the deregulation of the Californian electricity grid placed operators in the control room closer to the limits of safe operations. They were forced to balance load "just-in-time" in order to meet market requirements, making the organization function with very small, if not critical, margins for error. The rationale of a deregulated energy market to reduce user costs, in fact, resulted in a significant pressure on control room operators to relinquish from their safety standards.

Also Vaughan's (1990) analysis of the *Challenger* accident points to the effects of resource constraints on the ability of NASA and its regulators to prevent the disaster. The space shuttle program originated in times of "a consequent decline in congressional appropriations" and "funding struggles". As a result "[…] safety surveillance for the shuttle was characterized by scarcity. The Safety, Reliability and Quality Assurance Program was dependent on NASA decisions that allocated resources to it, and NASA had cut those resources. […] NASA trimmed 71 percent of its safety and quality control staff. [Consequently], overburdened SR&QA directors and staff members were not able to identify and correct their own misunderstandings" (Vaughan, 1990, p. 238). In conclusion, "inadequate staff numbers tend to increase the problems associated with discovery, monitoring, and investigation of safety issues in complex organizations" (Vaughan, 1990, p. 240).

The environments of critical infrastructure organizations thus seem more dynamic than the stable conditions of the bureaucratic mode suggest. Organizations have to cope with time pressure and uncertainty in order to restore stable operations. This calls for a resilient organization that is able to "to proactively adapt to and recover from disturbances that are perceived within the system to fall outside the range of normal and expected disturbances" (Comfort, Boin, & Demchak, 2010, p. 9). But what enables a critical infrastructure organization to be resilient when confronted with pressure, innovation or crisis conditions?

3.2 The High Velocity Organization

During time pressured operations the organization faces a contraction of available time. The time period in which operators will have to conduct their practices is compressed. Yet, the task environment is still familiar, known and understandable. The challenge to the critical infrastructure organization is to accelerate operations in order to enhance the reliability of service provision. What enables a critical infrastructure organization with risky technologies to speed up processes?

HRO research refrains from exploring critical infrastructure organizations in the realm of the 'unknown', but some studies have emphasized the capabilities of HROs to work in time pressured operating conditions. LaPorte & Consolini (1991) provide a compelling theory of how air traffic control and a nuclear aircraft carrier manage to enhance reliability in peak load times. Their findings provide multiple suggestions for what critical infrastructure organizations can do to cope with time pressure.

First of all, the operational response relies "on a clear specification of emergency events" (La Porte & Consolini, 1991, p. 35). Such events have also been coined as "routine emergencies" (Comfort, Boin, & Demchak, 2010, p. 2). When they occur, the actions of critical infrastructure organizations follow a specific set of contingency plans and protocols. These plans and procedures predetermine the allocation of duties, authority, coordination and communication. Operations in a way resemble a "scripted […] process of instant response" (La Porte & Consolini, 1991, p. 35). Operators know immediately what is expected of them to do and how to coordinate their activities with others. Special facilities and resources have been prepared to enable operators to do their job.

Secondly, in order to succeed in times of pressure operators have to practice their responses during frequent simulations in stable conditions (La Porte & Consolini, 1991; Sagan, 1993). Knowing what to do is one thing, actually being able to do it is something else. The response during time pressured conditions is existential. Decisions are based on prior training and experiences with similar events. HROs use realistic simulations to familiarize operators with time pressured situations.

Thirdly, the actual operational response is characterized by a decentralization of decision making authority on the basis of expertise and skill (La Porte & Consolini, 1991). It is recognized that superiors are not close enough to the situation to make informed decisions. Operators require discretion to cope with time pressured conditions. Moreover, it takes too much time for operators to channel their decisions up the chain of command. As a consequence, hierarchical coordination is substituted for intense collegial coordination. Relationships between operators 'on the scene' become more interdependent and tightly coupled. Communications intensify in terms of rapid feedback, on the spot negotiations and extensive information sharing between operators. Superiors retreat to the background and adopt a facilitating role making sure that operators have what they need to endure the situation. The norm is "non-interference with operators" (La Porte & Consolini, 1991, p. 32).

Fourthly, the lack of slack time is compensated by other slack resources such as redundancies in personnel. At air traffic control, for instance, back-up controllers are called to assist the controllers on duty in peak load times. The back-up controllers take over peripheral tasks from the on duty controllers to allow them to fully focus on the situation. Moreover, the on duty controllers' assistants come to function as an "extra pairs of eyes" who "give supportive assistance, sound alerts, and provide suggestions" (La Porte & Consolini, 1991, p. 33). This redundancy in personnel provides a mechanism for dealing with the risk of inattention or stress.

Based on these findings four hypotheses can be formulated.

H^1: In the high velocity mode the operational response is structured according to a set of pre-programmed set of practices, such as emergency protocols.

H[2]: *In the high velocity mode the operational response relies on experiences with similar emergencies and trained emergency simulations.*

H[3]: *In the high velocity mode the operational response is characterized by a decentralization of authority on the basis of expertise and skill.*

H[4]: *In the high velocity mode the operational response involves the use of personnel redundancies to compensate for the reduction of slack time.*

3.3 The Innovative Organization

Organizations operating in conditions of certainty are intrinsically risk-averse. They aim to ban every possible uncertainty from organizational processes and hedge against foreseeable errors. Such a risk-averse approach is at the heart of critical infrastructure organizations that wish to stay reliable. In fact, every organization wants "to replace the uncertain expectations and haphazard activities of voluntary endeavours with the stability and routine of organized relationships" (Wilson, 1989, p. 221). It is the natural organizational tendency to avoid and resist any situation in which the existing knowledge, rules and procedures don't provide proven solutions for emerging problems (Shane, 1995). Hence, efforts are directed at anticipating and precluding events that cause uncertainty.

But if we would be able to eliminate every possible uncertainty, there would be a lot less to worry about. In practice, uncertainty remains a condition that organizations can never fully avoid. "Real human situations usually involve a mixture of the known and the unknown […]" (Wildavsky, 1988; p. 80). A controller at CAISO explains that "part of the control room experience is to know when not to follow procedures. […] procedures are always with the caveat, "in your best judgment"" (Roe & Schulman, 2008, p. 60). This bears the question how an organization is able to enhance reliability when proven organizational routines are rendered ineffective. The answer is 'innovation'.

Although trying to define innovation is like "trying to find one medical theory to explain all diseases" (Wilson, 1989, p. 227), a literature overview on organizational innovation shows that innovation is generally referred to as "the generation, acceptance and implementation of new processes, products, or services for the first time within an organization setting" (Pierce & Delbecq, 1977, p. 28). It is a multi-phased process in which an organization initiates, adopts and implements novel practices within the task environment (Pierce & Delbecq, 1977). The three phases have been described as:

“*Initiation* of an idea or proposal that when adopted and implemented will lead to the enactment of some change within the organization;

Adoption of the idea or proposal, a phase that represents a decision being made by the appropriate organization decision maker(s) providing mandate and resources for the change, and;

Implementation, the installation of the adopted idea into a sustained recognizable behaviour pattern within the organization” (Pierce & Delbecq, 1977, p. 29)

From a business perspective, innovation is regarded as essential for surviving in a competitive marketplace (Shane, 1995). Entrepreneurs develop new products and services to improve the quality and efficiency of their business in order to attract more customers and outsmart the competition. Innovation is favoured and catered by organizations through the many special Research & Development departments. From a non-profit perspective, organizational innovation has become a synonym for organizational learning. Innovation is a virtue. To these organizations it is important to learn from past mistakes so public services can be improved.

Yet, as long as the organization operates in stable conditions organizational change is predominantly resisted. Operator compliance with the rules and routines is the hallmark of how critical infrastructure organizations need to operate in certain and slack time conditions (La Porte & Consolini, 1991). Organizational change becomes necessary when an organization is faced with uncertainty. Under uncertain conditions organizations have to alter and extend their repertoire of responses with new organizational practices. But how does such innovative process differ from the bureaucratic process in stable conditions? What enables a critical infrastructure organization to innovate in uncertain conditions in order to enhance reliability?

In his classic book *Searching for Safety* Wildavsky (1988) argues that innovation in uncertain conditions requires a strategy of trial-and-error (Wildavsky, 1988). Novel practices arise from an incremental decision making process. The trials are what Lindblom (1979) calls ‘successive comparisons’ with pre-existing routines. Operators try out new practices that differ slightly from routine practices in order to keep potential errors small. The undesired effects of these trials are subsequently observed and corrected providing a reference for new trials (Lindblom, 1979). This incremental learning process is slow and involves many small steps, but it enables operators to “reduce the size of that unknown world to bite-sized, and hence manageable chunks” (Wildavsky, 1988, p. 37).

HRO researchers criticise the trial-and-error strategy . The HRO research group argues that the cost of an error in a critical infrastructure organization with risky technology exceeds the benefit from the lessons learned from them (La Porte & Consolini, 1991). The operating processes of critical infrastructure organizations should therefore be “coloured by efforts to engage in trials without errors, lest the next error be the last trial" (La Porte & Consolini, 1991, p. 20). This argument of HRO researchers is based on the assumption that "the smallest probability of irreversible disaster overwhelms all other considerations" (Wildavsky, 1988, p. 23). Before something new is tried, experts need to be consulted in order to provide prior guarantees that the conducted trials will not lead to harm (Wildavsky, 1988).

But it is the essence of uncertainty that there are no prior guarantees to success. The idea of an incremental trial-and-error approach is precisely that "large numbers of small moves, frequently adjusted, permit tests of new phenomena before they become big enough to do massive harm" (Wildavsky, 1988, p. 27). HRO researchers assume that the smallest adjustment to the fixed operating process will result in catastrophic failure, but "if you can do nothing without knowing first how it will turn out, you cannot do anything" (Wildavsky, 1988, p. 38). Such mind-set is useful in stable conditions, but in uncertain conditions doing nothing can be more harmful than trying something new. Different from the stable organization, we would therefore expect that in the innovation mode the organization is able to enhance reliability by means of an incremental trial-and-error decision making process.

H^5: In innovation mode the operational response resembles an incremental trial-and-error process.

The literature on innovation management shows that the initiation and adoption of novel ideas is a creative process that is improved by an organic organizational structure. An organic structure has three characteristics: decentralization, differentiation and lack of formalization (Russell & Russell, 1992).

First of all, a decentralized organization, as opposed to centralized hierarchies, "facilitates innovation by increasing organizational members' awareness, commitment and involvement" (Damanpour, 1991). Research shows that autonomy and less restricted communication flows provide an organizational environment in which creative ideas are more likely to emerge (Pierce & Delbecq, 1977; Russell & Russell, 1992).

Secondly, a differentiated and heterogeneous group of people stimulates a creative and critical dialogue (Pierce & Delbecq, 1977; Russell & Russell, 1992; Damanpour, 1991). Diversity is argued to "provide a broader knowledge base and increase the cross-fertilization of ideas" (Damanpour, 1991, p. 558). The idea of differentiation closely resembles Schulman's (1993) definition of 'conceptual slack' which refers to "a divergence of analytic perspectives among members of an organization" (Schulman, 1993, p. 358). A constructive process in which diverse and conflicting views are critically discussed nurtures a creative environment.

Thirdly, an organic structure lacks formal rules, structures and procedures. "No formal procedure or set of rules can guide organizational members in solving the ambiguities of innovation because, by definition, innovation represents a new activity where rules and procedures have not been devised" (Russell & Russell, 1992, p. 643). Behaviour constraining rules limit the creative capability of organizational members to come up with new ideas. Rule compliance enforces adherence to existing routines and not to new practices. As Knight (1967) argues "an organization which keeps employees immersed in very routine activities is not likely to be a very creative one" (Knight, 1967, p. 481). Rather, informal relations, mutual adjustment and extensive information exchange characterize the innovation process (Russell & Russell, 1992).

As such we can derive three hypotheses about what organizational properties enable an innovation process that enhances reliability in uncertain conditions.

H^6: In the innovation mode the operational response is characterized by a decentralization of authority.

H^7: In the innovation mode the operational response is shaped by a heterogeneous set of organizational members.

H^8: In the innovation mode the operational response is characterized by a lack of formal structures.

Scholars of innovation management argue that the structural imperatives are not the only contributors to innovation. The behaviour of operators in critical infrastructure organizations is not only determined by role patterns derived from organizational structures. Rather, according to the 'logic of appropriateness', behaviour is influenced by the norms and values of the organization (Guy Peters, 2012). In this vein, the innovation literature has emphasized the positive contribution of values such as 'receptivity to change' or 'uncertainty acceptance' to innovation (Russell & Russell, 1992; Damanpour, 1991; Knight, 1967; Pierce & Delbecq, 1977; Shane, 1995). Shane (1995) explains that "in uncertainty-accepting cultures, it is easier to convince people to make these decisions because people in uncertainty-accepting cultures do not demand high levels of documentary evidence before making decisions" (Shane, 1995, p. 53).

In an uncertainty-accepting culture, errors are embraced as moments of learning. Learning occurs when "errors are detected and corrected" (Argyris, 1995, p. 20). There are generally two types of learning: single-loop learning and double-loop learning (Argyris, 1995). Single-loop learning is aimed at changing the behaviour of operators. Within the existing organizational framework the practices of operators are corrected. The organization functions as the 'repair man' conducting quick fixes. Double-loop learning, on the other hand, refers to changes in the basic norms, values and structures of the organization which define appropriate operator behaviour. Whereas single-loop learning changes the behaviour itself, double-loop learning changes the underlying cause of that behaviour – i.e. institutional change. Argyris (1995) argues that an uncertainty-accepting organization, or what he calls "Model II theory in use", has 'learned how to learn'. In such organization "action strategies openly illustrate how the actors reached their evaluations or attributions and how they crafted them to encourage inquiry and testing by others" (Argyris, 1995, p. 22). Double-loop learning requires a "climate of openness" (Weick & Sutcliffe, 2007) in which people feel safe to report errors and acknowledge mistakes. Reporting and acknowledging errors needs therefore to be encouraged and appreciated. Social scientists have also coined this a 'just culture'. A just culture is concerned with the balance between organizational learning and accountability. Operators are not prosecuted for errors that cannot be attributed to gross negligence or wilful violations. A just culture provides a social habitat in which operators do not have to fear error and are not constrained to learn from them.

H^9: In the innovation mode the operational response is based on values of uncertainty acceptance and receptivity to change.

3.4 The Crisis Organization

A rapid response in times of uncertainty while dealing with risky technologies places operators under considerable pressure to enhance reliability. Crises can result from sudden events that disrupt stable operations (Taleb, 2013). However, crises can also occur through a long-lasting process in which small discrepant events have gone by unnoticed and eventually build up to a pivotal moment of criticality (Turner, 1978). Crises may, for instance, develop from innovative or high velocity modes. Yet, they come unexpected and fall outside the set of anticipated events which organizations in routine conditions try to prevent. "There is no such thing as a routine crisis" (Boin & Lagadec, 2000, p. 185). An intrinsic feature of crises is that they inhibit deep uncertainty. Crises differ from routine emergencies in that they are "out of the ordinary" and do not provide "ready-made solutions for predefined problems" (Boin & Lagadec, 2000, p. 186). At the same time crises do not allow operators to go through an endless iterative process of incremental trials and errors to safely test novel practices. Crises ask for critical decisions at critical moments.

At first sight, enhancing reliability in a crisis mode looks like a 'mission impossible'. The only reasonable explanation for enduring crisis conditions and being able to return to stable conditions seems to be 'sheer luck'. A closer look, however, reveals that some organizational processes can contribute to an effective response in the heat of the moment.

First of all, an effective crisis response is characterized by improvisation. Decisions are "real time experimentations" (Roe & Schulman, 2008). The situational imperatives demand an immediate new and creative response. Improvisation looks like innovating under pressure. The incremental trial-and-error approach is replaced by more "vigorous trial-and-error" (Wildavsky, 1988, p. 27). The process remains the same: creative solutions are tried, observed, corrected and tried again. But the trials may differ from routine practices more than what is considered 'marginal' or 'incremental' due to time pressure. It may involve breaking the rules and doing something wildly different from what operators are used to.

Recall that such vigorous trials are avoided by HROs in stable conditions. HRO researchers have always expressed their concerns with adopting a trial-and-error strategy because the first trial could be the last error. But "complex bureaucracies are not designed or ideally suited to deal with nonroutine events" (Boin, 2009, p. 370). In crisis episodes, adhering to routines and pre-existing structures can be as dangerous as doing something new. "Armed solely with classic tools for new problems, our future crisis managers are lulled into a false sense of security: they think they are prepared, but they are not" (Boin & Lagadec, 2000, p. 185).

Roe & Schulman (2008) witnessed that real-time experiments of trial-and-error enhanced reliability at the California electricity grid. It is the ability of operators to anticipate potential dangers, formulate new solutions simultaneously and quickly adjust their assumptions to those of other operators. Improvisation is argued to be the product of a professional team-effort (Roe & Schulman, 2008).

The best examples of improvisation are found the series of decisions that got the *Apollo 13* spaceship back to Earth in 1970. While in outer space, the liquid oxygen tank of the spacecraft exploded and took out the main supply of oxygen and power leading to a critical situation for the crew on board. The cooperation among the astronauts and operators in the mission control room resulted in unthought-of practices that defied every routine, but which allowed the astronauts to get back to Earth safely. Decisions such as taking the long route around the Moon instead of a direct abort route, using the lunar capsule with three astronauts while it was designed for two, shutting down the main command module and starting it up again with batteries, and using duct tape and plastic bags to create an adapter for the air purifier in the lunar capsule are but a few examples of what enabled the astronauts to get back to Earth safely (Kranz, 2000). None of these actions had been done before.

H^{10}: In the crisis mode the operational response is improvised by operators through a process of mutual adjustments.

A second characteristic of an effective crisis response is to decentralize and centralize decision making authority at the same time (Boin, 't Hart, Stern, & Sundelius, 2005; 't Hart, Rosenthal, & Kouzmin, 1993; Roe & Schulman, 2008). In crisis conditions there is a tendency to rely on the leaders of organizations to take charge and responsibility for the situation (Rosenthal & Boin, 2001). Many crisis contingency plans structure this "self-evident centralization of decision making" ('t Hart, Rosenthal, & Kouzmin, 1993, p. 243) by concentrating decisional power within a small group of organizational executives. Crisis management researchers, however, seriously question the effectiveness of this sort of hierarchical centralization. To respond effectively to an unexpected event under high time pressure, operators need to be able to make the operational decisions because they are closest the situation. Hierarchical centralization distances the decision-making from where the problems 'happen' incurring transaction costs such as delays and information asymmetry. The consequence is that "a reduction in the level of competence is directed at the problem" (Weick, 1988, p. 312). Hierarchical centralization leads to decisions that are experienced by operators as "insufficient, ineffective, or even counter-productive" (Boin, 't Hart, Stern, & Sundelius, 2005, p. 54).

The need for operator autonomy encourages decentralization, but exclusively decentralizing decision-making in crisis conditions poses risks as well. Decentralization in uncertain and time pressured situations may lead to uncoordinated and fragmented decision making. "Unchecked, these influences could produce such diverse [operational decisions] as to dissolve the [critical infrastructure service] into an aggregate of separate entities, destroying it as an integrated, functioning organization" (Kaufman, 2006, pp. 86-87). There needs to be some form of centralization in order to keep everyone on the same page and prevent chaotic responses.

But if hierarchical centralization is not possible, than what does this centralization have to look like? Weick (1987) intelligently argues that culture can serve as a substitute for hierarchical centralization while adding in "latitude for interpretation, improvisation, and unique action" (Weick, 1987, p. 124). Culture "creates a homogenous set of assumptions and decision premises which, when they are invoked on a local and decentralized basis, preserve coordination and centralization" (Weick, 1987, p. 124). It follows that "before you decentralize, you first have to centralize so that people are socialized to use similar decision premises and assumptions so that when they operate their own units, those decentralized operations are equivalent and coordinated" (Weick, 1987, p. 124). In this way both centralization and decentralization are able to coexist simultaneously and to foster an effective operational response in crisis conditions.

H^{11}: In the crisis mode the operational response is characterized by simultaneous centralization and decentralization of decision-making.

Thirdly, the crisis response is argued to be more effective once closely coordinated with crisis partners. Crisis conditions usually require a networked response of multiple organizational departments and agencies. Predetermined institutional procedures about the allocation of duties, information sharing and group composition, such as used in the pressure mode, contribute to such networked response. Yet, crises often compel operators to coordinate activities beyond anticipated settings. “The social system that under normal circumstances provides the means to coordinate social behaviour and address uncertainty has also been “dislodged”” (Boin, 't Hart, Stern, & Sundelius, 2005, p. 61). Crisis researchers emphasize that in the improvisation process operators, departments and organizations exchange information to mutually adjust and coordinate their activities. The theory is that the collective search for information in crisis conditions nurtures an information marketplace in which demand and supply of information come together at so called “information nodes” (Boin, 't Hart, Stern, & Sundelius, 2005, p. 61). In times of crisis these nodes are subject to a process of “super-accelerated institutionalization” (Boin, 't Hart, Stern, & Sundelius, 2005, p. 61) in which the information channels, that foster the exchange of information, are embedded in ad hoc procedures and rules.

H^{12}: In the crisis mode the operational response is coordinated through emerging information nodes.

In sum, the management of crisis conditions is expected to resemble a process of improvisation, simultaneous centralization and decentralization, and coordinated network responses. They can be positive contributors in the conduct of enhancing reliability in uncertainty and time pressure.

Chapter 4
Research Strategy

To understand the ability of critical infrastructure organizations to ensure reliability in times of uncertainty and time pressure, the real-life operations of these organizations need to be examined. Theory needs to be accompanied by empirical results to investigate whether the hypothesized explanations for high reliability are evident in practice. This chapter discusses the research strategy that is used to bridge theory and practice in order to answer the central question of this thesis. Section 4.1 explains why a case study design has been chosen for this research and why Air Traffic Control the Netherlands was selected as the case of inquiry. In section 4.2 the research methodology is discussed. In this section I explain from what perspective the research is conducted and what steps have been taken to collect and analyse the empirical results.

4.1 Case Study Design

To explain why critical infrastructure organizations are able to perform highly reliable under extreme conditions, I use a case study design. A case study is defined as "an empirical inquiry that: investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 1994, p. 13). By adopting the case study design we can get as close as possible to what 'happens' in organizations. The case study design provides the opportunity to understand the dynamics of organizations with respect to the complexities of the organizations' task environments. The case study is chosen as the basic research design for a number of reasons.

First of all, the case study approach provides the researcher with enough time to study the situational context that critical infrastructure organizations operate in. Critical infrastructure organizations involve highly complex operations which take time to comprehend. Since the situational imperatives are essential to this research, they need to be explored. As such, it becomes possible to understand how and why critical infrastructure organizations operate the way they do. Consequently, the empirical results needed for answering the research question depend on the local knowledge within a critical infrastructure organizations. This means the organization needs to be studied at the micro level in the 'real-life context'.

Secondly, a case study makes it possible to study organizational phenomena over a period of time. Organizational changes from bureaucratic to high velocity, innovative or crisis operations cannot be understood from an observation at a single point in time. Change occurs when operations at t=1 are different from operations at t=2. A time interval is needed to capture organizational change. A case study design allows the investigation to take place within a sustained time frame which makes it possible to observe such changes.

Thirdly, trying to understand a critical infrastructure organization within a highly complex organization setting requires in-depth research. To derive 'thick' descriptions of performed operations requires attention to specifics and details. To be able to conduct such a research within the practical constraints of a master's thesis the empirical investigation will need to be limited to a specific case.

In this thesis, the goal of the case study is to explore the plausibility of the theoretical hypotheses. The theoretical framework in chapter 3 provides the foundation to explore the case. Case studies are used as "plausibility probes" (Eckstein, 2000, p. 140). The meaning of plausibility in this respect is "something more than a belief in potential validity plain and simple, for hypotheses are unlikely ever to be formulated unless considered potentially valid; it also means something less than actual validity, for which rigorous testing is required" (Eckstein, 2000, p. 140). The result of such explorative case study is a preliminary conclusion on if and how the theoretical framework is useful for studying empirical phenomenon. Do innovation management, crisis management and HRO literature provide plausible explanations for understanding reliability in conditions of uncertainty and time pressure? Do these explanations need further consideration, or not? If not, what does that mean for the validity of these theories?

A subsequent step would be to test the theoretical suggestions. Testing would require extensive comparisons between critical infrastructure organizations that differ significantly with regard to their performance in different performance modes. Since investigating critical infrastructure organizations is an effortful endeavour such thorough tests of theory are beyond the scope of this research. They may, however, prove useful for future research.

4.1.1 Air Traffic Control the Netherlands

The purpose of this research is to investigate if and how high reliability can be maintained once a critical infrastructure organization with risky technology is confronted with conditions of uncertainty and time pressure. These conditions are categorized in bureaucratic, innovative, high velocity and crisis performance modes. This means two things with regard to the selection of an appropriate case study.

1. The selected organization needs to resemble the ideal-type HRO. The research focus is on a specific type of organizations that perform society-critical services, deal with risky technologies and ensure highly reliable performance.
2. The task environment of the organization needs to be dynamic. The operating conditions need to shift from certainty to uncertainty, and from slack time to time pressure. In this

way the different performance modes can be investigated. Without these shifts, the hypothesized organizational changes cannot be observed.

Based on these two criteria Air Traffic Control the Netherlands (LVNL) is chosen as the case for this study. LVNL is an independent public agency responsible for providing air traffic services under the responsibility of the Ministry of Transport. Air traffic control, as one of the air traffic services, is the organization's core business. The central task of air traffic control is to separate aircraft in the air and on the ground. Air traffic controllers instruct pilots on how to conduct their flight. They are the pilots' 'eyes and ears on the ground'. At LVNL approximately 900 people, of which 250 air traffic controllers, are employed to keep the skies and airports safe. In this subsection I will argue why LVNL is an HRO and why we can expect a dynamic task environment in air traffic control operations.

Critical Infrastructure Organization

LVNL is part of the Dutch critical infrastructure of aviation. LVNL makes sure that air traffic in and out of the Netherlands is safe and efficient. Since the aviation sector is fundamental to the Dutch economy, the operations of LVNL are critical to the Dutch society. The aviation sector contributes 3% to the Dutch gross domestic product, connects Dutch companies with over 320 foreign destinations and provides work to approximately 175.000 employees and another 112.000 jobs in tourism (Zuidberg & Veldhuis, 2012).

A breakdown of the aviation sector would cause substantial problems to the Dutch economy. The volcanic eruption in 2010 has illustrated the cost of a closure of European airspace. In the Netherland Schiphol lost two to three million euros a day (ANP, 2010). Moreover, IATA argued that the ash cloud had cost airlines 1,3 billion euros worldwide (IATA, 2010). If LVNL is, for whatever reason, unable to service air traffic across the Netherlands a similar situation unfolds.

Apart from the high stakes involved, the work of LVNL not only affects the Dutch economy in terms of air traffic revenues or aviation related activities. Aviation is central to a much wider network of societal activities. Tourism, logistic sector, diverse business and other forms of transportation are all dependent on the functioning of the air traffic system. If LVNL is unable to provide their services all these dependent actors will be affected causing trouble throughout the Dutch, and even European, economy.

The fact that the stakes with reliable air traffic control are high and that many business and people depend on the 'always-on availability' of the system makes LVNL a critical infrastructure organization in the Netherlands.

Risky Technology

Air traffic control operations at LVNL involve over 40 different technological systems all used for making sure aircraft are separated in the air and on the ground. Radar technology and transponders, for instance, play a fundamental role in the work of air traffic controllers to give pilots the right instructions on heading, speed and flight level. A complete breakdown of the system will have a significant impact on the ability of air traffic controllers to separate aircraft and maintain safety across airspace. However, the introduction of radar technologies has given air traffic controllers substantial possibilities to improve safety and efficiency compared to operations in the past (La Porte, 1988).

The essential risk lies with the aircraft themselves. It is a vehicle with hundreds of passengers flying with 1000 km/h at an altitude of 33.000 ft.. Once aircraft collide or crash, the potential costs in terms of lives and property are severe. Accidents from the past illustrate the impact of such incidents. The recent MH17 crash in 2014 with 298 deaths or the Pan Am-KLM crash at Tenerife in 1977 with 583 deaths show what harm aircraft accidents can cause. With regard to Dutch airspace, these aircraft are controlled by air traffic control. As such the technologies that are controlled by LVNL are particularly risky.

Highly Reliable Performance

Despite the high stakes and risky technology, the performance of LVNL has been outstanding over the years. The performance of LVNL is framed in terms of safety, efficiency and environment (note: the Dutch abbreviation is VEM). With regard to all three criteria LVNL has proven to be highly reliable over the years. Based on a recently finished performance evaluation of LVNL by the Ministry of Infrastructure and the Environment, safety, efficiency and environment can be more explicitly discussed.

Safety at LVNL is measured in terms of 'safety significant events (SSEs)'. In compliance with the European regulation ESARR2 safety significant events are incidents and accidents. An incident is an occurrence in which safety was affected but didn't result in any harm or damage. An accident is an incident with damaging effects. Incidents can be categorized in 'serious incidents' and 'major incidents'. ESSAR2 legislation has defined both types of incidents as follows:

- *Serious incident*: an incident involving circumstances indicating that an accident nearly occurred (note: the difference between an accident and a serious incident lies only in the result).
- *Major incident*: an incident associated with the operation of an aircraft, in which safety of aircraft may have been compromised, having led to a near collision between aircraft, with ground or obstacles (i.e., safety margins not respected which is not the result of an ATC instruction)".

Over the years not one significant event per 10.000 flights occurred at LVNL (Kuiper, Geut, & ten Heuvelhof, 2014). In the year 2013 there were 27 safety significant events on more than 500.000

flights. Of these SSEs two were categorized as serious and 25 as major. This means that only 0,0004% of the flights led to a serious degradation of safety. No accidents occurred. Considering the figure below, it is remarkable that despite the high safety performance over the years the number of safety significant events still declines.

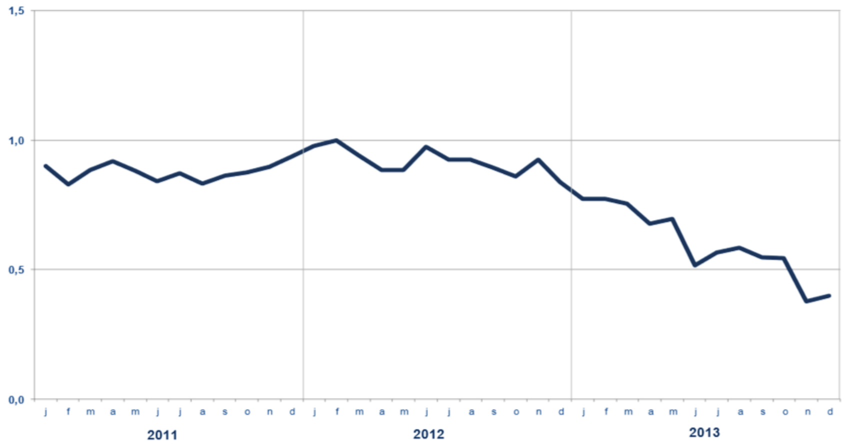


Figure 1: Safety significant events per 10.000 flights

The primary reason for the decline of SSEs in the last year has been the investment of LVNL in reducing runway incursions. Runway incursions are a specific set of SSEs. An incursion occurs when an object or person is on the runway while it isn't supposed or allowed to be there at that time. The incursions are also categorized from a minor (category D) to severe (category A) incident. The graph illustrates that hardly any serious runway incursions occurred and that there is a substantial decrease in the total amount of runway incursions in 2013.

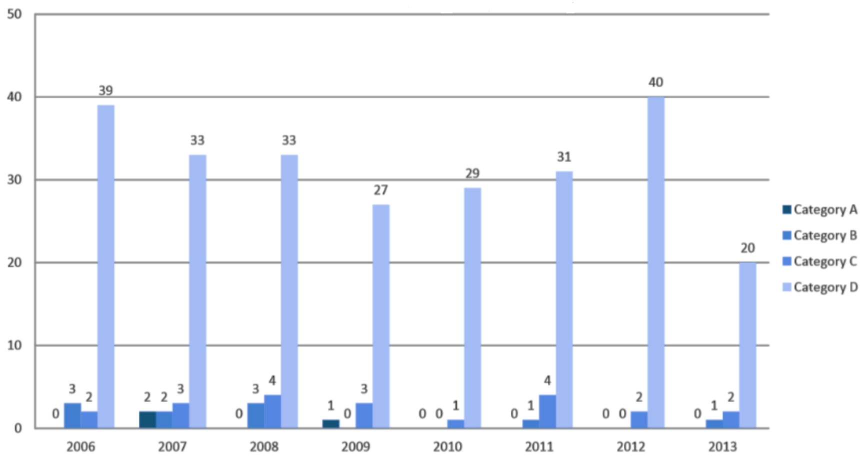


Figure 2: Runway incursions at Schiphol Airport per year

Apart from safety, LVNL also aims to use the airspace efficiently in order to accommodate as much flights as possible without too much delay. The main indicators for efficient performance are the delivered capacity and amount of delay. The numbers show that LVNL performs extraordinary well on both indicators. With regard to capacity, LVNL has managed to constantly perform above the norms and modelled expectations. Also the delays are consistently below the norm of 1 minute per flight. Only in 2008 the delay exceeded the norm slightly.

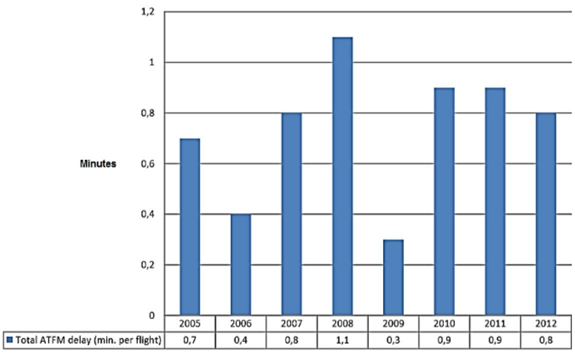


Figure 3: Realized capacity for first inbound peak

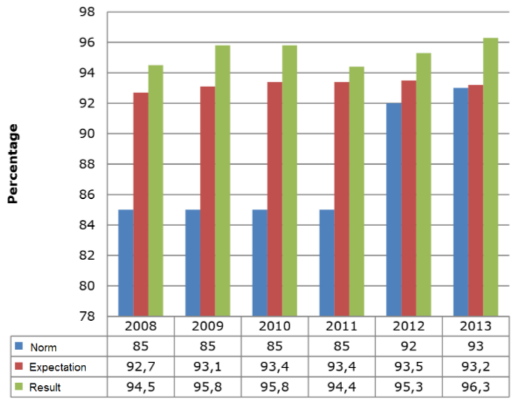


Figure 4: Total ATFM delay in minutes per hour

LVNL is compelled by law to provide safety and efficiency without causing unnecessary nuisance to the environment. As such, the Dutch government has imposed eleven rules in the Luchthavenverkeersbesluit (LVB) which LVNL has to comply with in air traffic control operations. The rules stipulate which runways and air routes are preferred to be used at different times of the day. Besides a few anomalies, the figures from LVNL annual report on environmental regulation show that LVNL did not exceed the legal thresholds over the past years.

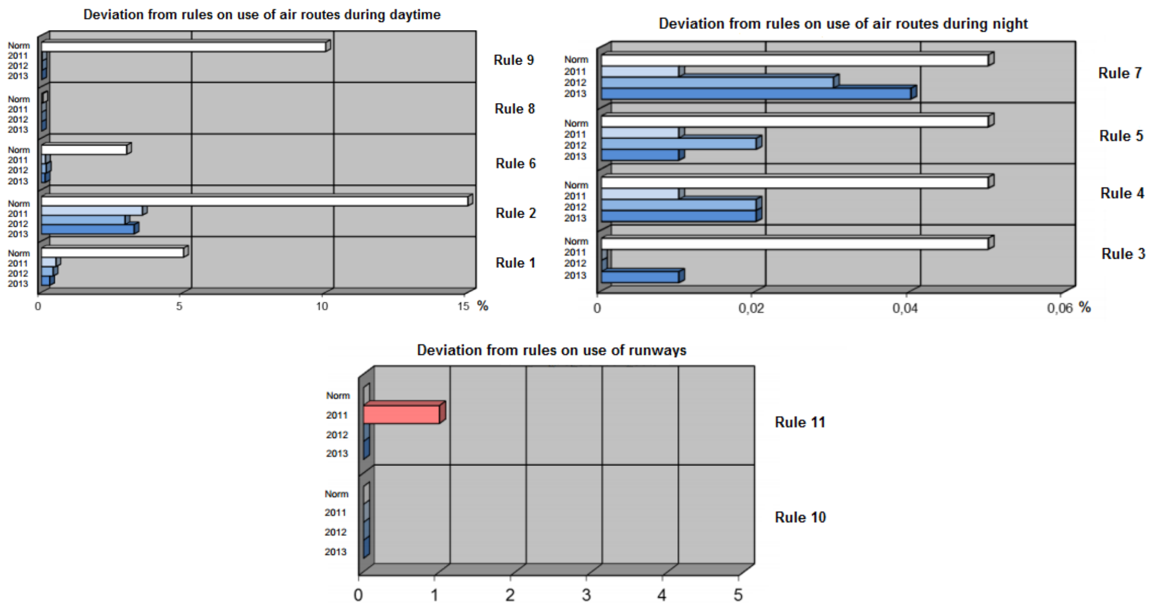


Figure 5: Environmental regulation compliance LVNL

LVNL manages to consistently achieve its goals of safety, efficiency and environment over the years. Together with the society-critical nature of the organization and the operation of hazardous technologies, LVNL resembles the ideal-typical HRO.

A Dynamic Environment

The environment in which this performance is delivered is particularly dynamic. Based on past events and recent developments in the aviation sector LVNL can be expected to operate across different performance modes.

First of all, the daily peak times of air traffic in the Netherlands confront air traffic controllers with time pressure. During the day there are seven peak times in which the maximum runway capacity at Schiphol needs to be used to facilitate the arrivals or departures. During these times it becomes very busy in Dutch airspace making controller workload increase significantly. Air traffic control also has to deal with bad weather conditions (ANP, 2014) or May Day calls (Luchtvaartnieuws.nl, 2014) on a regular basis which call for immediate responses.

Secondly, the goals of safety, efficiency and environment are not always commensurable and require trade-offs during air traffic control operations. The 'fixed goal requirement' of HROs in stable conditions is not applicable in the case of LVNL. The organization has to balance different demands without losing reliability. The performance evaluation committee concluded that LVNL will unquestionably experience a higher pressure from the European Commission and airspace users to perform more efficiently in the future. This would require LVNL to search for more creative solutions to meet those demands without losing reliability of safety (Kuiper, Geut, & ten Heuvelhof, 2014). Recent developments indicate that the operations at LVNL are changing in order to cope with the uncertainties of the future. LVNL, for instance, invests in the Single European Sky Air Traffic Management Research (SESAR) project, is renewing the main air traffic control system and is currently exploring remotely controlled tower operations.

Thirdly, past events suggest that the safety at LVNL sometimes needs to be enhanced in conditions of uncertainty and time pressure. In the event above Uitgeest in 2009, for instance, two aircraft approached Schiphol in parallel position. During such approach the horizontal distance between aircraft cannot be enhanced, which means that aircraft need to be vertically separated. In the event vertically separation was not possible, because the aircraft from the east approached the glide path to the runway at the same altitude as the aircraft that came from the west. Since approaching at a lower altitude is more efficient for airlines and no traffic from the west was expected to arrive at Schiphol for some time, the traffic from the east was temporarily set at a lower altitude normally used for traffic from the west. The safety report of the Dutch Safety Board (OVV) concluded that there was no procedure for such unexpected circumstance (Joustra, Muller, & Meurs, 2013). The report illustrates in detail how air traffic controllers managed to contain the unexpected and pressured situation and restore separation without causing any damage.

Since LVNL is an HRO facing a dynamic environment it is theoretically interesting to investigate this case to understand how reliability under uncertainty and time pressure can be maintained.

4.1.2 Practical Considerations

The choice for LVNL was also based on some practical considerations. Critical infrastructure organizations are a peculiar set of organizations with stringent regulations. Access to control room operations is rarely granted to outside researchers, let alone graduate students. The HRO research group at Berkeley explained in a reflection upon their work that gaining access and getting accepted by the people in the organization are the most difficult tasks in HRO research (Rochlin, 2011). This means that being able to investigate HROs largely depends upon the willingness of the organization to support the study.

At LVNL, the process of getting access took about two months. In different meetings managers, the director of air traffic control operations and a senior air traffic controller had to be convinced of the research idea. Between and after these meetings my research proposal was discussed multiple times by the management team of LVNL at the strategic level and operational level. All had to approve the proposal. After the research was granted security clearance was needed to be actually allowed into the building. Even within LVNL the control room itself is severely restricted and only open to air traffic controllers. Other personnel is not allowed in without prior clearance. A certificate of conduct had to be requested which means that security agencies perform a background check. With the certificate it was possible get access to the building. Access to the control room was only allowed after prior consultation with the operational manager, supervisor and air traffic controllers themselves.

Despite all security issues, LVNL allowed me to get an understanding of what air traffic control operations is about. They accepted me as a research student in the department of Strategy & Performance and for several months I was surrounded by knowledgeable and kind people. It was a chance to become part of a special organization and get as close as possible to real-time operations in a critical infrastructure organization. To be offered this exceptional opportunity was another important reason to choose LVNL as the case of inquiry.

4.2 Research Methodology

4.2.1 Normal Operations Study

Most research on risk, safety and crisis management has focused on what goes wrong or what might go wrong in organizations. Accidents are analysed, the causes of failure are identified and lessons are drawn on how to prevent such events from happening in the future. Hence, we can improve safety management systems, sharpen procedures and train operators in order to withstand similar adverse events.

Inspired by Eric Hollnagel and his White Paper at EUROCONTROL, this research will not focus on “what goes wrong” but on “what goes right” in critical infrastructure organizations (Hollnagel, Leonhardt, Licu, & Shorrock, 2013, p. 3) . It is the goal of this research to explain why critical infrastructure organization can be reliable in extreme conditions, not why they are hardly unreliable. Adverse events only happen rarely, especially with HROs. Measuring reliability in terms of the ability to ensure that “as few things go wrong” (Hollnagel, Leonhardt, Licu, & Shorrock, 2013, p. 3) would not necessarily provide a reliable measure for why ‘many things go right’.

In addition, identifying the causes of accidents in hindsight can be particularly misleading. Accidents result from an interaction of complex events which were at the time of the event unanticipated by the organization (Reason, 1990), for else they would have been prevented. In hindsight, there is a tendency to infer a linear pattern of causal explanations as to why the accident happened. But it is precisely the absence of such comprehensive causality that leads to the accident in the first place (Bourrier, 2002). Hindsight bias easily leads investigators to see what they expect, instead of appreciating the complex idiosyncrasies of such an event.

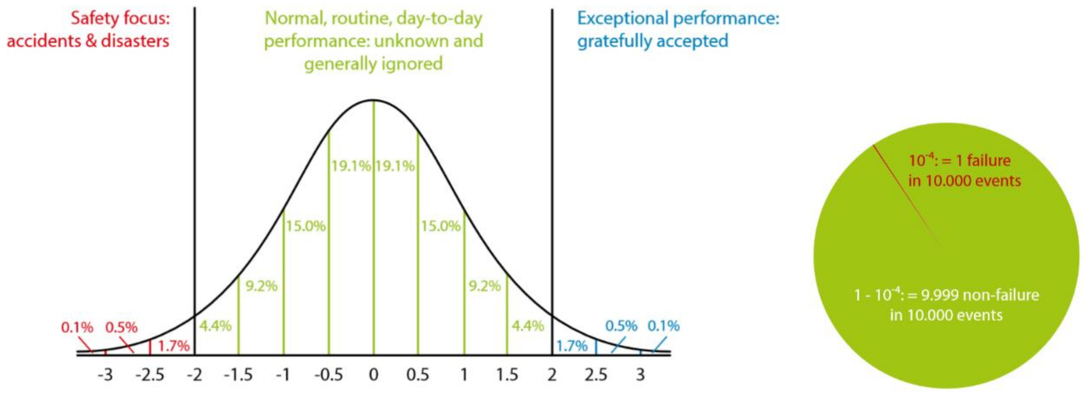


Figure 6: Safety & Normal Operations Study (Hollnagel, Leonhardt, Licu, & Shorrock, 2013)

To understand why LVNL is reliable as it is, the focus should rather be on ‘what goes right’ during normal day-to-day performance. Focusing on ‘what goes right’ means we have to research “work-as-done” instead of “work-as-imagined” (Hollnagel, Leonhardt, Licu, & Shorrock, 2013). Work-as-imagined describes “what should happen under nominal working conditions” while work-as-done describes “what actually happens, how work unfolds over time in a concrete situation” (Hollnagel, Leonhardt, Licu, & Shorrock, 2013, p. 15). If work-as-done corresponds with work-as-imagined, the organization can be argued to exist in bureaucratic condition. However, it is precisely the aim of this research to explore if and how work-as-done differs from the work-as-imagined in events where things keep going go right. It is expected that operators in critical infrastructure organizations will have to adjust to conditions of uncertainty and time pressure in order to ensure reliability. As a result, the ‘work-as-done’ defines the research scope.

The implication of looking at what goes right during work-as-done is that the investigation should aim at understanding the real-time operating environment of LVNL. Gaining such understanding requires researchers "to get out from behind our desk, out of meetings, and into operational environments with operational people" (Hollnagel, Leonhardt, Licu, & Shorrock, 2013, p. 15). Air traffic control operations at LVNL are conducted by air traffic controllers in control rooms. This is the place where the work is done. Like Wilson (1989) argues: "it is [the operators'] efforts that determine whether the agencies' clients (that is, we the people) are satisfied" (Wilson, 1989, p. 34). The research method needs to provide a way of analysing the practices of air traffic controllers during real-time situations.

4.2.2 Operationalization

In order to explore the operations of air traffic controllers, a framework is required to classify the task conditions. Uncertainty and time pressure need to be operationalized in order to categorize the observed air traffic control task conditions.

It is important to understand that uncertainty and time pressure are 'sensitizing concepts' rather than 'definitive concepts'. The difference is explained by Blumer (1954) as follows:

"A definitive concept refers precisely to what is common to a class of objects, by the aid of a clear definition in terms of attributes or fixed benchmarks. [...] A sensitizing concept lacks such specification of attributes or benchmarks and consequently it does not enable the user to move directly to the instance and its relevant content. Instead, it gives the user a general sense of reference and guidance in approaching empirical instances. [...] Whereas definitive concepts provide prescriptions of what to see, sensitizing concepts merely suggest directions along which to look" (Blumer, 1954, p. 7).

The operationalization of both concepts is not exhaustive. The suggested items for measuring uncertainty and time pressure need to be understood as indicators for interpreting and probing the task conditions of air traffic controllers.

Uncertainty

Definition	An incomprehensible and unpredictable situation.
Operationalization	➢ Operator has not experienced the situation before. ➢ Situation is not fully known. The scope, time and/or place of the event have not been predicted. ➢ At the start of the situation no effective operational procedure was available.

Time Pressure

Definition	A compression of available time for producing the preferred operational outcomes
Operationalization	An operator's workload per unit of time, based on: ➢ Traffic volume in airspace ➢ Workload increasing circumstances, such as complexity of traffic, bad weather or system malfunctions.

Air traffic controllers need to respond under specific task conditions. It is the goal of this research to identify organizational mechanisms that characterize the operational response of air traffic controllers to these specific situations. Organizational mechanisms provide a way for operators to cope with the uncertainty and time pressure and ensure reliability. Some of these mechanisms, such as decentralization, improvisation, trial and error, etc., have been translated into hypotheses in the previous chapter. An organizational mechanism is defined here as an effective solution for maintaining reliability in conditions of uncertainty and/or time pressure.

The term 'organizational' implies that the research focusses on mechanisms that determine how the response is *organized*. The term 'organization' refers to a "system of consciously coordinated activities or forces of two or more persons" (Barnard, 1968, p. 72). This implies that we can speak of an organized response in air traffic control when the activities of two or more air traffic controllers are (a) coordinated, and; (b) are consistent in similar conditions. In other words, the collective response of air traffic controllers in conditions of uncertainty and/or time pressure needs to portray a common pattern.

Organizational Mechanism

Definition	An organizational solution for coping with conditions of uncertainty and/or time pressure in order to sustain reliable performance.
Operationalization	A common pattern among operator practices in uncertain and/or time pressure conditions.

In conclusion the research model looks like the figure below. Uncertainty and time pressure are expected to have a negative effect on reliable performance unless organizational mechanisms are able to mediate these effects.

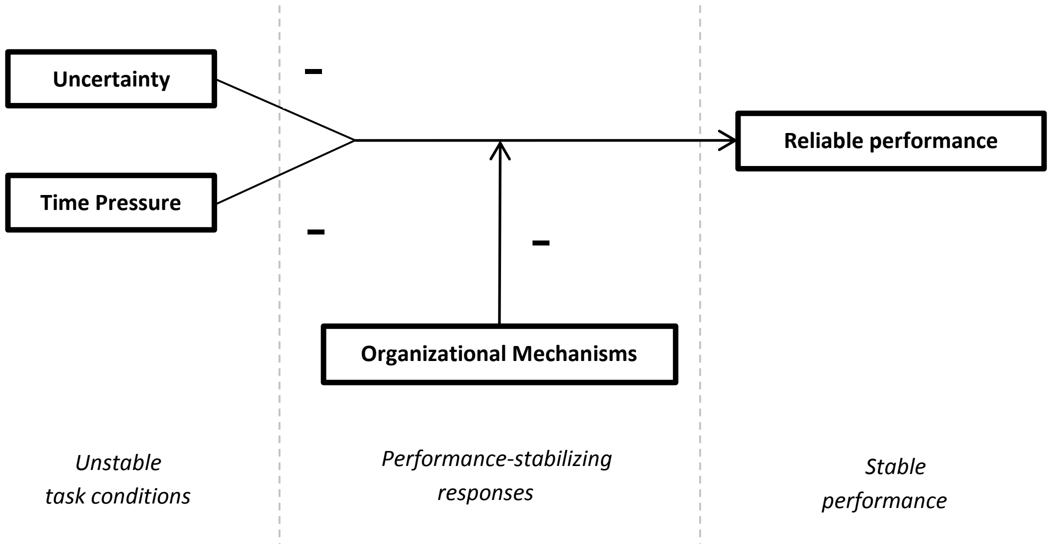


Figure 7: Research Model

4.2.3 Data Collection

For the case study different methods are used to collect relevant data. The process of data collection consists of a couple of chronological steps. Every time the researcher had access to control room operations all steps were repeated which resulted in an iterative process of data collection. In a way, the data collection matured during the research. Experiences from previous rounds of data collection refined new rounds of data collection leading to richer data.

1. Documents

Before getting into the complex environment of air traffic control operations, first the basic air traffic control practices were studied from internal procedures, charts, work flows, maps, guides and policies. More than 30 documents were analysed to get a sense of what air traffic control is about. Although it is impossible to fully understand all complexities within a few weeks, some general knowledge about airspace structure, traffic flows, separation, flight rules, radar plots is necessary to actually understand what air traffic controllers do. For laymen the most fundamental subjects are summarized in the next chapter.

Apart from gaining a general understanding of the work in the control room, the documents also provided insights in what air traffic controllers *ought* to do or how LVNL puts a lot of effort in thoroughly describing systems ought to function – i.e. work-as-imagined. The information in these documents helped to gain an understanding of how bureaucratic operations are organized and to what extent non-bureaucratic events have been anticipated.

2. Observations

During eleven days, I observed air traffic controllers and supervisors during their work. Observations preceded interviews so the observed situations could serve as input for more in-depth questions during the interviews. In this way, the observed situations and practices contributed to forming a shared interpretation framework among the interviewer and interviewee. In two cases observations could not be conducted prior to the interviews because the respondents were not available.

The observations took place in the radar control room at Schiphol-Oost and in the control room of the air traffic control tower at Schiphol airport. The researcher was allowed to sit next to air traffic controllers during the observations. By means of a headset it was possible to listen to communications between controllers and pilots which made it possible to understand what was going on. In calm periods the air traffic controllers and supervisors were open to have a chat and share some thoughts. These talks proved to be particularly important because they allowed for quick evaluations of unfolding situations. It was probably the closest an outsider gets to the actual operations – i.e. work-as-done.

The observations took place at all air traffic control units, being Area Control, Approach control, Tower Control and the Flight Information Centre. Each of these units controls different segments of the Dutch airspace, as will be explained in the next chapter. The observations focused on the how air traffic controllers or supervisors operate and relate to each other. During the observations bureaucratic, high velocity and innovative performance modes have been experienced. Crisis conditions fortunately do not happen every day, nor did they during the observations. The data about crisis conditions is therefore mainly based on prior crisis experiences of air traffic controllers.

The observations took place at different times of the day. In this way the different roles in air traffic operations could be analysed during both peak and off peak times. On average an observation lasted about five hours. During the observation notes were taken which were worked out later in a report of about three pages each.

Although the observations made it possible to get deeply involved with the people and the work, it has to be noted that becoming a full participant observer is simply impossible. Obviously, rules didn't permit the researcher to touch buttons, let alone talk to pilots. Even years of training wouldn't guarantee a researcher to become an air traffic controller because the selection and training criteria are exceptionally high. Previous HRO research has encountered the same issues (Rochlin, 2011).

3. Interviews

After each observation a formal interview was conducted with the observed air traffic controller or supervisor. In total eleven people were formally interviewed. Three respondent were female and eight of them were male. All of them were air traffic controllers and four of them were also supervisors. Five controllers were selected from area control and the other six from tower and approach control. The respondents varied in experience ranging from young controllers, who just finished the training program, to older controllers, who are about to retire. To vary in these personal and functional traits a more coherent and nuanced picture of operations could be derived. All controllers also work as Operational Experts in one of the office departments at LVNL which was helpful in discovering how the different departments of LVNL work together.

The interviews were meant to gain an understanding of how air traffic controllers and supervisors make sense of uncertain and time pressured conditions and how they respond to these situations. Interviews are particularly useful to get the story behind air traffic controllers' experiences with such situations. The conversations took place in a private room or office and were all treated confidentially. The advantage of interviews is that the respondents feel more comfortable to share sensitive matters which they would be reluctant to share in an unprotected environment. Especially in case of uncertainty and time pressure, respondents need to acknowledge that situations were not known, unanticipated and stressful. The respondents need to feel secure to talk about such sensitive subjects.

All the interviews were semi-structured based on a topic list that was prepared in advance. The respondents were asked to describe situations which resemble each of the four performance modes. For every situation, the respondent was asked to illustrate (a) why this situation was different from routine conditions, (b) how he/she responded, (c) what enabled and constrained an effective response, and (d) how that response was connected with the conduct of other air traffic controllers, supervisors, the staff, the management team and other organizations.

The interviews lasted an hour on average and were taped with a voice recorder. After the interview, the recordings were transcribed resulting in transcriptions between 15 and 20 pages for each interview. The transcriptions were sent to the respondents for review. A few respondents made some minor changes to the transcripts or requested the researcher to delete some parts that were deemed too sensitive. None of these changes were significant in terms of this research. Only one of the respondents objected against the use of the transcript for research purposes. Most of the data from this interview, however, resembled the data from other interviews which means that no specific findings are left out.

Since all interviews are confidential, the data is presented anonymously. No names or personal descriptions are used in the research report. The respondents are numbered and referred to as, for instance, 'R1'.

In addition to data collection during control room operations, eight formal interviews were conducted with staff personnel at LVNL. Managers and employees from different departments at LVNL were asked to clarify specific subjects in more detail, such as selection & training programs, change processes, safety and crisis management systems and the relationship between operations, management and staff. The topics emerged from the interviews with air traffic controllers and supervisors. Either air traffic controllers advised to investigate these issues further or the topics recurred frequently in the interviews with air traffic controllers. The additional interviews were used to substantiate the stories of air traffic controllers and to combine the results at the micro level with the macro organizational context.

Furthermore, I held numerous informal talks during observations, at lunch, during coffee breaks, in the office or at an occasional diner. These moments were useful for getting a general sense of what is going on at LVNL and to become engaged with the people. More importantly, some of the informal talks resulted in interesting brainstorms and moments of reflection which helped to improve the research process. During office times it was also possible to observe how staff personnel and air traffic controller at LVNL worked together and what their occasional discussions were about. This was an aid in interpreting the relation between the operational logic of air traffic controllers and the office logic of strategists.

4.2.4 Data Analysis

The collected data is analysed according to an interpretive analysis. Interpretive analysis is defined as "segmenting the data and reassembling them with the aim of transforming the data into findings" (Boeije, 2010, p. 94). The raw data is modelled into a set of meaningful categories so it can be interpreted theoretically. A number of steps were taken to systematically process and interpret the data.

First of all, the interview transcripts, observation memos and notes were segmented into situations. These situations are personal experiences of air traffic controllers or situations that were encountered during observations in the control rooms. In total 60 situations are derived from the data. For every situation the conditions and the response were coded. The situations involved a wide range of different issues. Bad weather conditions, May Day calls, , the introduction of new technologies, system malfunctions, large amounts of inbound traffic, pilot noncompliance, a fire at the apron and procedural changes are a selection of the situations that illustrate the variety.

As a second step, the situational conditions were categorized according to the performance mode framework. The situations were interpreted by the researcher according to the operationalization of 'uncertainty' and 'time pressure', as described in section 4.2.2.. Phrases from the situational descriptions were used as indicators to 'sensitize' both performance mode parameters. For instance, uncertainty was related terms as “new”, “unexpected”, “unknown”, “special”. Words such as “busy”, “a lot of traffic”, “heavy” and “accelerating” were, for example, used to discern whether an air traffic controller experienced time pressure.

The third step is interpreting and comparing the operational responses within each performance mode. Responses that were found to be similar in three or more situations within the same performance mode were characterized as an organizational mechanism. After close examination some of these initial organizational mechanisms could be summarized into more general organizational mechanisms. The result of this analysis are the findings that are described in chapter VI.

Chapter 5
The Context of Air Traffic Control

This research focuses on the organization of HROs in the context of Air Traffic Control the Netherlands (LVNL). LVNL is an independent public agency responsible for providing air traffic services under the responsibility of the Ministry of Transport. Approximately 900 employees, of which 250 air traffic controllers, work on keeping the skies and airports safe.

Air traffic control is the organization's core business. The central purpose of air traffic control is to keep aircraft separated from each other. Air traffic controllers use radio frequency to give the pilots clearances, directions and advice on how to conduct their flight. They are the pilots' 'eyes and ears on the ground'. The world of air traffic control is, however, mighty complex. The Netherlands is a small country with one of the biggest and busiest airports in the world. As a result, the airspace is packed with over 450.000 flight movements a year. In order to separate all these flights air traffic control relies on highly sophisticated technology, technical jargon, an immense set of procedures and an interdependent web of airways and routes, all embedded in a global arena of markets, regulations and societal demands.

To understand how air traffic control manages to perform reliably across different performance modes, it is first important to have some basic knowledge of how air traffic control works. For this reason, this chapter provides an preliminary introduction to the operational and institutional context of LVNL. The first subsection explains how Dutch airspace is structured, how traffic flows are managed and how air traffic services are provided. In the second subsection the operations of LVNL are cast in the wider institutional context of aviation governance.

5.1 Operations

Air traffic control operations take place on the ground, either behind the radar or visually from a control tower at an airport. It is the controller's responsibility to prevent aircraft from colliding. Approximately 95% of the aircraft controlled by LVNL are either landing at or departing from Schiphol. Every day approximately 1000 aircraft take off or land at Schiphol, which means that during day time operations around 65 flights per hour arrive or depart from Schiphol. But there is also other traffic in Dutch airspace that has to be controlled. For example, airliners making their approach to Dusseldorf or Brussels, business jets, air balloons, police or medical helicopters, photo flights, recreational flights, gliders, oil platform helicopter flights and training flights. Besides commercial airliners, all these types of aviation are categorized as civil aviation and require the attention of LVNL. With regard to military aviation, however, specific blocks of airspace are under control of Dutch military air traffic control (DutchMil). LVNL does not have authority in these areas so long they are used by DutchMil. The fact that LVNL has to share the airspace with DutchMil, however, restricts the available airspace for civil aviation making operations even more complex.

To get a basic understanding of how all these types of aviation are controlled in the Netherlands, a couple of subjects need further elaboration: airspace, airways and air routes, traffic flows, and air traffic control units.

5.1.1 Airspace

The Dutch airspace consists of the airspace above Dutch territory including a part of the North Sea. This airspace is referred to as the Flight Information Region Amsterdam (FIR). The FIR is divided into four types of controlled airspace: Control Zone, Terminal Manoeuvring Area, Control Area and Upper Control Area.

The *Control Zone (CTR*) is the lowest controlled airspace column and is situated around airports. The column stretch from the ground up to a specified upper limit. For Schiphol the upper limit this is 3000 ft. above mean sea level. The CTR usually has a circular shape. It is the airspace in which the take offs, landings and taxiing traffic at the airport are controlled.

The *Terminal Manoeuvring Area (TMA)* is a larger block of airspace that encloses the CTR. TMA Schiphol ranges from 1500 ft. above sea level to flight level 095. The TMA is the area in which arrivals and departures for the covered airport(s) are controlled. The difference with a CTR is that in a TMA all flights are airborne. A TMA is established around busy airports where arrival and departure routes are in confluence or close vicinity, and therefore need to be controlled. Within the TMA most arriving flights (inbound traffic) are directed from an arrival route to the CTR. Most departing flights (outbound traffic) leave the CTR and enter the TMA via a departure route.

The *Control Area (CTA)* is a general airspace block covering the whole FIR ranging from a specified lower limit to a specified upper limit. The CTA is located on top of the TMA. Departure and arrival routes from all airports and aerodromes in the FIR cross the CTA. In the Netherlands, the CTA is divided into five civil CTA sectors and one military CTA sector in order to allocate controller workload. The CTA sectors have diverse lower limits depending on the sector, and have shared upper limit of flight level 195.

The *Upper Control Area (UTA)* is the fourth type of airspace. The UTA covers everything above flight level 195. From the UTA inbound flights descend to the CTA. Outbound flights ascend along departure routes to the UTA where the aircraft are able to fly most fuel efficient since this is where aircraft experience least air friction.

Besides controlled airspace, there is also a considerable amount of airspace that is not covered by CTRs, TMAs, CTAs and UTAs. This is called *uncontrolled airspace*, which means that air traffic is not under air traffic control. In these uncontrolled regions the primary responsibility for aircraft separation is allocated to the pilot. LVNL only provides the pilot with information and advice about what happens in and around his airspace. LVNL cannot command a pilot to fly at specific altitudes, headings or speed in this region.

The figure underneath shows a simplified cross-section of the FIR. The controlled airspace structure is also referred to as an 'upside down wedding cake'.

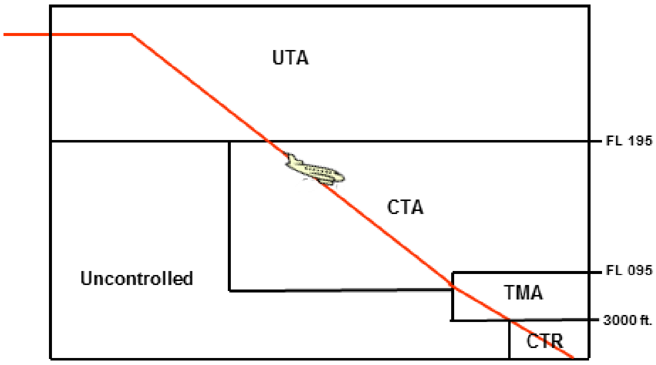


Figure 8: Airspace structure

Each type of airspace is attributed a specific class. In the Aeronautical Information Package (AIP) the airspace classification is determined. For every class the AIP specifies the flight rules, the separation distance and whether traffic is controlled by LVNL. In aviation there are two kinds of flight rules. Visual Flight Rules (VFR) apply when a pilot wants to fly visually. Flying VFR is prohibited in bad weather conditions and outside daylight periods since the pilot must be able to observe other flights and the runway. Whether VFR flights are allowed also depends on the airspace classification. Some areas are just too busy for VFR flights. Instrument Flight Rules (IFR) apply for aircraft that use the instruments on board to operate the plane. Flying IFR allows a pilot to fly in bad weather conditions and outside Universal Daylight Period (UDP).

In the Netherlands the UTA, CTA and TMA are all categorized as class A airspace. In class A airspace no VFR flights are allowed, only IFR. Air traffic controllers have to give clearance to pilots for entering the airspace. All flights are under air traffic control which means that air traffic control determines speed, heading and flight level in order to separate the aircraft. Class A determines that all flights should be separated with a minimum horizontal distance of 5 nautical miles (NM) and a minimum vertical distance of 1000 ft.. In the TMA Schiphol, however, a minimum separation of 3 NM and 1000 ft. is possible since the radar images at LVNL are accurate enough to use these minimum distances.

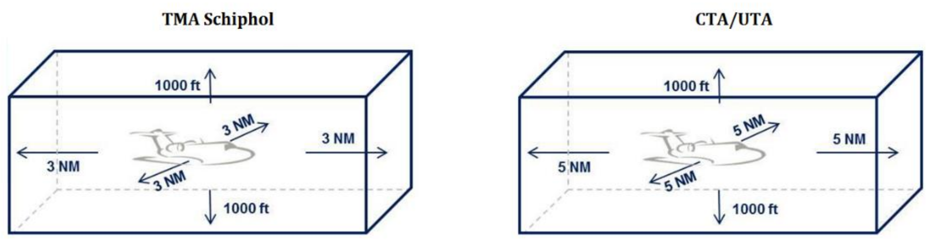


Figure 9: Separation TMA & CTA

The CTR Schiphol has airspace classification C which means that pilots need clearance from the air traffic controller before entering the airspace. The same separation criteria apply as in the TMA which is 3 NM and 1000 ft.. However, there are a few exceptions. If two aircraft are established on the Instrument Landing System (ILS) air traffic control does not have to enforce the minimum separation. The ILS produces a virtual glide path in the air which guides aircraft to the runway. This system ensures a separated approach once used appropriately. Moreover, once on the ground there are no minimum separation criteria.

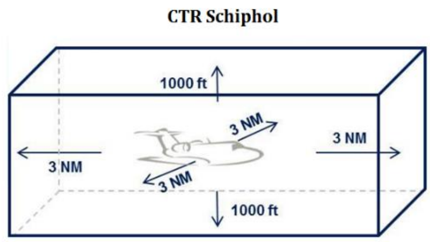


Figure 10: Separation CTR

All the uncontrolled airspace has airspace classification G. This is the lowest control category. Air traffic control does not have to clear aircraft from entering this airspace nor are they responsible for separating the aircraft. Air traffic control only provides pilots with information and advice on the aircraft's environment. Ensuring separation is a responsibility of the pilot.

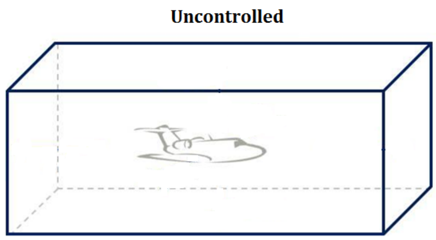


Figure 11: Separation uncontrolled airspace

5.1.2 Airways, Routes & Runways

Since Schiphol is the main airport of the Netherlands, much of the airways and routes are organized in a way that provides the most safe and efficient flow of air traffic to and from this airport. In Dutch airspace there are five main entry and exit 'corridors' at high altitude in which planes are guided to, from and over the Netherlands (see blue lines in figure 12). Each of these corridors have entry and exit points, which are connected to respectively departure routes (see green lines in figure 12) and arrival routes (see red lines in figure 12).

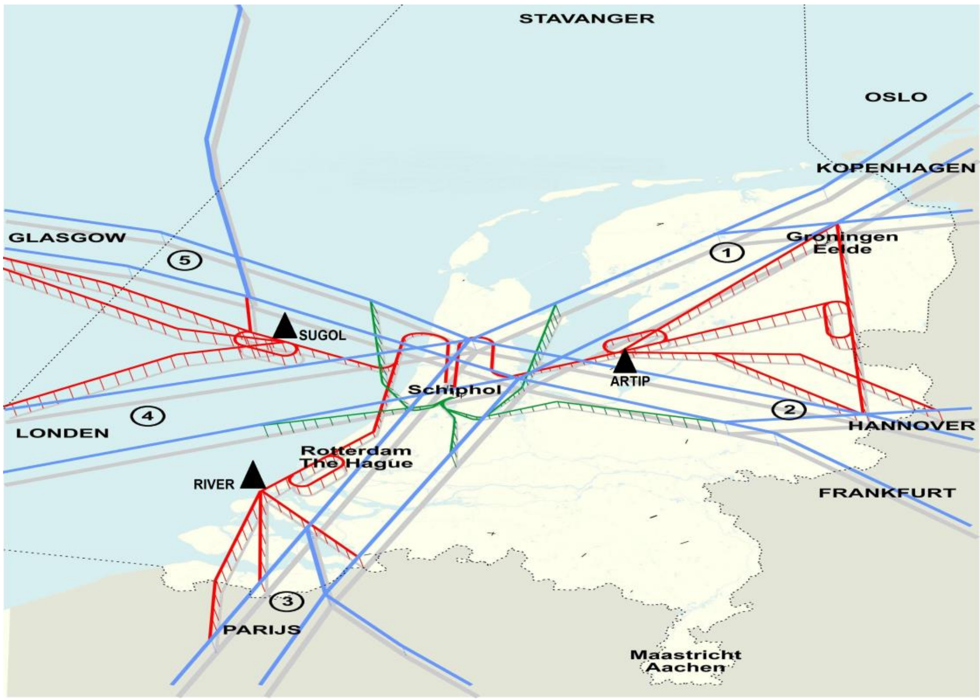


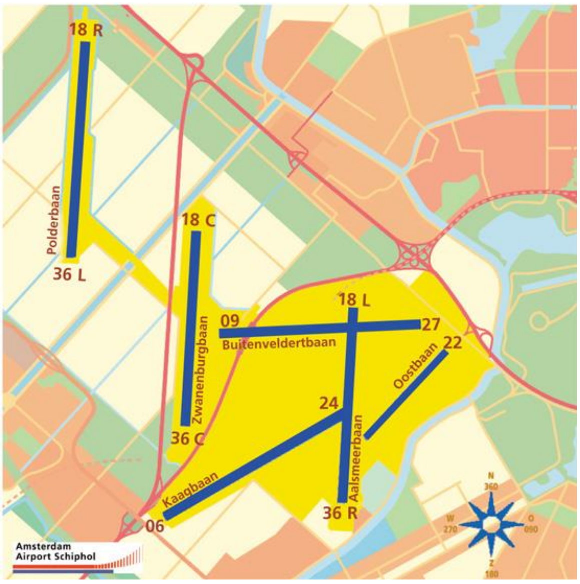
Figure 12: Airways, arrival routes & departure routes

For inbound traffic of Schiphol, the arrival routes lead to one of three initial approach fixes (IAFs); ARTIP, SUGOL or RIVER. In the figure these are highlighted with black triangles. At the IAFs pilots start their initial approach to Schiphol. The IAFs are located on the boundaries of the Schiphol TMA. Air traffic is handed over at an altitude between flight level 070 and 100. From here, airplanes enter the TMA and are directed by air traffic control to an approach fix which is a position in the TMA from where the pilot can start the final approach to the runway.

For outbound traffic, pilots are given specific instructions on which departure route to take. These instructions are called standard instrument departures (SIDs). SIDs instruct the pilot to fly to a number of waypoints or headings which lead to an entry of one of the five sectors.

In reality the airways and routes are not as standard as the figure above suggests. The arrival routes shown lead to two runways on Schiphol. The departure routes come from one runway. This means that the arrival and departure routes in use depend on the runway combination in use. At Schiphol there are six runways. Each runway is given a name, but in air traffic control jargon the code name for the runway is used. The numbers in the runway name refer the horizontal angle of the plane's heading when approaching the runway. Letters in runway names are used for distinguishing runways with the same approach angle. The letters to Left (L), Centre (C) and Right (R) to define its position in relation to the other similar runways. That is why, for instance, the

Polderbaan is named 18R when approached from the north. The Aalsmeerbaan is named 36R when approached from the south.



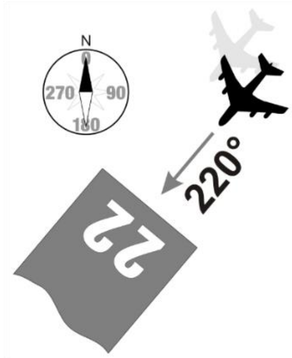


Figure 13: Runways Schiphol Airport

The use of runways is determined by multiple factors. First all, the weather is the most critical one. Landing or taking off with nose wind is necessary since strong side winds can destabilize the aircraft. In addition, mist affects air traffic control visibility in the control tower and snowy conditions requires runways to be cleared from snow which means they can temporarily not be used. All this affects which runways can be used safely. Secondly, the runway combinations are dependent on traffic load. When lots of traffic is inbound Schiphol, more landing runways are needed than runways for take-off. Thirdly, government regulations demand air traffic control to use the runways which produce least noise to the environment. Fourthly, some runways may conflict when used simultaneously. A take-off from runway 24 may for instance conflict with a go-around on runway 18C. All these factors have to be weighed by air traffic controllers when deciding what runways to use.

Considering there are 30 different runway combinations at Schiphol, and that all these runway combinations need specific arrival and departure routes, it becomes imaginable how complex and interdependent the system is.

5.1.3 Traffic Flow

Air traffic in the Netherlands is patterned in peak-times and off-peak times. Peak-times are periods in which a lot of inbound traffic wants to land at Schiphol or when a lot of outbound traffic wants to depart. As a result, there are inbound peaks and outbound peaks. Inbound peaks normally require two landing runways and one departure runway, while in outbound peaks two departure runways and one landing runway are used. Peak times occur seven times a day and require the full extent of airspace capacity and runway capacity. As a consequence, the airspace becomes highly saturated pressuring the operations of air traffic control. The periods between peaks are termed off-peak times.

The peak-times and off-peak times are a result of the aviation market. Schiphol functions as an international hub. The Dutch market for air traffic is too small for airlines to rely on if they want to compete in a global aviation market. Schiphol and its home carrier Air France-KLM use the hub functionality for transit passengers. To make transfers as convenient as possible Air France-KLM tries to minimize the transfer time for passengers. As a result, all planes arrive at the same time allowing people to quickly change to the next flight and continue their journey.

To prevent the airspace from becoming congested, the flow and capacity of air traffic is regulated. On one hand, airports have a limited amount of slots available. Slots are time periods in which an aircraft is allowed to arrive at or depart from the airport. The Stichting Airport Coordination Netherlands (SACN) allocates these slots based on market demands. On the other hand, the Network Manager at EUROCONTROL is responsible for assessing the flight plans of all the flights that cross European airspace. They assess whether the flights plans are commensurable with the airspace capacity. The flights are planned in a way that airspace is used most efficiently without exceeding the airspace capacity limits as determined by air traffic control providers.

5.1.4 Air Traffic Control

Within the environment of airspace blocks, airways, air routes, runways and capacities, the air traffic control of LVNL is responsible for making sure that airspace users are able to safely conduct their flight. Since there are different types of airspace, there are also different types of air traffic control. We distinguish between Area Control (ACC), Approach Control (APP) and Tower Control (TWR).

Area Control is responsible for managing flight operations in the CTA and the UTA up to flight level 245. Above flight level 245 Maastricht Upper Area Control (MUAC) has control. Area Control is located at Schiphol-Oost and is employed by radar controllers. This means that air traffic controllers sit behind radar screens and communicate with pilots based on radar information. It is the duty of ACC to direct inbound traffic from adjacent countries, like Germany, Belgium, England and Scotland, to one of the three IAFs. They merge traffic from different arrival routes in one sequence and separate aircraft with 5 NM and 1000 ft.. At the IAFs they are transferred to Approach Control. For outbound traffic, Approach Control transfers the separated flights to Area Control. Area Control makes sure that these flights continue their climb along the departure routes and are handed over to adjacent countries. Since ACC works with flights that come from adjacent countries, they also needs to keep in touch with air traffic controllers from those countries. These are also referred to as ‘adjacent centres’.

Approach control controls the TMA Schiphol airspace. APP is also employed by radar controllers in the control room at Schiphol-Oost. Approach controllers make sure that inbound traffic at the three IAFs – SUGOL, RIVER and ARTIP – is merged into sequences for the designated runways. Once they are ‘on final’, the arriving flights are transferred to tower control. For outbound traffic, approach has to make sure that departing traffic is conflict free from inbound traffic. Since arriving flights descent and departing flights ascent they will meet in the air if their routes are convergent or crossing. APP gives the flights heading, speed and flight level directions in order to avoid these conflicts. Once there are no conflicts left, APP transfers outbound traffic to Area Control.

Tower control is located at the air traffic control tower at Schiphol airport. In the tower air traffic controllers are responsible for visually controlling traffic in the CTR. Inbound traffic ‘on final’ is given landing clearances by the runway controller. Usually every runway has got its own runway controller. Once the aircraft has landed and exits the runway, the aircraft is transferred to a ground controller who is responsible for safely guiding the aircraft to the gate. For outbound traffic, a delivery controller assigns one of the available runways to the aircraft for take-off including the SID and a slot-time in which the take-off will take place. The start-up controller informs the pilot when he can safely start up the engines at the gate. The start-up controller plans the take-off sequence based on the type of aircraft and destinations. The start-up controller than transfers the flight to the ground controller who gives the push-back clearances and directs the aircraft to the assigned runway. If the aircraft needs to cross or get onto a runway, the runway controllers needs to give permission to the ground controller in order to avoid runway incursions. Not only in the air but also on the ground, air traffic control fulfils a crucial job to keep flights separated.

ACC, APP and TWR together provide air traffic control services in controlled airspace. In uncontrolled airspace, however, the Flight Information Centre (FIC) communicates with pilots. The FIC is no air traffic control since they do not have the authority to give heading, speed and flight level instructions. It is their job to provide pilots with the necessary information and advice on how to conduct their flight. The decisions, as well as the responsibility for separation, are with the pilot. Although FIC is no air traffic control unit, it is an important air traffic service that can be pretty complex and intense. Especially with more than 100 offshore platforms, helicopter flights are a substantial part of their work.

5.2 Governance

The operations of LVNL are closely linked to the conduct of other actors in the aviation sector. For this reason, the governance of LVNL needs further explanation. Governance refers to how the relations between LVNL and other actors are organized (Rhodes, 1996). A useful way to approach this issue is regarding the aviation sector as a "policy network" (Rhodes, 2007, p. 1244) consisting of market, regulatory and civil society actors.

5.2.1 Market

The Dutch aviation market centres around Schiphol Airport. During the 1980s Schiphol was advanced by the central government as one of the two mainports of the Netherlands. Together with the Port of Rotterdam, Schiphol was successfully promoted as the gateway to Europe for passengers and business. The passenger and cargo volume experienced a strong growth over the years, making Schiphol the fourth largest airport of Europe and the heart of the Dutch economy. In 2013 52.6 million passengers travelled via Schiphol and 1.5 million tonnes of cargo were transported from and to the airport. As a result, most of air traffic in Dutch airspace is bound to Schiphol. In 2013 the number of air transport movements rose to 425.565 which is approximately 95% of all air transport movements that are controlled by LVNL.

The growth of Schiphol is mainly the result of the joint strategy of Schiphol and its home carrier KLM to use the airport as a hub airport. Schiphol is connected to 323 global destinations and invests in enhancing maximum peak capacity to make transfers as convenient as possible. In 2013 41,9% of the passengers was a transfer passenger and around 70% of all passengers were transported by KLM. The hub strategy has made Schiphol and KLM one of the key players in the global aviation market and consequently a major asset to the Dutch economy.

In 2004 KLM extended its aviation network by merging with Air France and entering the Sky Team Alliance. Air France-KLM became the biggest air transportation provider in the world. The merge allowed Air France-KLM to use both Schiphol and Charles de Gaulle in Paris as a dual-hub strategy. The large market share of Air France-KLM in the Dutch aviation sector makes KLM the most important stakeholder to LVNL. The air traffic services of LVNL are mostly paid for by the airspace users. As a result, Air France-KLM is LVNL's main client and sponsor.

The interdependencies between Schiphol, Air France-KLM and LVNL affect the air traffic control operations. The increasing competition in the aviation industry, for instance, puts pressure on economic margins and calls for a more efficient use of air traffic management. The shorter the routes the lesser the costs to airlines. In addition, the limits on the growth of Schiphol have prompted Schiphol to invest in Lelystad Airport as a new airport. The idea is that Lelystad Airport can accommodate part of Schiphol's non-transfer traffic so Schiphol can advance its hub strategy in the future. For LVNL this has considerable consequences since airspace and route structures will have to change, traffic flows will alter and new points of conflict in air routes will emerge.

Apart from the intricate relationships with Schiphol and Air France-KLM, air traffic management itself is slowly starting to become a market as well. LVNL was part of the Ministry of Transport but became an independent administrative body in 1993. Although LVNL, the Dutch military and Maastricht Upper Area Control are the only providers of air traffic services in the Netherlands, article 5.14b of the Act on Aviation provides the possibility for other air traffic service providers to enter the Dutch air traffic service market. Until now LVNL maintained its monopoly position, but it is not something LVNL can take for granted. The United Kingdom serves as an example of privatised air traffic control.

5.2.2 Civil society

The growth of the aviation market has also caused an upsurge of interest groups and residential committees to express the local concerns of the people who live close to Schiphol. Especially in the near vicinity of Schiphol, people are confronted with noise that is produced by arriving and departing aircraft. In addition, the traffic growth would require an expansion of Schiphol through infrastructural projects such as the development of new runways. This would threaten the housing and living in Schiphol's direct environment.

The protest against further expansion of air traffic at Schiphol affected the market growth of Schiphol. Redesigning infrastructure would require the support of local and regional government. Decisions about spatial planning are made by democratically elected local and regional governments. To overcome the tensions between local residents and interest groups in 2006 the 'Tafel van Alders' - i.e. Alderstafel - was found. This is a consultative body of representatives of Schiphol, KLM, LVNL, local government and local interest groups. The chair of the Alderstafel is Hans Alders, who has been the Minister of Infrastructure and the Environment in the period of 1989 to 1994. The goal of the Alderstafel is to come to a shared strategy for 2020 on how to develop Schiphol within the bandwidths of acceptable nuisance and pollution. The outcome of the Alderstafel serves as advice to the central government.

In order to accommodate the growth of Schiphol as hub airport and keep nuisance and expansion to a minimum, part of the advice entails a renewed operational concept of air traffic management. Over the years these new operational concepts are implemented in LVNL's operations. One example is the 'preferential runway use'. Based on noise research the runway combination of the Polderbaan and Kaagbaan was found to produce the least nuisance. In effect, the runway combinations have been ranked according to the level of noise they foster. It is the duty of LVNL to use the most preferred runway combination.

Another element of the operational concept, now being investigated at LVNL, is the use of the Continuous Descent Approach (CDA) for arriving flights. In the CDA procedure the pilot starts his descent at a greater distance from the airport and glides the airplane to the runway at a fixed angle. The benefit of a CDA is that nuisance can be kept to a minimum since the pilot doesn't have to use the engines in his descent. The CDA procedure is currently used at Schiphol at night but not during daylight because the amount of air traffic during daylight is just too vast to use such a procedure. The conclusion is, however, that the operations of LVNL are attuned to the demands from civil society groups such as local residents and interest groups.

5.2.3 Regulation

The global aviation market with highly complex operations calls for unilateral rules and regulations on how to achieve safe and efficient air operations. Most of these regulations are set by the International Civil Aviation Organization (ICAO) which is one of the United Nation's agencies. Based on the Chicago Convention in 1944, in 2014 191 member states and air traffic organizations adhere to the ICAO standards and recommended practices. Many of the basic rules regarding air operations are derived from ICAO, such as the minimum separation between aircraft, airspace classification and flight rules. In the Netherlands ICAO regulation has been incorporated into Dutch law and provides the fundamental regulations for air traffic operations at LVNL.

Also on the European level efforts are made to harmonize European air traffic operations. The Single European Sky project was initiated in 2004 with EC regulations 549/2004 to 552/2004. The Single European Sky provides a framework for airspace structure, traffic flows and requirements for air traffic service providers. Traditionally airspace is structured along national borders leading to a fragmented European airspace structure in which national considerations determine the flow of air traffic. A Single European Sky caters for a more expeditious flow of air traffic across Europe resulting in lower costs to airspace users. The Single European Sky is a long term project that requires substantial changes in the Dutch airspace structure and air traffic service provision. The ambitions for the Netherlands have been incorporated in the National Airspace Vision of the Dutch government. According to the vision, a cross-boundary airspace between the Netherlands and Germany will be created for accommodating military training of Dutch and German air forces. The result is that the military airspace in the south of the Netherlands can be used for civil aviation which creates a more efficient connection between, for instance, Amsterdam and Frankfurt. Such changes, however, imply new air routes, a fourth initial approach fix and tight agreements between the Dutch and German air traffic service providers. The Single European Sky project is therefore closely linked to the operations of LVNL.

Apart from international and European regulation, the Dutch government enforces the Act on Aviation which describes the requirements and responsibilities of airspace users, air traffic service providers and airports. The Luchthavenverkeersbesluit Schiphol (LVB) serves as an extension to the Act of Aviation. The LVB includes rules and thresholds regarding the risk, noise and pollution in the environment around Schiphol. These rules, for instance, determine the tolerable runway combinations and tolerable amount deviations from air routes in horizontal and vertical distance. As such, they affect the operations of LVNL.

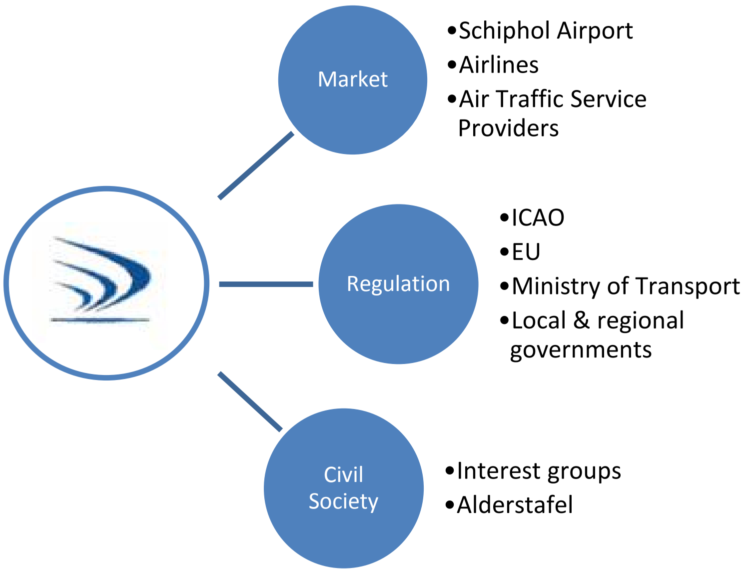


Figure 14: Governance LVNL

Chapter 6
Air Traffic Control the Netherlands

Air Traffic Control the Netherlands performs critical tasks. Operators in the air traffic control rooms ensure the safety of millions of passengers a year. At the same time, there are demands for an efficient and environment friendly use of airspace and runways due to the consistent growth of air traffic. Air traffic controllers have to make vital decisions on a daily basis to balance these requirements and maintain reliability. The conditions under which these decisions have to be made are, however, not always stable. Changes in weather, traffic volumes and available runways, or unexpected events such as May Day calls regularly test the capacity of air traffic controllers to perform reliably in conditions of uncertainty and time pressure. It requires air traffic controllers to continuously assess air traffic situations and respond in an adequate way. But what does that operational response of air traffic control look like under these varying conditions?

In this chapter the findings from the data analysis are presented and contrasted with the formulated theoretical hypotheses in a discussion. The goal of the discussion section is to understand too what extent the findings corroborate, refine or conflict with the current state of knowledge. Section 6.1 illustrates how the organizational goals of LVNL are translated into operational tasks. In sections 6.2 to 6.5 the results are structured according to the different performance modes and give insight into the ability of air traffic control to perform reliably in conditions of uncertainty and time pressure.

6.1 Safety, Efficiency & Environment: Between Goals and Tasks

LVNL pursues multiple goals. Market, regulation and society demand air traffic controllers to operate safely, efficiently and environmental friendly at the same time. Combining multiple organizational goals in a consistent manner under different conditions is a difficult task. Studies of other organizations show that people can easily disagree over the meaning of organizational goals, resulting in inconsistent task definitions by front-line workers (Wilson, 1989). Even if there is a shared definition of the goal and tasks among the members of the organization, there can be disagreement over “what other goals should be sacrificed to attain them” (Wilson, 1989, p. 33). Considering the operations at LVNL, a number of findings illustrate how the goals of air traffic control are specified and, more importantly, how operators translate these goals into real-time decisions during bureaucratic, high velocity, innovative and crisis modes.

As a first finding, the safety, efficiency and environmental goals are thoroughly described and specified in thick policy documents. These documents provide a shared framework for interpreting the desired organizational performance. The documents provide detailed information about how the goals are measured, what minimum level is required and what external and internal factors affect the attainment of these goals. Safety is, for instance, defined as a situation with "controllable or acceptable risks" (LVNL, 2011). Risk is measured objectively as the product of the probability and severity of a safety occurrence. A safety occurrence can be any air traffic control related incident that falls outside the course of expected and procedural action. Such incidents primarily involve the (potential) loss of separation between aircraft, ground and other obstacles. The norms for safety are strict which means hardly any safety risk is tolerated. These norms are derived from a global statistic of occurred safety incidents. As a consequence, the goal of safety is directly related to enhancing separation of aircraft.

LVNL policies also stipulate that goal attainment is dependent upon (a) the capacity of the organization, and (b) the conditions in which operations take place. One of the documents describes that safety, efficiency and environment require trade-offs. The resources and capacity of the organization need to be allocated across these different goals. This means that investing in one goal can come at the expense of another (LVNL, 2006). Once operational conditions change a different allocation of organizational capacity may be needed. "Changing external conditions may require more or less capacity to attain the same level of safety, efficiency or environment" (LVNL, 2006). It is interesting that, despite a collective definition of goal attainment, the organizational policy provides operators with the autonomy to adjust their practices to changing circumstances. But do air traffic controllers adjust their operations? And if they do, then how do they do it?

As a second finding, air traffic controllers unequivocally agree that safety is a precondition for efficient and environmental friendly air traffic services. An approach controller for instance explained: "3 mile, 1000 ft. is the only rule that is interesting to me. All other rules are designed to enforce that one rule" (R8). Safety is not something to be tampered with. It is a state of affairs that needs to be maintained at all times. The separation of aircraft is the fundamental task of air traffic control. The definition of 'separation' by air traffic controllers stems from ICAO rules on separation. In response to the question "What does safety mean?" an area controller illustratively answered with "5 mile, 1000 ft." (R1). Safety is part of the organization's DNA. There is widespread consensus that safety is the primary concern of air traffic control operations.

Once an acceptable level of safety is enhanced, air traffic controllers try to cater for a more efficient and environmental friendly operation. "We start working on efficiency and the environment if it is safe enough" (R15). Besides the preoccupation with safety, air traffic controllers have an intrinsic drive to perform as efficient as possible. Controllers are eager to satisfy their clients – i.e. KLM and other airlines (R1; R4; R2). One of the air traffic controllers, for instance, argued: "the fact that I'm here in this seat today, and do my job to the best of my ability, enables KLM to earn money" (R8). On the other hand, performing safely and at the same time efficiently is deemed as a "challenge" (R8) which is "fun" (R10). In the interviews, controllers consistently referred to it as a 'puzzle' that needs to be solved every time again. There is also a sense of honour in solving that puzzle. A controller argued: "The separation norm is 5 mile and 1000 ft.. Air traffic controllers are proud enough not to make it 6 miles. That is just our professional honour." (R4)

Thirdly, the operations of air traffic controllers show that stable conditions provide more opportunity to combine the goal of safety with goals of efficiency and environment than more critical conditions. In stable conditions air traffic controllers face predictable situations with enough time to think of creative alternative solutions for to operate more efficiently or environmental friendly. But high velocity, innovation and crisis modes require air traffic controllers to invest their available time and resources in enhancing safety. For example, in the event of a fire at one of the aprons on Schiphol a tower controller said: "The first thing on my mind is 'safety'. That is what requires my attention. The rest can wait" (R9). Such strong focus on safety has consequences for efficiency and environment. In the case of the apron fire, all traffic had to wait and be rerouted to different gates which means they will need a longer time to taxi resulting in inevitable delay and more fuel consumption for the airlines. Similarly, an area controller argued that at very busy times with a lot of traffic from multiple directions "you let go off everything and all you do is aimed at enhancing safety" (R2).

In sum, the policy and operations of LVNL both show a consistent interpretation of organizational goals and, at the same time, provide operators the autonomy they need to adjust their operational practices to changing conditions. Safety, efficiency and environmental goals are continuously balanced. In that balance an acceptable level of safety is the baseline criterion.

6.1.1 Discussion

The findings on the relation between the goal setting and operations at LVNL corroborate with the notion of this thesis, and of HRO literature, that safety is a precondition for the reliability of service provision. The findings show that this is not only the case in stable conditions, but also in uncertain and time pressured conditions.

Table 2: Safety, Efficiency & Environmental Goals

HRO Characteristics	Findings
➢ Indisputable support from the environment to prioritize safety above all other values. ➢ Consensus and shared definition among organizational members of safety goals.	➢ Organizational goals are thoroughly defined and specified in clear performance measurements. ➢ Safety is regarded a precondition for the attainment of other organizational goals. ➢ Stable conditions provide better opportunities for combining safety with efficiency and environmental goals.

The case of LVNL shows that safety is not traded for the attainment of efficiency and environment. If the conditions provide enough time and certainty, safety can be combined with efficiency and environmental goal. But once time pressure and uncertainty define the task environment, full capacity is needed to ensure the safety of the system.

In the case study at the California Independent System Operator (CAISO) Roe & Schulman (2008) similarly found that the safety of the system is a precondition for the organization's critical service delivery process. According to Roe & Schulman, safety "enables market transactions" (Roe & Schulman, 2008, p. 10). Safety is a "background condition" (Roe & Schulman, 2008, p. 10) that makes it possible for organizations to pursue other goals, such as efficiency.

Secondly, the findings indicate the presence of a "persistent, patterned way of thinking about the central tasks of and human relationships within an organization" (Wilson, 1989, p. 91). The case study shows how safety is prominently embedded in a substantive legal framework – e.g. ICAO, European requirements and national law – , policy documents and operations. Safety resides in the organization's DNA.

Besides demands for safety, LVNL is also required to operate efficiently and environmental friendly. The case study shows that the balance between safety, efficiency and environment needs to be constantly reassessed by air traffic controllers in changing conditions. As Wilson (1989) argues, the translation from multiple goals into tasks requires professional judgments by front-line workers based on the imperatives of encountered situations.

6.2 Bureaucratic Operations

Stable conditions for air traffic controllers consist of peak and off peak times. Traffic volumes come as expected, the weather does not hinder operations, and there are no significant issues that disturb the predicted course of action. Situations are ordinary and do not differ substantially from past experiences. Stable situations can be busy during peak times, but do not involve substantial time pressure. Air traffic controllers referred to these conditions as "business as usual" (R1), "normal" (R10) or "routine" (R2).

A number of organizational mechanisms are found to characterize the operations of air traffic controllers in this bureaucratic mode. First of all, there is an operational focus on monitoring the variables in the air traffic control process in order to anticipate the next step ahead. This anticipatory analysis takes place during different activities by different officials. The supervisor and his assistant at area Control, for instance, check the traffic volume charts on the displays at the supervisor desk. These charts show how much traffic is planned for the different CTA sectors and initial approach fixes (IAFs) in the next hours. A fixed red line in the graph indicates the predetermined maximum capacity of these areas. The supervisor's job is to monitor these graphs and make sure that air traffic controllers who work in one of these CTA sectors will not be overburdened with high traffic load.

Another example of anticipatory analysis is the activity of the Meteorological Advisor Schiphol (MAS) to check the weather forecasts for Schiphol and air routes. The Royal Meteorological Institute (KNMI) has a designated spot in the control room with over six screens that show how the wind, temperature, rainfall, mist, clouds and thunderstorms are likely to develop in the coming hours. The meteorological predictions of the KNMI are discussed four times a day in a joint session with the supervisor of area control, the supervisor of approach control, the airport manager at Schiphol and a representative of the operational control centre of KLM. Together they assess the impact of the weather on their operations. LVNL determines the airspace capacity based on the weather predictions. The declared capacity is shared with the other the aviation sector partners during these meetings. Since the interdependent operations of LVNL, Schiphol and KLM, in this way all parties are kept on the same page

A third example of anticipatory analysis relates to the conduct of air traffic controllers themselves. Based on the availability of ground radar, approach controllers are able to see how many aircraft are lined up at the runways. This allows them to foresee potential conflicts in the TMA even before these outbound aircraft are airborne. A controller explains: “At approach control we have adopted ground radar. […] It is so useful. You know what you can expect. You know what tower control is doing. You are able to look ahead further in time and use that information to decide whether to instruct aircraft in the TMA to ascend or descend” (R8).

What stands out from these examples is the prominent role of technology in the process of anticipating future circumstances. Meteorological models, traffic volume systems and ground radar are only some of the technologies that support the conduct of air traffic control to anticipate the operational conditions. Since these systems are so important to the operational conduct of air traffic control, a second finding is that LVNL invests heavily in making these technologies highly redundant. “There is a lot of redundancy in technological equipment. Here everything is duplicated 2, 3 or 4 times. We never approach the absolute minimum” (R3). Another controller argued it is “common practice in Western-Europe that communication systems have two back-ups. If one breaks down, you still got one main system and one back-up system left to run full operations. Generally speaking, if you only have one back-up system left air traffic control operations need to stop. In this case air traffic capacity will need to be reduced to zero” (R5). The redundancy in technology provides air traffic controllers with a feeling they can rely on the technology.

Although controllers go to great lengths to anticipate the operational environment, a third characteristic of the operational response is that even in stable conditions situations constantly differ and require professional skill. All controllers explained that not one day is the same. There are always minor differences or small changes that air traffic controllers need to adjust to. This means that “there are no standard solutions” (R1). Weather forecasts, for instance, are based on probability analyses. It is never completely certain how the weather will develop over time. The forecasts provide an inconclusive, yet reasonable, indication if the weather will hinder air traffic operations. During one of the observations a supervisor said: “There is no procedure or guideline for interpreting the weather. A probability means it can happen, not that it will. For me, a chance of 25% of fog is reason enough to temporarily adjust the capacity. 25% of one hour is 15 minutes of foggy conditions which is a significant amount of time that may cause problems to our operations” (R3). A controller remarked that the dynamic environment, even in stable conditions, is the essence of the job and requires human judgment. “A robot cannot replace us because air traffic control means dealing with situations that can never be fully anticipated. […] All technologies are supportive. None of them determine at what heading, flight level or speed an aircraft needs to fly. The technology provides the information and the people need to make the decisions” (R8).

The changes in the operational process during stable conditions are not wildly different from what controllers are used to. The operational adjustments by air traffic controllers are within the realm of routine solutions. An air traffic controller tried to explain this as follows: “Traffic comes a little earlier and it is distributed across the airspace slightly different, but it is not so markedly different that you can’t handle it on a routine basis. For instance, this morning I still had to make decisions. It wasn’t like ‘Let’s sit down, lean back, cross arms and everything will function automatically’. Yet, I could handle it in a routine way” (R3). Although routine practices are not always completely the same, they share similar traits and involve a recognizable pattern. Past experiences provide a good proxy for future operations.

A fourth finding is that the repertoire of routine practices is established and maintained through extensive training. To become an air traffic controller an individual will need to successfully pass four years of training. The training consists of two programs: the initial training and unit training. During the initial training the basics of air traffic control are explained in theory and practice. Once the initial training has been passed, the student obtains a license that is mandatory to become an air traffic controller. After the initial training the student continues in one of the unit trainings. For Schiphol there is a specific unit training for tower & approach control and another one for area control. In the unit training different modules are trained in simulated and on the job environments. Only after succeeding the unit training a student is able to become a fully licensed air traffic controller at LVNL. A training expert explained that the unit training aims at familiarizing student controllers with the variety of situations an air traffic controller has to deal with in reality (R19). In the training students are first tested on handling these diverse situations in a safe way. This is regarded the highest priority. “We are a safety organization. […] In the training everyone knows that failing in terms of safety is not an option” (R19). Once they are able to enhance safety, they are tested at operating both safely and efficiently. In this learning phase students learn to keep separation between aircraft while providing an expeditious flow of air traffic. During the final phase they will have to demonstrate their ability to operate both safely and efficiently over a longer period of time. This is called the ‘consolidation phase’. Once this phase is completed, the student is regarded to be sufficiently familiar with air traffic control operations.

Even after becoming an air traffic controller training remains essential. Procedures, regulations and systems change which means that air traffic controllers will also need to be trained accordingly. In addition, regulations and ISO standards demand the competency of air traffic controllers to be regularly tested. At LVNL so called ‘assessors’ periodically observe air traffic controllers during their work without prior notification. In case there are any competencies that need to be improved, the air traffic controller will do a ‘refreshment training’ to get up to speed.

In summary, training plays a pivotal role in routinizing controllers in air traffic control operations. Almost all controllers specifically mentioned that training is helpful since it is something to fall back on. Training also harmonizes the operational response. At the FIC, for instance, there are no separation criteria to hold on to. Whether to give a pilot in uncontrolled airspace information about approaching aircraft at a distance of 5, 10 or 20 miles is disputable. During training, however, senior controllers pass on their best practices to the junior ones. In this way training fosters a kind of “path dependency” (Guy Peters, 2012, p. 20) by making sure routine practices persist through generations of air traffic controllers.

Although routine practices provide stable proxies for operating in stable conditions, they are not all covered in standard operating procedures. In fact, as a fifth finding, professional routines allow air traffic controllers to combine safety with efficiency and environment whereas the standard procedures can constrain that ability. For example, the standard procedure prescribes area control to clear pilots up to flight level 245. To cater for more efficiency, area control professionally coordinates with controllers from upper area control at Maastricht (MUAC) that they clear outbound flights to flight level 250. By allowing pilots to climb to flight level 250 as soon as possible the airlines are able to save costs because at a higher altitude planes consume less fuel.

Another example is the instruction of area controllers to pilots to fly a ‘direct’ if weather conditions are stable and air traffic volumes are low. A ‘direct’ means that pilots can directly head for a specific point in airspace, such as Schiphol or a nearby waypoint. In this case they do not have to follow the standard arrival or departure routes, saving pilots a couple of minutes. This means aircraft have to use less fuel and may arrive more quickly at their destinations.

A sixth characteristic of air traffic control in stable conditions is the operators’ dedication to expect the unexpected. One of the controllers explained that “Assumption is the mother of all screw ups. Taking things for granted is very dangerous. Of course you assume and anticipate, but you have to constantly check whether an aircraft is doing what it is supposed to be doing” (R1). At tower control, for example, runway controllers regard every landing as a potential go-around.

They never assume the aircraft will land until it actually does. Instead, they check whether the aircraft will not conflict with departing and arriving traffic at other runways in order to assure a safe go-around when needed.

Also at area control people are on the lookout for unplanned circumstances. In one situation a controller, for instance, managed to separate a military aircraft that was inbound for Eindhoven Airport from a China Freight plane that was outbound Schiphol because he kept monitoring heading, altitude and speed of the Chinese freight plane. The controller found that the China Freight didn't climb as quickly as planned. The controller explains: "What you observed was that I first gave the Royal Dutch Airforce aircraft a heading of 195. But I saw that the China Freight was climbing so poorly. I had to give the military aircraft a different heading of 180 to create more horizontal separation else it would get too close" (R1).

The examples show how air traffic controllers are constantly checking the effects of their initial decisions and how they do not and cannot take their assumptions for granted. Air traffic controllers explained that it is particularly important to search for potential interruptions when there is not much traffic. Especially when there is not much to pay attention to, there is a human tendency to become negligent. An air traffic controller explained that in such circumstances "it is essential to trigger yourself and keep paying attention" (R8). In a similar vein, a supervisor argued: "The general idea is that the risky moments are those in which conditions change from intense to calm. So, as a supervisor, it is important to make sure that controllers don't get too busy or too relax." (R5).

Although the term 'supervisor' implies a hierarchical relationship with air traffic controllers, a seventh finding is that air traffic controllers have a decentralized authority to determine their course of action. The supervisor at area control determines what airspace is used, where air traffic controllers are seated and what air traffic capacity will be. The air traffic controller, however, can autonomously decide at what heading, speed and altitude a pilot needs to fly. During certain and slack time conditions hardly any prior consultation with the supervisor is needed, except when a controller wants to take a break or switch position with someone else. A supervisor described his tasks as: "They – [i.e. air traffic controllers] – are very good at controlling air traffic so I let them do their job themselves. I only create the circumstances in which they are able to do their jobs well" (R5). Another supervisor similarly concluded that a supervisor "facilitates and coordinates" (R3).

During my observations supervisors regularly walked around, brought some coffee, asked how everyone was doing, informed controllers about upcoming traffic and coordinated with the other supervisors. All interviewed supervisors emphasized the importance of being in touch with the controllers on the work floor. "You just try to keep a good relation with air traffic controllers. […] It improves the control room's atmosphere" (R2)

The fact that all supervisors are also controllers makes the relationship between a controller and supervisor even more equal. At approach control and tower control the supervisor is both supervisor and air traffic controller during the same shift. At area control some of the air traffic controllers can be radar controller or planner one day and supervisor the next. This means that all supervisors are regularly subordinate to those whom they supervise. Such collegial relationship doesn't mean, however, that supervisors are easily overruled. On the contrary, air traffic controllers know that the supervisor plays a pivotal role in helping them do their job and respect his or her responsibilities. Moreover, everyone understands that the supervisor today may be your planner or assistant tomorrow. The strong reciprocity and interdependency leaves little reason to frustrate such relations.

In summary, in the bureaucratic mode eight main mechanisms were found that characterized the operational response of air traffic control at LVNL.

1. Monitoring and anticipating potential interruptions;
2. Designing highly redundant technological systems;
3. Adjusting to minor interruptions based on professional skill;
4. Routinizing controller practices through extensive on the job training;
5. Employing professional routines to enhance safety, efficiency and environmental goals;
6. Expecting unexpected events;
7. Decentralization of decision-making authority to air traffic controllers.

6.2.1 Discussion

The findings at LVNL indicate a couple of issues that conflict with the theoretical assumptions about HROs in stable conditions.

Table 3: Managing Reliability in the Bureaucratic Mode

Bureaucratic Mode Characteristics	Findings
➢ Organizational efforts aimed at anticipating and precluding a set of core events. ➢ Emphasis on operators' compliance with rules and standard operating procedures. ➢ Operators are trained and socialized as highly technical competent experts. ➢ A culture of scepticism and suspicion. ➢ Extensive resources and redundancies.	➢ Monitoring and anticipating potential interruptions; ➢ Designing highly redundant technological systems; ➢ Adjusting to minor interruptions based on professional skill; ➢ Routinizing controller practices through extensive on the job training; ➢ Employing professional routines to enhance safety, efficiency and environmental goals; ➢ Expecting unexpected events; ➢ Decentralization of decision-making authority to air traffic controllers.

First of all, the ability to combine safety with other values, such as efficiency, requires air traffic controllers to employ professional routines. Air traffic controllers have an exceptional ability, based on thorough training and experience, to adjust operations and accommodate traffic in efficient ways. This seems to defy the bureaucratic assumption that human behaviour is by definition a liability to the system that should be constrained by rules and supervision as much as possible. In fact, the case of LVNL shows that it is precisely the professional ability of humans that enables the attainment of both safety and efficiency in stable conditions.

Secondly, discretion and autonomy of controllers is mainly constrained by rules and procedures, but not by hierarchical intervention. The supervisor facilitates and hardly ever orders air traffic controllers to do something. This observation is at odds with the argument of HRO theorists that in stable conditions relationships are bureaucratic and hierarchical (La Porte & Consolini, 1991). The emphasis on professional skill at LVNL explains why decision making needs to be decentralized, whereas in a bureaucratic organization such human discretion is unwanted.

Despite these contrasts, the air traffic control operations do correspond with five out of seven HRO characteristics one would expect in a bureaucratic mode. For one, there is a shared understanding among air traffic controllers about what constitutes safety. Maintaining separation of aircraft is deemed by all controllers to be their primary responsibility. Secondly, there are numerous systems that help supervisors and controllers anticipate the flow of traffic and weather in order to prevent traffic overload or bad weather to surprise controllers. Activities in the control room are aimed at preventing uncertainty or time pressure which could overwhelm operators. Thirdly, radars, communication systems and other vital technologies are designed in a highly redundant fashion, making sure that a break-down does not immediately cause control room panic. Redundancy fosters certainty by providing a margin for technological disruption. Fourthly, to become an air traffic controller one has to pass extensive and extreme training. The training functions as an important means for air traffic controllers to routinize and harmonize operational practices. Fifthly, air traffic controllers are aware of possible culprits in the operation. They understand that unexpected events can quickly materialize and are reluctant to take things for granted. This correlates with the 'culture of scepticism and suspicion' which was found in most HROs operating in stable conditions.

In summary, the HRO theory provides a plausible explanation for why organizations in stable conditions are able to enhance reliability. However, the case study also shows that HRO theory does not explain the professional and decentralized operation in which controllers deliver a safe, efficient and environmental friendly performance in stable conditions.

6.3 High Velocity Operations

During high velocity operations air traffic controllers are confronted with time. In such conditions the workload of air traffic controllers increases. There are multiple reasons why time pressure occurs. Traffic volumes can become high, complex traffic can lead to more conflicting movements, bad weather can constrain the available airspace to manoeuvre in, technological systems can be temporarily unavailable or the required runways, taxiways or gates may be out of order.

A number of characteristics are derived from the interviews with air traffic controllers and from the observations inside the control room. First of all, the operational response falls back on the standard and fixed operating procedures. Alternative practices to gain more efficiency are not encouraged. The standard routes and procedures provide a helpful and consistent tool for coordination of controller practices. In this way everyone is 'on the same page' which makes operations more predictable. The following abstract from one of the interviews is illustrative:

"With a lot of traffic during an inbound peak it becomes very busy. You need to get your priorities straight and work harder. In such situations air traffic control operations change. [...] It transforms from to tighter and more stringent operations. When there isn't much traffic pilots can keep their own speed and I keep checking everything. But the busier it gets the less aircraft can be attended to simultaneously. In that case you have to secure separation in such a way that you know the aircraft are OK, even when you are not able to pay attention to them for some time. [...] So what happens is that you organize operations in a more fixed way. For instance, you stick to the standard routes. These standard routes are made for keeping inbound and outbound flights separated. You don't instruct pilots to fly a 'direct' because that creates new conflicts. That is something you want to avoid. You want to have as few conflicts as possible because it is so busy. The standard routes provide certainty. Based on the standard routes you know where the potential conflicts between aircraft are going to be. Also in standard routes there are points where flights meet, but at these routes it is known where these conflicts are located." (R5)

The abstract tells us that a fixed structure helps air traffic controllers make better sense of the situation in time pressured conditions. The standardization of conflicts supports the controller in allocating his/her limited span of attention. It simplifies the complex operational picture.

However, it must be noted that some procedures also constrain the ability of operators to deal with high amounts of traffic in tense conditions. Environmental regulations, for instance, require air traffic controllers to follow strict procedures regarding the use of routes and runways. Tower control is allowed to use only two departure runways and one arrival runway during outbound peaks, and two arrival runways and one departure runway in inbound peaks. This is called a 2+1 runway use. Only when the inbound and outbound peaks overlap, tower control can temporarily decide to use a 2+2 combination to accommodate traffic. This should be seen as an exception to the rule. But with vast amounts of traffic in high velocity operations a fourth runway can be welcome or necessary resource. A controller commented that "environmental regulations determine that some runways cannot be used or that aircraft are not allowed to fly in specific areas. This constrains the physical space in which aircraft are able to manoeuvre." (R7). In other words, the regulations provide air traffic controllers with less space to safely accommodate traffic in time pressured conditions.

A second important characteristic of the operational response is the use of buffers to compensate for the compression of time. Extra resources in terms of airspace and personnel are applied in order to regain more time and stable workload. The interviews and observations provide numerous examples. One of the first responses of radar controllers at area control is to use more airspace in order to increase the separation between aircraft. A controller explains: "You are going to use more rough solutions. You are not going to separate aircraft at exactly 5 mile, but you take more margin to create time to think and decide on the next steps" (R2). By heading, speed and altitude instructions controllers establish more space between aircraft to allow themselves some time to control the situation.

Once the air routes become too saturated, air traffic controllers and the supervisor at area control can additionally decide to use the holdings. A holding is a waiting area. Near every IAF there is a holding. When aircraft are put in the holding they have to fly one or more rounds in the waiting area before they can make their approach to Schiphol. Airspace can become saturated once there are a limited amount of runways that can be used due to, for instance, strong winds from an undesirable direction, snow or foggy conditions. Bad weather such as thunderstorms can also limit the available airspace in the TMA. In all cases, the amount of traffic exceeds the available capacity at the airport or air routes. In such circumstances, area control directs inbound traffic to the holdings to wait until routes and runways become available. The next figure gives an indication of what holding looks like. It shows what happened on the 6th of November 2014 when Schiphol was experiencing severe fog.

Figure 15: Holding patterns during fog at Schiphol 06-11-2014

Since holding requires a lot of work, the area control supervisor is able to split up a CTA sector over more air traffic controllers. This is usually done when the supervisor expects traffic volume or the complexity of air traffic to impact the workload of the air traffic controller on duty in that sector. There is always an air traffic controller on stand-by in or near the control room to assist when situations get more tense. In addition, when traffic is put in the holding the supervisor can also assign a specific stack controller. This is a controller that only controls the flights in the holding. In this way the radar controller for that particular CTA sector can focus on separating and sequencing inbound, outbound and other traffic.

In addition to using the holdings and back-up personnel, the supervisor and his assistant at area control are also able to restrict inbound traffic. When this happens, the assistant-supervisor passes these restrictions on to the Network Manager at EUROCONTROL who is responsible for managing the air traffic flow across Europe. As a consequence, the network manager adjusts the slot times of departing flights from other airports in Europe to Schiphol. This means that, for instance, fog at Schiphol can cause delay for departing flights at Heathrow. Yet, by doing this the supervisor makes sure that the supply of traffic for Dutch airspace remains manageable for air traffic controllers.

In tower control operations there are similar buffer techniques. The start-up controller or assistant controller can, for instance, decide to start up less aircraft to create more space for ground, runway and approach controllers. Moreover, the tower supervisor and approach supervisor can decide to use a different runway combination when for instance winds make specific runways unavailable. In this way they are still able to provide as much capacity as possible at Schiphol under differing weather conditions. The unused runways can also be employed by ground control to park aircraft when all gates at Schiphol are occupied. In this way the taxiways remain available for getting outbound traffic to the runways. In short, air traffic controllers in pressure conditions use buffers of (air)space and personnel in order to reduce the time pressure.

A third finding about high velocity operations is that air traffic control training involves preparing for situations with heavy time pressure. The training not only focuses on stable conditions in which operators are expected to perform safely and efficiently. A training expert at LVNL explains that in the training controllers are confronted with complex and pressuring situations that will probably never occur in real time. “Air traffic controllers are actually trained more than they will normally need. They are trained at 120% while they need 70% to work on a normal day. But you will need to have experience with extreme situations to know what you can be up against. In simulators these situations can be realistically trained” (R19).

During an observation an air traffic controller acknowledged these claims about the training. “You are trained for the most extreme situations. Those situations almost never happen and in 95% of the time you won’t need the ability to cope with them, but it is the 5% that matters when you want to become an air traffic controller” (R5). All the responses, such as holding, restrictions, personnel buffers, runway changes, etc., are all thoroughly trained so controllers know what to do in these circumstances. One of the air traffic control trainers mentioned that “during training a trainer always asks the student controller to come up with more alternative solutions for the problem he is facing. ‘What more can you do? If this or that will happen, what will your next response be?’. In this way you become prepared for a wide variety of circumstances” (R9). When speaking to air traffic controllers all these practices are considered remarkably ‘normal’ or ‘routine’. When asked how air traffic controllers cope with heavy fog, a controller replied: “To me it is clear what I have to do. I will need to put aircraft into the holding. That is predictable” (R1). A supervisor later confirmed the controller’s story. He said: “You only have to tell an air traffic controller ‘We are going to hold’ and they switch to a holding scenario” (R5). In short, training is an essential preparation for coping with pressure situations.

Fourthly, the operations during time pressured conditions are similar to stable conditions in that both involve a decentralized authority structure. In fact, during high velocity operations the supervisor is even more inclined to let air traffic controllers at ease so they are able to deal with the high pressure. “When it is very busy I will leave them alone and make sure it won’t get too busy for them” (R5) said a supervisor. Another supervisor confirmed that “the controllers can do it themselves. Their decisions do not have to be approved by a supervisor. They assess themselves where aircraft need to go to. Nobody has to tell them how to do that” (R3).

Different from the bureaucratic mode, however, is that the pressure during high velocity operations alters the atmosphere in the control room in a number of ways. The first is that area control and approach control operations become predominated by a peaceful calm. The social talks, which are possible in stable conditions, stop immediately when things get tense. People who have no role in the operational process retreat to the background. Controllers are focussed and communicate in a directive, selective and formal way. After a very busy period a controller explained that under such high pressure conditions “there is no time for pleasantries and courtesies” (R4). The same happens in the tower control room. But since the tower control room is much smaller than the radar control room, it can still get pretty hectic. In both control rooms you can feel and sense when situations get tense.

A second change is that communications between the different controllers in the control rooms intensify. There is more collaboration between, for instance, the radar controller and planner at area control. The planner anticipates the upcoming traffic for the radar controller and cross-checks his decisions. There is constant feedback and negotiations to coordinate activities. Most of the interviewed air traffic controller stated that such intense collaboration in the heat of the moment is fostered by a strong mutual trust among colleagues. “Air traffic controllers want to know whether the person that is sitting next to them can be trusted to do the right thing. […] I trust all my colleagues and try to render that feeling of trust to my colleagues” (R10). Especially in time pressured conditions there is not much time to discuss with each other what to do.

Trusting on each other's decisions becomes even more important. After an exceptionally busy inbound peak the air traffic controller described the collaborations as follows:

"I didn't even negotiate with the controller next to me what to do. I just followed his lead. That just happens. […] Subconsciously, you know how your colleagues work. For every colleague I have a general conception of how he or she works. I can hardly explain it. […] I trust my colleagues blindly. If we decide 'I follow you' than I don't bother to take a second look, so to speak." (R2)

The fact that air traffic controllers have to pass an intense training program is one of the reasons for that strong mutual trust. Once an air traffic controller passed the training he has proven to be able to work in extreme conditions. "Once you passed all exams you must be able to do the job" (R10) a controller said.

In sum, during high velocity operations a couple of mechanisms are found to characterize the operational response.

1. Falling back on standard safety procedures
2. Using buffer capacity in (air)space and personnel to restore time
3. Employing responses based on trained high pressure events
4. Decentralization of decision-making authority to air traffic controllers with:
    a. Directive, formal and selective communications
    b. Collaboration based on strong mutual trust

6.3.1 Discussion

Considering the operation of air traffic control in emergency conditions, it is apparent that the case study supports the hypotheses.

Table 4: Managing Reliability in the High Velocity mode

Hypotheses	Findings
H1: In the high velocity mode the operational response is structured according to a pre-programmed set of practices, such as emergency protocols. H2: In the high velocity mode the operational response relies on experiences with similar emergencies and trained emergency simulations. H3: In the high velocity mode the operational response is characterized by a decentralization of authority on the basis of expertise and skill. H4: In the high velocity mode the operational response involves the use of personnel redundancies to compensate for the reduction of slack time.	➢ Falling back on standard safety procedures ➢ Employing responses based on trained high pressure events ➢ Decentralization of decision-making authority to air traffic controllers with: a) Directive, formal and selective communications b) Collaboration based on strong mutual trust ➢ Using buffer capacity in (air)space and personnel to restore time

First of all, hypothesis I holds that the response is expected to be structured according to a set of pre-programmed practices. The findings show, indeed, that air traffic controllers fall back on predetermined standard operation procedures, such as standard routes. While under stable conditions more efficient or environmentally friendly alternatives are professionally derived, in time pressured conditions the standard routes help to sustain safe operations. Also, methods such as holding, restrictions or using different runway combinations are all part of the pre-programmed repertoire of air traffic controllers to deal with high traffic load, bad weather or any other form of time compression.

It is important to remark there are different types of standard procedures. Air traffic control operations illustrate that environmental procedures, such as preferential runway use, can constrain the controllers' abilities to ensure the safety of air traffic in pressure conditions. The merits of regulations and procedures therefore depend on their effectiveness in varying circumstances.

Based on hypothesis II, we would expect the operational decisions to rely on experiences with similar emergencies and trained simulations. Observations at air traffic control support this expectation. During training controllers are exposed to very stressful conditions that may never come to pass in real time operations. The extensive training of air traffic controllers requires a cognitive capacity that exceeds the capacity needed for operating in stable conditions. The training functions as a mechanism for routinizing air traffic control responses in conditions of time pressure. Training establishes a useful repertoire of responses that enables a swift and coordinated response.

Hypothesis III indicates that response is expected to be characterized by a decentralization of authority on the basis of expertise and skill. The findings tell us that high velocity operations are indeed decentralized. Air traffic controllers remain responsible for the safety of air traffic and the supervisor hardly interferes directly with the operation. This is not any different from what is observed in the bureaucratic mode. What is different, however, is the way controllers coordinate their responses. The collegial interactions among controllers intensify, and at the same time transform to very formal relations with direct and selective communications.

The findings also indicate that the decentralized decision-making with tight collegial coordination is based on high levels of trust among controllers. Mutual trust is regarded as an invisible glue that ensures the effectiveness of a collegial cooperation. The fact that all controllers passed the same intense training was argued to be an important reason why people trust each other. Besides the idea that training is important for socializing and harmonizing operational conduct (Weick, 1987), the issue of collegial trust is not particularly embedded in literature on high reliability organizations. The role of collegial trust in time pressured conditions might, therefore, be an interesting topic for future research.

Hypothesis IV suggests that the compression of time can be offset by using redundancy in personnel. Control room practices indicate that during high velocity operations back-up personnel is employed to split up air traffic. In this way workload is allocated over more controllers which reduces the pressure on individual controllers. This implies the hypothesis is plausible, and extra manpower can help restore operations to stable conditions.

In addition, the findings imply that personnel is not the only resource that can reduce time pressure. Extra airspace or space on the ground can also be applied to allow controllers more time in their dealings. Holding aircraft or using runways for parking aircraft are probably the most vivid examples. This observation suggests that a compression of time may be offset by employing other resources. The type of resources does not have to limited to personnel. Other resources can have the same effect, as the example of space indicates.

6.4 Innovative Operations

Apart from the stable and time pressured conditions, air traffic control operations is also subject to uncertainties that require innovative practices. There is a tremendous amount of procedural and systemic changes that are implemented in the control operations on a daily basis. All these changes are either a response to the dynamic institutional environment with new stakeholder requirements (external) or to assessments of air traffic control operations (internal). Both external and internal origins of change stem from uncertainty. It is uncertain whether the current state of the air traffic management system will provide the necessary services and benefits in the future. The system will need to develop into a new state in order to undo these uncertainties.

At LVNL there are numerous examples of change processes that are initiated because of external demands. Some examples of externally driven changes are: the development of a Single European Sky, the integration of civil air traffic control with military air traffic control, the adjustment of air traffic control procedures due to bigger airplanes such as the Airbus A380, a new air route structure in response to the development of Lelystad Airport, the development of a fourth initial approach fix (IAF) and the preferential runway usage because of environmental regulation.

At the same time there are also many innovative practices that originate from the operations itself. Air traffic controllers file around 8000 reports a year in which they address operational situations that were out of the ordinary, unclear or unusual. These reports are checked and analysed every day by the Operational Support & Development (OSD) department to assess whether adjustments in procedures or systems are needed.

In addition, the Performance department monitors the service delivery performance of air traffic controllers. When, for instance, safety related occurrences – e.g. separation infringements and runway incursions – happen, this department starts an internal investigation. A group of safety experts analyses what happened during the event, determines the risks in the operation and gives advice on what change is needed to prevent such occurrences in the future. This process is called the 'Basic Safety Loop' at LVNL. Both the operational reports at OSD and the outcomes of the Basic Safety Loop can trigger changes to control room operations.

Based on the Basic Safety Loop LVNL, for instance, initiated a program to review and rewrite the Operations Manual for air traffic controllers Investigations by LVNLindicated it is important to clarify what procedures need to be enforced and what procedures serve as guidelines in the operational process.. In this way ambiguity in control operations can be minimized.

Considering the operational response in innovative conditions, a first important finding is that innovation at LVNL is characterized by a structured change process that is predominantly organized outside the control room. The change process is disentangled from the process of air traffic service delivery. A controller indicates: "the change process happens behind the scenes. It doesn't affect me until I need to partake in a test or when I hear on duty that there is a new system" (R8).

Once external demands or internal analyses call for a change of air traffic control operations, a request for the change is first submitted to a strategic consultative body consisting of representatives from different departments. The goal is to advise the management team of LVNL on what changes to the air traffic management system (ATM)– i.e. operator, procedure and/or technology – are desirable and what needs priority. The management team of LVNL subsequently decides on the ATM change in the spirit of LVNL's corporate vision and strategy. If the change is approved, a so called 'Study Team' is appointed to suggest a design of the new ATM system. They test multiple alternative solutions to determine which is best. Once the design is finished and approved, a multidisciplinary 'Integrated Product Team' is going to focus on the further development and implementation of the change.

Both the Study Team and the Integrated Product Team perform multiple analyses with regard to the effects of the change on the performance of air traffic control operations. These analyses are called VEMERs – i.e. Safety, Efficiency and Environmental Effect Reports. If the new design meets the stakeholder requirements and doesn't negatively affect performance, the change is assessed by Operational Support & Development. They approve or decline the proposed change based on the operational requirements. OSD checks whether the new procedure or system is practically useable, clear and well considered.

If the change is approved, the implementation of the change into the daily operations of the control room is guided by a transition plan. The plan stipulates the consequences for the air traffic controllers to safely implement the change. Air traffic controllers will, for instance, need extra training to get used to the changes in the system. Additionally, big changes are often accompanied with preventive capacity reductions to allow air traffic controllers more time to get used to the working of the new system. An air traffic controllers explains: "When there is a big system change the capacity will be lower than 65 inbounds an hour like we've seen today. There will be a reasonable chance that it will decrease to 45 inbounds to leave enough time to think about what has changed. Step by step the capacity will be increased" (R3). Once the change is implemented, the new solution is again monitored by analysing operational reports and performance.

The benefit of a disentangled change process is that the delivery process is able to continue without direct outside interference. Staff personnel explains that the change process is designed to bring change to the system in "a dosed and structured way" (R12; R17). Air traffic controller can continue routine operations undisturbed while new solutions are negotiated, tested and trained. It ensures the stability of the day to day operations in the control room. A staff employee stated that "it is our duty to prevent the control room from experiencing surprises" (R17). This is also what air traffic controllers expect from the departments of LVNL that manage these changes. One of them argued: "I expect that changes in the procedures are well managed and introduced. I expect that new air traffic controllers are well trained. Actually, I expect them to make sure everything is arranged so we can do our job" (R2).

A second finding is that the organization of the change process functions as a buffer to protect against impulsive and quick-and-dirty changes to the service delivery process. The change process is organized in different stages. For each stage formal approval is needed before the change can be further developed and implemented. Both controllers and staff personnel, for instance, perceive the management team's decisions to be an important "first line of defence" (R13; R12). At the strategic level the management of LVNL is expected to regulate the external requirements and internal wishes in order to prevent an overload of system changes. "Leadership is important to remain resistant to changes that the system is not able to accommodate" (R15). These strategic decisions are deemed essential for keeping priorities straight and enhancing enough resources – e.g. personnel, financial means, etc. – to nurture an effective change process.

The Operational Support & Development department can be regarded as a 'second line of defence'. This department needs to formally approve a change from an operational point of view. Before a change can be implemented, it needs to be assessed by Operational Experts (OEs) who are air traffic controllers themselves. They need to formally endow the change before it can be implemented. The Operational Experts function as gatekeepers between the primary service delivery process and change process. They assess changes from an operator's point of view. For LVNL it is important to make sure that the changes are useful and manageable by the front-line air traffic controllers. The acceptance of the innovation by the Operations department is an important and essential step in the change process.

Based on the second finding, a third observation is the process of decentralization in the innovation mode. Decisions on whether to initiate a change are first subject to a centralized management team. The changes need to be negotiated with external stakeholders and require substantial investments that need to be accounted for by the management team to air traffic control users. But once the change has been initiated, decision making authority is gradually decentralized. First experts from different departments are allocated resources and authority to decide on how to design the new system. In the Study Team and Change Team they coordinate their efforts. Once there is a change proposal, it is in the end the air traffic controllers that must approve the change before it can be implemented. In other words, the decision to innovate the air traffic management system migrates from a centralized to a decentralized authority during the change process.

Although it seems like the air traffic controllers are at the end of the line in the decision making process, a fourth finding is that the operational perspective of air traffic controllers is embedded in all hierarchical levels and meetings of LVNL. In the management of LVNL the CEO is a former air traffic controller and the Director Operations still is an air traffic controller himself. Also in all other departments air traffic controllers are found. A group of dedicated controllers function as Operational Experts (OEs) in these departments to give an operational perspective on specific elements of the air traffic management system. The Operational Experts are led by the Core Team Supervisors (LKTS). All OEs and LKTS come together every few weeks to coordinate activities and establish a shared operational perspective with regard to changes in the ATM system. The OEs and LKTS are the "operational tentacles" (R12) in the organization of LVNL. By embedding the operational perspective throughout the change process the gap between the disentangled service delivery process and change process is bridged.

The Operational Experts and Core Team Supervisors also function as linking pins between 'the office' and 'the control room'. At the office people perform different day-to-day activities than air traffic controllers. . "Air traffic controllers are trained to first act and evaluate the decisions afterwards. If it wasn't a good decision, a new decision is made. That is how it works. Outside the control room this works differently. As an air traffic controller you are educated to think in terms of black and white, but at the office you are asked to think in terms of grey, to nuance and negotiate decisions. That is contrary to the work we do every day" (R2). Operational Experts contribute to combining the different perspectives in a useful and coherent innovation . As an Operational Expert argued: "We have to do it together. […] As air traffic controllers we need to understand the interests of people at the office. We are all important in the process" (R5).

As a fifth finding, the change process is characterized by an incremental trial-and-error process in an experimental environment. The goal of this strategy is to establish a trial-without-error operation in the real operating environment. Positive outcomes of simulated trials function as prior guarantees for implementing the change safely in the real operation. "Everything that is implemented is well considered. It's not like 'Let's try something new and see what happens'. These decisions do not happen overnight" (R3). For every change to the ATM system the consequences for safety are thoroughly analysed before implementation. Safety performance is analysed by measuring the probability of air traffic control related accidents and incidents. These probabilities are compared to the safety norms, which are derived from an analysis of global accident probabilities in aviation. If the accident probability in the Netherlands stays below the global norm, performance is regarded safe.

However, when implementing a change in the ATM system the past performance provides no reliable indicator for the safety of the new system because the past performance is based on the operation of the old system. A staff employee, for instance, explains: "We want to implement digital flight strips in tower control. [Flight strips show the flight information of the aircraft that are under control. Currently at tower control, these are physical strips.] How are we to measure the effect of that change? We don't have any data on accidents that are caused by the use of digital flight strips. Even if it were possible in the first place to determine the causality between the accidents and the use of digital flight strips, such events have not yet occurred and cannot be analysed" (R15).

As a consequence, a lot of the safety cases are based on expert judgment by air traffic controllers. In teams air traffic controllers and safety experts think off all possible hazards and scenarios that may result from the change. This is done from a conservative point of view. The motto is "If you don't have a clue whether the hazard is probable, you need to think the probability is 100%. If trials prove otherwise, you adjust the range. As such, you leave a trail of margin" (R15). Different methods, such as the Tripod, Bow-tie and hazard analysis, are used to structure that conduct.

Subsequently, the innovation is tried in a simulated environment by air traffic controllers. The controllers' experiences and practices are reviewed and analysed. Based on this data, the initial (conservative) hazard assumptions or the design of the new system is adjusted. "This is the method that is most often used to assess the safety consequences of system changes. That's also part of safety." (R15). Only if there is a shared belief among all safety experts, including the air traffic controllers, that it is sufficiently safe, the change is approved. Else additional trials are conducted to come to a solution that the experts and air traffic controllers are convinced of.

In conclusion, a number of mechanisms are identified in innovative operations that characterize the operational response.

1. Disentangling the service delivery process from a highly structured change process;
2. Buffering the demand for change by formal 'lines of defence' in the decision making process;
3. Migrating the decision to innovate from a centralized authority to a decentralized authority during the change process;
4. Embedding the operator's perspective in all the hierarchical levels and departments of the organization;
5. Using a conservative trial-and-error strategy in a simulated environment to gain more certainty about the effects of the innovation before it gets implemented.

6.4.1 Discussion

The findings of air traffic control operations in innovative conditions have different implications for the plausibility of the hypotheses. One by one, the hypotheses will be discussed in light of the results.

Table 5: Managing Reliability in the Innovative Mode

Hypotheses	Findings
H5: In innovation mode the operational response resembles an incremental trial-and-error process. H6: In the innovation mode the operational response is characterized by a decentralization of authority. H7: In the innovation mode the operational response is shaped by a heterogeneous set of organizational members. H8: In the innovation mode the operational response characterized by a lack of formal structures. H9: In the innovation mode the operational response is based on values of uncertainty acceptance and receptivity to change.	➢ Disentangling the service delivery process from a highly structured change process; ➢ Buffering the demand for change by formal 'lines of defence' in the decision making process; ➢ Migrating the decision to innovate from a centralized authority to a decentralized authority during the change process; ➢ Embedding the operator's perspective in all the hierarchical levels and departments of the organization; ➢ Using an incremental trial-and-error strategy in a simulated environment to gain more certainty about the effects of the innovation before it gets implemented.

Hypothesis V is partly supported by the results from the case study analysis. The change process at LVNL is characterized by extensive incremental trial-and-error processes. Initial designs of the new air traffic management system are considered, simulated, evaluated and redesigned. This observation is in line with what is expected from theory on innovation. An additional finding is that most of this trial-and-error process is based on expert judgments because doing something new makes it hard, if not impossible, to derive conclusions from past experiences. By trying well considered innovations in simulated settings, experiences are gained which can be used for deriving certainty about the effects of the innovation. However, the findings also show that this trial-and-error process is uncoupled from the air service delivery process. The innovation process occurs parallel to the actual control operations in order to prevent the uncertainty of new trials to creep into the stable operations of the control room. Only after the trial-and-error process has resulted in enough evidence to support the safe use of the new procedure or technology, the system will be changed. In other words, the change will only be tried in the control room once there are enough prior guarantees that errors will not occur.

This result has two implications. On the one hand, the findings suggest that HRO theory is right in arguing that the operational response is characterized by trial-without-error. Change in the primary operational process is resisted until avoidance of error is warranted. On the other hand, the trial-and-error process and the trial-without-error process are not mutually exclusive. These are able to coexist in parallel processes. In this way the trial-and-error process can generate the guarantees needed to implement the change according to the trial-without-error philosophy.

Hypothesis VI is supported by the findings. The innovation process at LVNL shows that the decision making is first centralized and becomes decentralized. The decision to initiate changes to the air traffic management system are first made by the management team. During the change process the decisions on continuing and implementing the change migrate down the organization to the air traffic controllers. Operators have the last call on the implementation. Combined with embedding the operational perspective at all levels of the organization, this mechanism gives air traffic controllers ownership and responsibility for ensuring a safe implementation of the change. This supports the hypothesis that decentralization leads to increasing awareness and involvement of organizational members.

An implication of this result is that a distinction has to be made between *decentralizing* decision making (process) and *decentralized* decision making (fixed state). During innovative conditions decisions were first made by a central authority and later migrated to a decentralized authority. The shift is what characterizes the process of decentralization. This is different from decision making in stable and pressure conditions. In these conditions decision making remained decentralized throughout the operational process. Decision making authority in innovative conditions is not localized or fixed but it moves through the organization.

Hypothesis VII seems to be supported by the finding that the change process at LVNL involves a more diverse set of departments, functionaries and central authorities than is the case during stable and pressure conditions. Air traffic controllers argued they need to cooperate with personnel from other departments to effectively implement innovations. The Study Team and Change Team consists of a diverse set of people including air traffic controllers. This diversity fosters a broader knowledge base providing more nuanced and well considered solutions.

Although it was hypothesized that heterogeneity nurtures a constructive process in which conflicting views are critically discussed, the findings also suggest that heterogeneity may make it difficult to come to shared solutions. It means people need to set aside their own world views in order to come to terms with one another. Air traffic controllers indicate that this can be difficult if perspectives differ wildly. This implies that heterogeneous groups also induce the risk of not reaching a shared understanding of what needs to be done.

Interestingly, hypothesis VIII is not supported by the findings from the case study. The change process at LVNL involves a rational process with numerous formally prescribed analyses and checkpoints. The change process is highly structured and prescribes a consistent set of practices in order to arrive at a tolerable change to the air traffic management system. Moreover, different people at LVNL argued that these formalities are helpful as 'lines of defence' against impulsive and reckless changes to the air traffic management system. They provide preventive mechanisms against potentially unsafe changes to the primary service delivery process.

This implies that a formal structure can actually serve as a contributor to enhancing reliability in innovative conditions. Not every demand for innovation can be accommodated by the operational system. The formal structure may be a useful mechanism in innovative conditions to ward off, or temporarily stop, changes in order to make sure that operations remain stable and do not become overly complex.

Last but not least, hypothesis IX is also supported. The fact that LVNL has a distinct change process is an indicator by itself that people are aware of the need for change in order to cope with the uncertainty of dynamic organizational environments. LVNL invests in creating a climate in which air traffic controllers feel comfortable to report mistakes and out of the ordinary situations. The fact that 8000 reports a year are filed shows that operators are not shy to share their experiences with the rest of the organization. Air traffic controllers are aware that the system is not perfect and needs timely adjustments to be improved and stay reliable.

However, being receptive to change doesn't mean that LVNL welcomes every adjustment to air traffic management with open arms. The change process involves critical scrutiny before a new procedure or technology can be implemented. There seems to be a trade-off between being receptive to change and preventing changes to be implemented too easily.

6.5 Crisis Operations

Air traffic control operations sometimes involve crisis conditions. May Day calls in a busy inbound peak, a warning of the short term conflict alert system (STCA) about an imminent separation infringement, a severe degradation of technology or an aircraft crash are examples of highly tense situations. These events unravel unexpectedly and call for immediate action by air traffic controllers to contain the situation and return to stable routine operations.

The operational response in these circumstances is aimed at ensuring the safety of air traffic. In all 'out of the ordinary' circumstances the air traffic controllers are expected to use the ASSIST principle which stands for Acknowledge, Separate, Silence, Inform, Support and Time. The ASSSIST principles provides a guideline for structuring the response of air traffic controllers in crisis conditions. The principles suggest that air traffic controllers first need to make sure that the nature of the problem at hand is understood and acknowledged accordingly (Acknowledge). Secondly, they need to ensure the separation of aircraft (Separate) by giving aircraft instructions. One of the air traffic controller explains that in the event of a separation infringement "You immediately intervene because you want to keep that 3 mile separation" (R8). Ensuring the separation in these conditions involves critical decisions. Doing nothing is not an option. "In threatening situations you have never encountered before, you do not want to stop functioning. You do not want to sit still and think 'This is not happening'. You have to do something!" (R2).

First, air traffic controllers need to improvise to avert the threat and regain control over the situation. In the event of a separation infringement, the immediate intervention to separate aircraft may be enough to solve the situation but in the event of, for instance, a May Day call additional actions have to be performed to improvise a solution. In one of the interviews an air traffic controller described a situation in which he was confronted with a May Day call of an aircraft above the North Sea with the message of a potential bomb on board. The pilot wanted to return to Schiphol by staying as long as possible above sea at a high altitude. Once above land the pilot wanted to descent rapidly to Schiphol. The controller, who was on duty at that time, explained that this manoeuvre wasn't predetermined in procedures. Instead, it was improvised in that instance. "This solution wasn't described anywhere, although in hindsight it all seems pretty logical" (R5).

However, improvisation is not regarded by air traffic controllers as doing something unthoughtful. In different interviews controllers argued the ability to improvise an appropriate solution depends on having prior experience with similar crisis situations. These prior experiences do not prescribe the controller what to do, but instead provide a toolbox with potential solutions. A controllers explains: "You will encounter unexpected situations throughout your entire career. I have, however, developed so much experience that more situations look familiar. With every experience you develop a greater arsenal of solutions you can put to use in these new conditions. […] That is a process that takes place subconsciously" (R2). This suggests that improvisation is not doing something wildly different, but instead means choosing a course of action based on assumptions which are deduced from prior experiences.

Secondly, part of the operational response is aimed at decoupling the unexpected event from the continuation of other traffic. Air traffic controllers repeatedly emphasized the importance of making sure that all other traffic is safely controlled despite the unexpected problem. "You cannot focus too long on that specific event because else the rest of the traffic will not go as planned" (R5). Different actions are taken to isolate the critical case. The supervisor, for instance, can decide to use back up personnel to assign a specific controller to work on the May Day call. This allows other air traffic controllers to focus on the normal traffic. Another tool is the discrete emergency frequency (DEF). The DEF is a special frequency that can be assigned to the May Day call. The benefit is that there is enough radio time for other traffic to communicate. At the same time, the pilot who initiated the May Day isn't bothered by irrelevant conversations with other pilots. Another way to isolate the event, is to designate a special runway to the plane that is in trouble. A ground controller explains that in case of a May Day "they will try to give that aircraft a special runway, because if the aircraft would strand on the runway other traffic is of course not able to land on that runway" (R10). Isolating the event is similar to the method used in innovative conditions to separate the delivery process from the change process.

However, completely isolating the event from other traffic is not possible. Therefore, additional emergency responses are put in effect, such as holding traffic, restricting airspace capacity and changing runways in order to accommodate other traffic. The fact that, for instance, a May Day call gains precedence to land at Schiphol means that other traffic will have to wait. As with high velocity operations, this has consequences for efficiency. Safety, however, has the highest priority at that moment.

A third finding is that the operational response in crisis conditions is structured according to predetermined roles and responsibilities. In explaining the response to a May Day call of an aircraft with technical problems, a radar controller at area control argued "Everybody has got its own role. The radar controller keeps communicating with pilots. The planner sets everything through. If the pilot says something, I write it down and the planner taps in and may also write things down. In that way you can discuss it with each other. These roles are arranged and determined up front" (R1). The predetermined role patterns are helpful in providing a consistent and coordinated response. It prevents chaotic and unstable responses in the wake of critical conditions. An approach controller explained that "if you have made arrangements with each other, you are able to operate. If there is something unclear it would be very annoying. In that case one will go left and the other goes right so to speak. This makes it instable. You constantly search for stable traffic flows so everything is expected. […] so everything is predictable" (R8).

Not only for air traffic controllers, but also for supervisors and the rest of LVNL roles and responsibilities are predetermined. The supervisor at area control is assigned with the coordination of the operational response. In the event of a substantial disruption of control room operations, a strategic crisis team will get together to coordinate activities with external stakeholders, partner organizations and the media. The crisis team consists at least out LVNL board members, the Director Operations and management of LVNL, a crisis coordinator, a communications advisor and a secretary. At LVNL there is a fully equipped crisis room where the crisis team meets. There are detailed protocols that prescribe how these roles and responsibilities are assigned.

A fourth finding is that decision making is mainly decentralized, but becomes centralized at moments when strategic decisions have to be made or when coordination with other organizations has to take place. The basic idea is to keep the allocation of roles and responsibilities as close as possible to the organization in routine conditions. The primacy of decentralized decision making, and non-interference with operational conduct during crisis conditions, is important to allow controllers to fully focus on the problem at hand. A supervisor argues: "Air traffic controllers are best at controlling traffic. That's what needs to be done by them. The supervisor knows best how to coordinate in the control room so that's something that should be done by the supervisor. What happens outside the control room is important to know as a supervisor because you want to act in the spirit of LVNL. But its more than enough when they inform me about what happens. Based on that information I make my own operational plan. […] That is something that should not be interfered with" (R5). More air traffic controllers argued that there should be a distinction between operational decisions which are made by air traffic controllers and the supervisor, and strategic decisions made by the crisis team. The strategic decisions provide directions for the operational conduct, but should not stipulate what has to be done at the micro level. In the relation between the operations of air traffic controllers and the crisis team, the area control supervisor plays a pivotal role. The supervisor needs to translate the strategic decisions to operational decisions. Apart from LVNL, multiple actors and organisations become involved that all play a role in the containment of the event. Examples are the fire department, Schiphol airport, the airlines, adjacent centres, the Royal Dutch Airforce and the Royal Military Police. In other words, the supervisor becomes a critical information node in the crisis operation.

A fifth finding is, however, that the information channels to and from the supervisor do not emerge from the situation but are triggered by predetermined protocols. Based on the type of event that is encountered, the supervisor initiates calls to the relevant organizations to inform them about what is happening. Which organizations and actors are relevant is predefined in alarm protocols and calling lists. These protocols also stipulate the order in which the relevant actors need to be informed. An important distinction, however, is that the predetermined protocols do not determine the content of the information but only trigger the information transfer. It outlines who needs to be informed, not what has to be said.

In sum, the crisis operations is characterized by some special mechanisms that allow air traffic controllers to cope with the uncertainty and time pressure in particular threatening situations. These mechanisms are:

1. Improvising solutions that are deduced from prior crisis experiences;
2. Isolating the unexpected event from the control of other air traffic;
3. Following a predetermined organization of roles and responsibilities;
4. Decentralization of operational decisions *and* centralization of strategic decisions and coordination;
5. Initiating information channels with partner organizations based on predetermined protocols

6.5.1 Discussion

In this section the findings are discussed in relation to the theoretical assumptions about enhancing reliability in crisis conditions.

Table 6: Managing Reliability in the Crisis Mode

Hypotheses	Findings
H10: In the crisis mode the operational response is improvised by operators through a process of mutual adjustments. H11: In the crisis mode the operational response is characterized by simultaneous centralization and decentralization of decision-making. H12: In the crisis mode the operational response is coordinated through emerging information nodes.	➢ Improvising solutions that are deduced from prior crisis experiences; ➢ Isolating the unexpected event from the control of other air traffic; ➢ Following a predetermined organization of roles and responsibilities; ➢ Decentralization of operational decisions *and* centralization of strategic decisions and coordination; ➢ Initiating information channels with partner organizations based on predetermined protocols

First of all, the crisis management literature presumes that in crisis conditions improvisation is necessary to cope with uncertainty under time pressure. Hypothesis X holds that this improvisation process is the outcome of rapid adjustments between operators' assumptions which resemble a quickened trial-and-error process, as seen in the innovation mode. The findings from the case study support the thesis that improvisation of new solutions is important to enhance reliability in crisis conditions. Air traffic controllers explained that new and unexpected situations require quick decisions that may lead to doing something different than usual.

However, the findings do not indicate that adjustments between operators' assumptions define that improvisation process. Rather, air traffic controllers argued that experiences with prior crisis conditions serve as the bedrock for new solutions. This seems to imply that improvisation is not primarily a social, but rather a cognitive process. It is, however, important to differentiate this result from what was found during high velocity operations. In time pressure conditions the practices are trained procedural solutions that can be applied because the situation is similar to what has been experienced before. In crisis conditions, however, the situation is not similar but familiar. Prior crises may not be the same, but can hold clues on how to cope with the new situation. This seems to correlate with the idea of Roe & Schulman (2008) that operators are able to derive patterns from their existential knowledge base and attune these patterns to developing crisis scenarios (Roe & Schulman, 2008). Cognitive research on the art of improvisation may provide additional insights into the working of this process.

Secondly, hypothesis XI stipulates that simultaneous centralization and decentralization is expected to favour an effective response in crisis conditions. Decentralization of decision making is argued to allow those closest to the problem to handle the situation. In the bureaucratic and high velocity mode the air traffic control operations are essentially decentralized. In innovative conditions decision making gradually shifts from a centralized authority to decentralized authority. In crisis conditions, however, decisions are subject to both centralization and decentralization. Since both centralization and decentralization seem to characterize the response, hypothesis XI is said to be partially supported by the data.

The findings of this research imply that decentralization and centralization should be interpreted as two distinct forces that are able to coexist. This corroborates with the argument of Karl Weick that "the real trick in high reliability systems is somehow to achieve simultaneous centralization and decentralization" (Weick, 1987, p. 124). Although Weick (1987) argues that centralization is established by socializing and training operators into a shared organizational culture, the findings from the case study show that centralization also happens through hierarchical structures that are predefined in crisis protocols. The interesting question is what decisions are pushed or pulled up and down the organization. Some decisions are decentralized in air traffic control operations. These are mostly operational decisions such as headings, flight level instructions, declared airspace capacities, runway combinations etc.. These are also decentralized in a bureaucratic mode. Strategic decisions that are related to the demands of external stakeholders, media and other organizations are centralized to a higher hierarchical level such as the management of LVNL in the crisis team. Also coordinative decisions are centralized to the supervisor to make sure air traffic controllers remain focused on their operational decisions. This finding suggests that processes of decentralization and centralization are dependent on the type of decisions that have to be made.

Thirdly, hypothesis XII does not seem to be supported by analysis of air traffic control operations. Most of the coordinated activities of air traffic control with other partner organizations are conducted along pre-orchestrated information channels. Crisis protocols stipulate what partner organizations need to be informed when unexpected events happen. Although it requires a professional judgment of the supervisor to determine which organizations are linked to the unravelling event, the lines of communication are provided up front. They do not seem to emerge from the situation in a process of super-accelerated institutionalization. The supervisor is a critical information node in crisis operations because that is his predetermined role as laid out in protocol.

Although the spontaneous emergence of information channels and information nodes is not present in the operational environment, it could be a relevant theory for strategic environments such as crisis management teams. Like in innovative conditions, the management team may serve as a protective barrier to the operational environment. Emerging information nodes at the strategic level may precede the formation of new information channels in the operational context.

Chapter 7
Conclusion

Some organizations play a vital role in the functioning of societies. They deliver important services such as transport, electricity, and financial products by operating risky technologies. Society requires these critical infrastructure organizations to function reliably at all times. People and businesses rely on their “always-on availability” (Bruijne & van Eeten, 2007, p. 18). It was the aim of this thesis to examine *if* and *how* critical infrastructure organizations with risky technologies are able to perform reliably under critical conditions. Drawing on the insights from crisis management literature, such extreme conditions are characterized by uncertainty and time pressure. In summary, this research set out to answer the following central question:

What enables critical infrastructure organizations with hazardous technologies to perform reliably under conditions of uncertainty and time pressure?

With regard to this central question, the case study of Air Traffic Control the Netherlands (LVNL) provides a number of learnings with implications for both theory and practice. In this chapter these learnings and implications are discussed.

The central reason for why air traffic control manages to perform reliably under different performance modes is the ability of its professional air traffic controllers to adjust their practices to different situations. There is no ‘one size fits all’ solution for performing highly reliable under varying circumstances. This research has illustrated how the organizational culture and design of LVNL nurtures, fosters and protects the expertise and discretionary space that these professionals need in order to adapt. The primacy of decentralized decision making, protection of operators by staff and management against impulsive system changes, investment in training of operational personnel, and trusting a controllers’ expert judgment in the adoption of new practices; they are all examples of how LVNL invests in and relies on the professional skill of air traffic controllers.

Investing in the adaptive ability of professional operators is important because the task environment of operators can quickly change from one mode to another. Different performance modes require different responses. Although air traffic control is beset by large amounts of rules, procedures and protocols, this research shows that air traffic controllers experience critical situations in which these standardized operational concepts do not always provide the optimal solution. Even in stable conditions careful professional judgment is needed to produce more efficient and environmental friendly air traffic flows, instead of only adhering to standard routes.

Once conditions become more uncertain and/or time pressured, the need for professional skill intensifies. In the innovative mode operational expert judgment, controllers' experiences in simulations and 'control room acceptance' are pivotal. They are key aspects in the process of gaining certainty about the effects of new procedures or technologies. In the high velocity mode professional decisions have to be made in real-time such as alerting extra personnel, using holdings and restricting traffic. Crisis modes require controllers to improvise new solutions that go beyond routine based practices.

The idea that operator decisions are for a great deal responsible for the highly reliable performance of air traffic control must surely frighten engineers, designers, economists and risk-averse bureaucrats to whom the 'human factor' has long been a liability to the organizational system. When reflecting on the case of LVNL, the operations in the control room show highly technically competent controllers being very mindful about their decisions and operating environment. They go to great lengths to anticipate the next step ahead, and can withstand the tendency to take assumptions for granted. Recall that every landing at Schiphol is considered as a potential go-around.

Although discretionary space is necessary for operators to adapt, procedures and protocols do provide useful proxies and 'best practices' from which operators can infer solid professional judgment. They are an essential aid for air traffic controllers in administering an effective response. In time pressured conditions standard routes were, for instance, helpful in structuring operations and allowing controllers time to focus on the most urgent issues. Similarly in crisis episodes, the ASSIST protocol, checklists, predetermined role patterns and predefined communication channels give controllers a stable reference, or toolbox, for improvising a response based on professional skill and experience.

In addition, it doesn't only matter *what* an operator decides but also *why* these decisions are made. The application of procedures, routines, prior experiences, simulated trials or sheer improvisations is foremost aimed at enhancing safety under all performance modes. The widespread consensus among operators in the air traffic control rooms on the absolute need to enhance safety under all circumstances is as important as having the tools and resources to do so. Organizational goal setting, legal frameworks and training provide the incentives for nurturing such safety culture. In critical infrastructure organizations the requirements for reliability are closely related to enhancing safety. Safety is the baseline principle for enabling a reliable service delivery process in terms of, for instance, efficiency.

In essence, air traffic controllers enhance safety and perform highly reliable "not simply because they have to, but because they want to. And they can because they are equipped to do so" (Kaufman, 2006, p. 198). Such professional and organizational devotion to enhancing safety is at the heart of why few things go wrong and many things go right at LVNL.

But what are the theoretical implications of these lessons? What does this mean for theory on high reliability organizations? First of all, high reliability theory needs to be updated with the insights from studies that have analysed high reliability organizations across different performance modes. The outcomes illustrate that managing reliability under different conditions requires different situational responses. This necessitates high reliability theory to be extended and connected with other strands of literature, such as crisis management, innovation and change management literatures. The performance mode framework, such as formulated in this thesis, provides a helpful model for relating the different theories.

As a second implication, the 'high reliability' of an organization should not only be determined by failure-free performance. Failure-free performance presents the tautology that "no amount of good performance can falsify [the argument that the organization will someday fail] because it can always be said that the organization is only as reliable as the first catastrophic failure that lies ahead, not the many successful operations that lie behind" (Boin & Schulman, 2008, p. 1053). Because HROs do not fail, reliable performance is not tangible or visible. "Reliable outcomes are constant which means there is nothing to pay attention to" (Weick, 1987).

The case study has indicated that it is not only the 'absence of failure' that makes LVNL highly reliable, but also the 'presence of resilience' (Roe & Schulman, 2008; Weick & Sutcliffe, 2007). That is, the ability of the organization "to proactively adapt to and recover from disturbances that are perceived within the system to fall outside the range of normal and expected disturbances" (Comfort, Boin, & Demchak, 2010, p. 9). Uncertainty and time pressure invoke such critical operating conditions. Different from stable conditions, unexpected and pressured situations challenge operators' ability to perform reliably. High reliability should thus be considered as the ability to adapt to these critical circumstances in an effective fashion, in order to enhance failure-free performance.

A third implication is that the theme of professionalism deserves a more central place in high reliability theory. Not only this study, but also the extensive research done by Roe & Schulman (2008) at CAISO illustrates the importance of professional operators. Especially changing operating environments without standard solutions – i.e. nonbureaucratic organizations – demand expert judgment. Like James Q. Wilson argued back in 1989: "Experience, professionalism, and ideology are likely to have their greatest influence when laws, rules, and circumstances do not precisely define operator tasks" (Wilson, 1989, p. 70).

Fourthly, the outcome of this study does involve many findings that are similar to these of prior HRO research. Training, decentralized decision making, coherent safety goals and redundancy are organizational characteristics that contribute to the high reliability at LVNL. The findings strengthen the idea that HROs are a special class of organizations that share similar characteristics.

In addition to these theoretical suggestions, there are also some implications for practise in critical infrastructure organizations.

The first implication pertains to a wider concern about the erosion of professionalism in modern society. In many sectors the professionals, be they doctors, judges, policemen or teachers, are under pressure of market demands, critical citizens and extensive regulations. The Scientific Council for Government Policy (WRR) concluded that:"The public service delivery is encountering increasing tensions between the institutional regime in which these services are delivered, the philosophy of public service organizations and its professional operators, and client demands with regard to these services. For this reason, the varying interests, tasks, requirements and demands are inadequately aligned or in conflict, causing the actual service delivery process (and its front-line workers) to be constrained" (WRR, 2004).

According to the recent report of the performance evaluation committee, LVNL will experience similar pressures in the near future (Kuiper, Geut, & ten Heuvelhof, 2014). The European airspace integration, changing airline market and critical citizens are expected to ask for more efficient and environmental friendly air traffic control operations. As discussed in this thesis, pressures to operate more efficient or environmental friendly can come at the expense of safety. The challenge for LVNL will be the protection of its professional safety culture among these growing concerns for efficiency and environment. The external demands for innovation of the air traffic management system – i.e. operator, technology, procedures – should not be allowed to exceed the capacity of the system that is needed to accommodate these changes in a safe way. This suggest it is important that the change process at LVNL is preserved in its current form; a process in which the air traffic controller plays a decisive role and the management protects their professional habitat. A desire to search for higher efficiency and meet environmental requirements may not result in a softer or less professional approach to enhancing safety.

This development also bears a more fundamental question to modern society: do we – citizens, politicians, and industry – accept a higher risk of safety accidents as the price for our increasing demands of more efficient or environmental friendly air traffic control? And if so, will we be able to defend that position once things go catastrophically wrong? Will we take responsibility for such adverse events and admit that our demands may have come at the expense of safety? As long as the answer to these questions is 'No', society is not in the position to constrain the capacity of critical infrastructure organizations which is needed to enhance safety at all times. If safety is regarded as a precondition, society should empower critical infrastructure organizations with the means, deemed necessary by professional operators, to achieve failure-free performance.

As a second implication, the operational conditions determine to what extent operating procedures are effective in enhancing reliability. Critical infrastructure organizations, such as

LVNL, involve extensive amounts of procedures to structure operational conduct. The usefulness of these procedures depend on what they contribute to the operational decision making process under different conditions. This study has shown that for the sake of reliability 'work-as-done' must be allowed to differ from 'work-as-imagined' if conditions ask for it. This means that the application of rules, procedures and other predetermined structures should be considered in the context of the conditions in which they are, or will be, used. The rules and procedures need to help professional operators, not hinder an effective response. In designing, monitoring and assessing procedures it would realistic to incorporate a discretionary space for operators so they can safely adjust to changing conditions.

In general it can be concluded that cross fertilization between HRO theory, innovation management, change management and crisis management literature proves useful. It extends our knowledge on what organizational mechanisms are able to contribute to enhancing reliability in a variety of operational task conditions. Yet, we are still at the beginning of understanding the remarkable traits of high reliability organizations. Over the years research has not advanced much beyond the landmark study of the HRO research project at Berkeley in the 1980s. Considering the importance of reliable critical infrastructure organizations, hopefully this thesis will inspire new contributions to the search for high reliability.

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