

NOT ANOTHER AIR CRASH INVESTIGATION

Reading the black boxes of aviation safety cultures



DAVID PASSENIER

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NOT ANOTHER AIR CRASH INVESTIGATION

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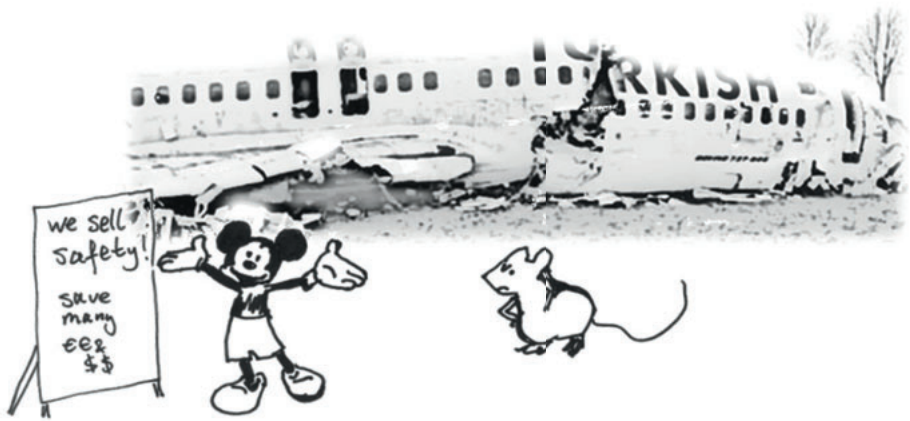
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Chapter image: *Designed by clowns?* Adapted cartoon, published on 'Socializing Science' blog (<https://socializingsciencevu.com/2018/03/29/1576/>)

CHAPTER 1

INTRODUCTION



1.1 CONFLICTING READINGS

“By the way, how did you get Sidney Dekker’s report?”

Professor John Stoop, expert in the field of accident investigation, sounded alarmed. It was December 2011 when I was conducting research for my master’s thesis. I was in Stoop’s office at the Aerospace Engineering faculty of the Technical University Delft, the Netherlands, where I was just about to ask him about a strange thing that I had found regarding an air crash investigation. Almost three years earlier, in February 2009, a Turkish Airlines Boeing had stalled¹ and crashed just before landing in Amsterdam. After a year of investigating the Dutch Safety Board had concluded that several parties, including the pilots who had tragically perished, had contributed to a fatal loss of control. Specifically, the pilots and an air traffic controller had violated certain standard operating procedures, which could have helped them catch the technical cause of the accident. However, an advisory report written on behalf of the investigation had concluded from painstaking analysis of the black box recordings that the pilots were not to blame. This report was written by the Dutch safety scholar Sidney Dekker.

“You do know it is a *confidential* report, don’t you?” professor Stoop continued his interrogation.

“Yes,” I replied, although I had not realised it was such an issue. I had stumbled upon Dekker’s advisory report when I started interviewing aviation experts to comment on the Board’s conclusions and lessons that could be drawn. After an interview, one of the experts had emailed Dekker’s report to me.

“It has never been released.”

“Well, I believe you can find it on the Internet.”

“You may be able to get it, but know that there is a legal side to this. If you were to write your thesis about these contrasting reports, don’t be surprised to get a worried response from the Dutch Safety Board. Like, how did you get this confidential report that was never published? So be aware of this.”

“Right, that’s good to know.”

“Yes. But be careful, this is very sensitive.”

About eight years later, it turned out that professor Stoop had not been exaggerating. The NY Times published an article accusing the Dutch Safety Board of burying Dekker’s report (Hamby, 2020, 21 January). Like me, they had stumbled upon Dekker’s report. It argues that the Turkish pilots had conducted themselves professionally and were not to blame. This pointed the finger to the Boeing 737 ‘Next Generation’ (NG)’s unreliable technology. The appendices of the final report show that in response, a team of Americans, including Boeing and federal safety officials, attacked the board’s rendering of Boeing’s safety processes as ‘technically incorrect’, concluding that prior to this crash,

1 Stall occurs when an aircraft exceeds its well-defined flight envelope, such as when flying too slowly at too great an (nose-up) angle with respect to the airflow, and means a sudden loss of lift and control. Recovery from stall is not always possible, notably when flying low, and stalling is therefore strictly avoided.

no risks were demonstrated (Dutch Safety Board, 2010, p. 150-151). Subsequently, 'the Dutch Safety Board either excluded or played down criticisms of the manufacturer' (Hamby, 2020, 21 January).

However, in the wake of two recent crashes of the 737NG's successor, the 737MAX, journalistic coverage on Boeing raised serious questions about the safety culture of the organisation (Laris, 2019, October 19). Like the 737NG, the MAX was programmed in ways that pilots were not informed about or trained to handle. Autonomously operating safety systems could suddenly act up and cause flight crews to lose control. In case of the 737MAX, to compensate for aerodynamic consequences of larger, more efficient engines, there was a Manoeuvring Characteristics Augmentation System (MCAS), which was completely hidden from pilots, even though it could deeply intervene in control. Members of the Boeing company apparently knew that the design might be flawed but convinced the USA's Federal Aviation Administration to certify the system in a way that prevented expensive pilot retraining on the MAX type (Kitroef, 2020, January 9). These dealings cast a questionable light on an array of earlier actions by the Boeing company, which the NY Times traced back to the 2009 Turkish Airlines crash.

This dissertation encompasses a set of studies that address persistent yet problematic assumptions about the way complex and hazardous technologies are operated by the members of aviation safety cultures. In aviation, safety culture plays an important role in fostering work practices with underlying norms and belief systems that contribute to safety. Safety culture can be defined as "the assembly of underlying assumptions, beliefs, values and attitudes shared by members of an organisation, which interact with an organisation's structures and systems and the broader contextual setting to result in those external, readily-visible, practices that influence safety" (Edwards, Davey & Armstrong, 2013, p 77). Aviation safety cultures have gathered a great deal of knowledge from accident investigations and are often taken as examples of professionalism, discipline, and commitment to safety. As a result, aviation safety culture is often described as humble in terms of its acceptance of human errors and technical failures, underscored by the many redundancies, meticulous planning, and adherence to standard operating procedures (Hudson, 2003). But as the case of the Turkish Airlines crash suggests, recovering the black boxes, reading them out, and analysing the contents are not a guarantee for learning. Some lessons may be hard to learn, when faced with the fragmented, politically charged snapshot that the black box read-out provides. The Turkish Airlines case highlights that, precisely because of the extensive standardisation and conformity presumed necessary to stay in control of the extremely, but not completely reliable aviation technology, it is hard to grasp how deviations from standards belong to such a culture. Deviations from standards however are implied in the more varied, fragile, and messy processes in which operational experts like pilots, flight attendants, air traffic controllers, maintenance technicians, and ground personnel actually work. The central research question of my dissertation therefore is:

What role do deviations from standards play in committed safety cultures?

In this introduction I first describe my research approach to safety culture, the context of the Dutch aviation industry, and a characterisation of the safety ideology that members of the culture use to make sense of working and organising with hazardous and complex technologies. Next, I examine the contrasting air crash investigation narratives on the loss of control over Turkish Airlines flight TK1951. My approach acknowledges that air crash investigations are not objective depictions of reality, but after-the-fact sensemaking (Gephart, 1993), based on fragmented data (Dekker, 2004) by experts who seek to craft authoritative narratives (Brown, 2004). I first show how the Dutch Safety Board’s final report construes deviations from standards as inherently dangerous. Then I show how Dekker’s advisory report, which draws on alternative ideas, deconstructs some of the assumptions underpinning the board’s narrative. I go on to extrapolate this line of thinking to guide my subsequent research on the role of deviations from standards in committed safety cultures. The sub-questions formulated from this discussion of the accident are foreshadowed below in Table 1 and elaborated in the final sections of the introduction chapter.

Table 1. Overview of research questions

Central research question:	<i>What role do deviations from standards play in committed safety cultures?</i>
Chapter 2:	<i>How do contrasting risk perceptions manifest themselves in the societal context of airline risk management processes, and how do these social manifestations impact regular work in the cockpit?</i>
Chapter 3:	<i>How does deviance become normalised in reflective safety-critical work practices, and what are the consequences for risk management?</i>
Chapter 4:	<i>How does the commitment to safety of maintenance technicians emerge and develop under social and organisational influences?</i>
Chapter 5:	<i>How can 'safety 2' analyses of organisational deviance incorporate bottom-up processes?</i>

1.2 RESEARCH APPROACH AND CONTEXT

1.2.1 Studying aviation safety culture in the Dutch research context

I approach safety culture as an anthropological concept, in contrast to the more common functionalist approach (Edwards et al., 2013; Guldenmund, 2000, 2010). According to the functionalist approach, organisations can engineer safety cultures by using the right techniques and systems (Reason, 1997). However, this approach has been widely criticised for ‘its inability to demonstrate causal relationships between such features and safety performance; a lack of conceptual clarity as to what, exactly, constitutes a safety culture; and a neglect of inequalities in power and authority and competing sets of legitimate interests in organizations’ (Hardy, Maguire, Power & Tsoukas, 2020, p. 1041). In anthropology, there are no functionalist claims regarding culture: cultures describe

contexts in terms of the way people, native to these contexts, understand them (Geertz, 1973). In safety cultural contexts, particular arrays of practices and technologies exist that are widely understood in terms of their ability to make possible the safe operation of demonstrably hazardous industrial processes (Edwards et al., 2013; Gherardi, Nicolini & Odella, 1998; Guldenmund, 2000; Turner & Gray, 2009). To some extent, a culture like a particular organisation's safety culture, is also a political and discursive phenomenon. Members of an organisation themselves articulate their own espoused safety values (Schein, 1990), which may or may not correspond with what these people actually do, and which often becomes entangled in relations of power and (office) politics (Antonsen, 2009). Safety culture may therefore sometimes refer less to an inherent quality by which a certain group or organisation behaves and more to an ideological struggle to (re)define what the appropriate cultural behaviours are (cf. Kunda, 1992).

Indeed, as my studies show, there is considerable nuance and debate within 'the culture' of aviation safety about what constitute safe practices and technologies. I use quotation marks because putting boundaries around a culture is inherently a somewhat arbitrary exercise in view of the dynamics by which cultural identities are reproduced; that is, precisely by defining and redefining culture along practices and people who belong and those who do not (Martin, 2001). Furthermore, in specific organisations and professional communities, such as the communities in the Netherlands where I conducted my studies, safety culture emerges in context-specific ways. These 'subcultures' often articulate different aspects of practices and technologies, such as anonymous reporting systems, reporting practices, paper or digital checklists, and procedural discipline (Edwards et al., 2013; Hudson, 2001; Reason, 1998).

Grounded in phenomena I encountered in the Dutch research context, I focussed on what the Turkish Airlines crash revealed as the most salient debate across various local Dutch articulations of the globalised aviation safety culture. That debate centres around what it means when highly trained and experienced aviation professionals deviate from 'safe standards' when operating hazardous technologies that are extremely, but not completely reliable.

There is ample indication that the essence of aviation professionalism may be described much like other technical work practices, such as Julian Orr's (1996) influential study of the work done by copying machine service technicians. Technicians' work could be characterised as a continuous, methodically prepared and executed improvisation, which highlighted the surprisingly fragility of technical understanding and control over the process of servicing (Orr, 1996). Analogously, studies in High Reliability Organisations like air traffic control and aircraft carrier operations found that expertise is demonstrated most clearly when teams improvise, deviate from plans, and exercise discretion in response to often only ambiguous signs of trouble (Bigley & Roberts, 2001; LaPorte & Consolini, 1991; Roberts, 1990; Weick & Roberts, 1993).

However, it is hard to capture the essence of professionalism in aviation safety cultures, because safety is often articulated in terms of regulation and standards. It is difficult to reconcile the view of high-tech safety-critical work as a continuous

improvisation, with the view that such work is highly standardised and regulated. As such, caricatures of aviation safety culture persist in both practice and theory that in a way act as a *theoretical* black box (Gross, 2009; Winner, 1993). A theoretical black box conceals the process by which inputs (e.g. unreliable moments in otherwise extremely fail-safe and redundant systems) are transformed to outputs (e.g. very high safety levels and conformity with standards). This process of transformation, which one might call the throughput, is subject to different and indeed sometimes conflicting readings. Thus, the nuance that can be found within aviation safety cultures on the processes and practices by which safety is achieved, is often lost in the translation of safe practices and technologies to 'other' cultures, such as health care. In health care, translations of aviation safety culture have been made to encourage lower ranking personnel to 'speak up' when physicians make mistakes and employ checklists to catch medical errors (Salazar et al., 2014). However, caricatures of aviation safety culture as conformist and standardised have also driven safety protocolisation while pushing improvisations, which might have expressed safety commitment in different ways, underground (Batista, Clegg, Pina e Cunha, Giustiniano & Rego, 2016).

In aviation, too, the caricature has an interesting way of refracting back onto the culture it was meant to represent, as well as importing caricatures of other industrial safety cultures, such as Reason's (1990) human error taxonomy and 'Swiss Cheese Model' (SCM) of accident prevention developed in the oil and gas industry (Reason, Shotton, Wagenaar, Hudson & Groeneweg, 1989). The SCM uses the analogy of safety procedures and other technical and organisational management tools as layers of Swiss cheese, stacked on top of each other, to catch hazards such as human errors and technical failures. An example of an organisational barrier is the disciplined reading of a landing checklist, by which flight crews can catch earlier, dangerous errors like incorrect aircraft configuration. Technical safety barriers stacked on top of the organisational barrier include for example an audible warning, automatically activated when the landing gear has not been deployed below a certain altitude. Each safety barrier thus encapsulated in safety-critical practices is potentially helpful to catch dangerous events from cascading out of control, but they are also imperfect, as visualised by the holes in the Swiss Cheese. Under certain conditions holes emerge, such as when crews are interrupted and the checklist procedure becomes less focused, or when a technical warning system is not activated as it should. Whilst this way of thinking and designing has probably contributed to safety, it sometimes elicits a normative management ideology (cf. Barley & Kunda, 1992), which promotes a conformist caricature of aviation safety culture at the expense of articulating more fragile safety processes like improvisation or the use of heuristics (Suarez & Montes, 2019; Tuccio, 2011). After all, the more conformity with various procedures, the smaller the holes in the safety barriers through which dangerous events can escape control.

The black-boxing of aviation safety culture is well illustrated by how the public debate over the Turkish Airlines crash got reduced to the question whether it was human error, or unreliable technology that caused the crash. Pieter van Vollenhoven, a

noteworthy public figure in the Netherlands who was the Safety Board chair at the time of the Turkish Airlines crash, was recently asked to respond to the allegation that he had bowed to pressure from Boeing. Boeing's way of dealing with the 737NG software bugs after all appeared to be more problematic in the light of recent 737MAX crashes. Van Vollenhoven however resolutely denied: he argued that Boeing had also been assigned responsibility for the crash. He pointed out that the final report therefore mentions a combination of human *and* technical factors (Nieuwenhuis, 2020, January 21). While Boeing's technology was unreliable, the pilots had violated crucial safety procedures, which meant they were not monitoring the unreliable automatic system when it made a critical error. Van Vollenhoven commented:

We can get so enthused about machines. It is also said about ships and cars that they can be controlled automatically. It's good that the operators keep getting trained to land the plane manually. At KLM they also fly manually much more often than at Turkish Airlines. But with machines come errors. You should not trust those automatic systems too much (Nieuwenhuis, 2020, January 21).²

This debate, which for about a decade remained buried within professional aviation communities, triggered my interest. Van Vollenhoven's comment implies that pilots and their organisations should foster a measure of distrust in automatic system and that this commitment to safety should be expressed in (better) conformity with standard operating procedures. However, there is research that suggests that in practice working with automation generates reliance on automation. Pilots are embedded in the cockpit instruments and controls they operate (Hutchins, 1995b) and collaborate with automatic systems integrated in cockpits (Adriaensen, Patriarca, Smoker & Bergström, 2019), while standard operating procedures inform, rather than fully determine, how these systems get operated (Jahn, 2019).

The latter, admittedly much more complex view of reality however rarely survives public debate and more 'theoretical' (or rather technocratic) safety engineering discourse by which important technological choices are made. For example, in the case of the 737MAX, the choice to keep stacking new software systems in an already complex technical design of the original 1960s Boeing 737 airframe in ways that were apparently only believed to be commercially viable if pilots were rudimentarily informed about how the software operates. In hindsight, this was a choice that expressed problematic commitment to safety as it undermined pilots' control in important ways. Perhaps by learning to open up to the more fragile realities underlying safety problems, such technical choices can be made with more foresight.

2 Original quote in Dutch, my translation.

1.2.2 Relevance beyond aviation and safety

A careful reading of the black boxes of aviation safety cultures may be a relevant exercise for researchers and professionals beyond the traditional safety-oriented industries. The importance of professional judgment is widely acknowledged since industrial processes are automated by increasingly intelligent software (Dreyfus & Hubert, 1992; Faraj, Pachidi & Sayegh, 2018). To stay adaptive in complex high-tech fields, working in the spirit of the rules (DeSanctis & Poole, 1994) may well be leading in popularity over following rules to the letter, given our tainted confidence in bureaucratic structures like hierarchies, silos, and standard operating procedures (Grey & Garsten, 2001). This popularity makes sense in a world of Silicon tech companies, where systems are constantly updated and programming errors are considered part of the game (Lee & Xia, 2010; Leonardi, 2011). But when it comes to safety (or health, or security), these enlightened views seem to rarely survive the dominant reasoning. The dominant assumption, notwithstanding well-established notions of redundancy, error management, and professional discretion, is that safety is largely assured by compliance with standards, while deviations, and especially the structural occurrence of deviations from the published standards, imply a potential loss of control. We love a pilot who knows how to improvise, but we prefer that they just follow procedures as long as we are on board.

The aviation setting seems to be an excellent test case of ideas about trusting professional expertise, artificial intelligence, and flexible, adaptive work routines. These ideas are also reflected in aviation safety ideology, or espoused safety values, which are expressed in technological and organisational design. While the ideology is thus grounded in material reality, many of its underpinnings are contested. I therefore provide some further background on espoused safety values typically found in aviation contexts around the world.

1.2.3 Espoused safety values in aviation

The aviation industry prides itself on professional expertise, embedded in a unique safety culture (Pidgeon, 1997), where operational professionals supposedly consider safety to be their first priority, even in the face of intense commercial pressures and volatile markets. A few decades ago, a cultural shift occurred in the industry with the integration of digital instruments and autopilots, with whom a new generation of pilots learned to share control (Gras, Moricot, Poirot-Delpech & Scardigli, 1994; VanderBurgh, 1997). While pilots remain responsible for judging situations, selecting the suitable level of automation, and intervening when necessary, control is increasingly mediated by digital 'fly by wire' systems that translates pilots' control inputs and manages on-board processes like pumping fuel between different tanks. Airbus is working on a system that may in the future allow the autopilot to taxi and take off as well (Adams, 2020, 16 January). Software is also used for safety by 'augmenting' flight characteristics, such as the Boeing 737MAX's Manoeuvring Characteristics Augmentation System (MCAS) and Airbus's 'alpha protection', which are in different ways meant to prevent stalling and losing control over the aircraft.

Meanwhile, following traumatic crashes such as the 1977 collision between a KLM and a PanAm Boeing 747 in Tenerife (Weick, 1990), the industry tried to flatten hierarchies in the cockpit to prevent superiors from silencing valid safety concerns of subordinates (Helmreich, Merritt & Wilhelm, 1999), although the stripes on crews' uniforms show that the airline business retains a traditional hierarchical system. Within the cockpit, roles and responsibilities are minutely described and allow pilots to switch from being in control of the aircraft as 'pilot flying' to 'pilot non-flying'. The captain, always in the left seat, has the highest authority and as such the final responsibility for safety and both informally as well as sometimes formally acts as a trainer and examiner of co-pilots in the right seat. Rotating team schedules furthermore prevent groups to develop diverging practices or unwarranted informal authority, while anonymous safety occurrence reporting feeds local, national, and global 'safety intelligence' systems that are used to identify and mitigate risks (Pidgeon, 1997).

Through human factors pilot training courses known as Crew Resource Management, the industry fostered constructive, more humble professional attitudes that made pilots accept the fact that they inevitably make mistakes and developed practices that enable learning from and managing errors when they happen in the cockpit (Helmreich, 2000). These cultural traits are said to enable pilots to regularly exercise discretion to deal with grey areas encountered within the corpus of programming, planning, procedures, and protocols used to control, coordinate, structure, standardise, and safeguard air transport. Indeed, the lessons learned in the cockpit also became a guide for the other professionals and operational personnel in the industry, for example in aircraft maintenance and ground services, as well as other sectors, such as health care. However, because aviation is an industry where incidents trigger public scrutiny, aviation also presents a research site that reveals tensions and conflicting views on professional discretion. For example, as evidenced by accident investigations, debate regularly erupts on the extent to which it is legitimate for aviation professionals to deviate from standard operating procedures, if these were designed to ensure safe operations.

1.3 LOSS OF CONTROL

The Dutch Safety Board's (2010) narrative on why Turkish Airlines flight TK1951 lost control provides a good illustration of how espoused safety values, which hold authority, fuel an authoritative safety discourse. That is, the safety board's narrative is convincing because it applies or implicates authoritative concepts to make sense of a very complex problem out of fragmented and partially contested data (cf. Brown, 2004). I illustrate how the narrative achieves this by highlighting how it implicates the authoritative concepts of normal accidents, high reliability organising, and safety barriers.

1.3.1 A normal accident

The first more technical explanation for the accident resonates with a classical sociological literature of *normal accidents* (Perrow, 2011). Charles Perrow argues that accidents should be considered normal in certain types of *socio-technical systems*, if these systems are inherently dangerous. Socio-technical systems are comprised of human operators as well as various (semi-)autonomously operating technical systems. In case of interactively complex, tightly coupled systems, such as aircraft and nuclear power plants (Perrow, 2011), complex interactions between people and technical systems will inevitably sometimes trigger a cascade of unexpected events that escapes the control of human operators. If one accepts that sociotechnical systems can be described along these dimensions, the more defining design characteristic might be complex interactivity, rather than tight coupling (Hollnagel, 2009). Redundancies, such as redundant altimeters on an aircraft, are designed to create loose coupling: if one system fails there are others which can take over. However, these very redundancies can interact complexly with other elements, especially when software is involved (Leveson, 2011), and thus still trap operators in situations with limited time and options.

In terms of normal accidents, the technical hazard revealed in the B737NG featured a complex software interaction, which emerged unpredictably. Corrosion in the fuselage probably caused a disturbed sensor signal of the left-hand radio altimeter, which then jumped to a nonsensical reading of -8 feet. Investigation testing the software revealed that the system then sometimes interpreted this reading as aircraft touchdown. This made the auto-throttle system switch to the 'flare - retard' mode and cut engine power for the final landing flare, even when the autopilot, which drew its data from other sensors, continued flying the approach. This complex software interaction had been reported before by some pilots flying the 737NG airplane in different parts in the world (Dutch Safety Board, 2010). It was being investigated by Boeing's fleet resolution process, which analysed data, prioritised problems, and generated solutions to be shared with B737 operators around the world. Since pilots rarely reported the problem, and the resolution was to simply switch the automatic thrust control off, the issue had not been prioritised much. Therefore, no warning or technical design change had been issued. This kind of unreliability was as such considered acceptable within the industry and covered by existing non-normal procedures. In fact, if one dives into the technical formalities, it was even hard for the Board to classify the faulty radar altimeter as malfunctioning at all. To be precise, the Thales company who manufactured the computer pointed out that 'tests performed during the investigation have established that both Radio Altimeter computers from the accident aircraft were operational and comply with their specifications' (Dutch Safety Board, 2010, p. 100).

Because as a socio-technical system, air transport is so tightly coupled, it seems almost inevitable in hindsight that a crew would ultimately get 'trapped' in a particular combination of circumstances where the complex interaction would prove fatal. The tightly coupled conditions of flight TK1951 are provided by a number of factors. First, Schiphol's air traffic controller had directed the Turkish Airlines crew on a shorter,

steeper line-up for the final approach path than how it was published in the official procedures. This meant that the airplane at first had to descend steeper to pick up the final, shallow glidepath of the Instrument Landing System (ILS) towards the runway. Second, the autothrottle had to cut engine power to idle in order to descend quickly and make the shortcut, but as I mentioned, it did so for another reason: due to the erroneous radio altimeter signal, the system 'thought' that the airplane had already landed. Once the independently acting autopilot pulled up from the steep descent, the autothrottle did not restore engine power as the flight crew expected. Third, because the crew were still busy getting ready for landing, and it is very hard to notice something that is *not* happening (restoring engine power), they also failed to notice that they were rapidly losing airspeed. Fourth, because it happened at such a low altitude, they were too late to recover the aircraft when it stalled. The Dutch Safety Board (2010, p. 8) therefore concludes:

The various different factors, and even a combination of some of them, will occur somewhere in the world on a daily basis in flight operations. What is unique about this accident is the combination of all the factors in a single flight.

1.3.2 Failed High Reliability Organising

Second, mirroring the established literature of *high reliability organisations* (Weick et al., 2008), the narrative provides evidence of human error by demonstrating how the accident resulted from failed organising on the part of the flight crew. The high reliability organisation (HRO) literature resulted from a set of ethnographic studies of a Berkeley social research group. In the 1980s, they began observing safety-critical high tech organisations such as air traffic control operations (LaPorte & Consolini, 1991), aircraft carrier deck operations (Weick & Roberts, 1993), and nuclear power plant operations (Schulman, 1993). In the light of a then dominant pessimistic literature about the mindlessness, sluggishness, and fallibility of traditional organisations, these studies found surprising mindfulness (Weick & Sutcliffe, 2007), adaptivity (LaPorte & Consolini, 1991), and infallibility (Robert, 1990) given their extremely challenging conditions. Weick and Sutcliffe (2007) summarise that members of HROs are apparently 'chronically worried' as they stay vigilant even if nothing appears wrong, and track small failures because even small failures can cascade into fatal accidents.

When applying this literature to accidents, however, investigation narratives can demonstrate the failure of involved teams and organisations to live up to the ideal-type HRO that has consequently been construed in the literature (LaPorte, 1994; Rijma, 1997; 2003). In the case of the Turkish Airlines flight, as Van Vollenhoven recently again emphasised, the Turkish pilots failed to be mindful of the erratic behaviour of the autopilot. They failed to be mindful of the evolving situation and track small failures. Some failures may seem relatively insignificant: the radio altimeter was only one of several redundant altimeters, for example. But they can turn out to be a weak early signal of a process that is busy cascading into a big failure.

The events leading up to the Turkish Airlines crash can indeed be read as failures of high reliability organising. The radio altimeter jumped to the -8 value shortly after take-off, but there is no evidence that the crew was aware. There is evidence that on approaching Schiphol, the Turkish Airlines crew noticed a warning 'radio altimeter' as well as 'landing gear'. However, there is no evidence that they understood the connection between the two or tracked any potential impact on the evolving situation. It seems that, unlike some of the other crews who had earlier encountered the problem, the Turkish Airlines crew had not signalled that the autothrottle had switched to 'retard flare' mode (Dutch Safety Board, 2010, p. 204-205). However they seem to have missed several opportunities to discover the problem. When for example, as a consequence of the retard flare mode, the crew is unable to arm the speed brake for landing, Boeing notes that '[t]he crew did not discuss the warning light nor the associated nonnormal procedure contained in the QRH³' (Dutch Safety Board, 2010, p. 145).

Perhaps distracting the crew from these weak signals precipitating the accident was the fact that it could be seen as a relatively busy flight. The captain was simultaneously teaching the co-pilot how to fly to the complex airport of Schiphol, although there was a third safety pilot in the jump seat to compensate with an extra pair of eyes. In any case, the crew in this case had *not* switched the automatic thrust control (auto-throttle) off. Then, as the crew approached Schiphol airport, the air traffic controller on duty deviated from standard operating procedure. The controller positioned the aircraft on a shorter approach path than the published procedure, without explicitly indicating this to the flight crew. This meant that the flight crew, which probably had not realised they were on a shorter trajectory, suddenly needed to speed up their work process as they were getting ready for landing. The safety pilot, who was supposed to safeguard the process, instead helped the process speed up by alerting the cabin crew to get seated for landing. Nobody was watching the instruments when the speed dropped.

The crew's final moments can also be read as a lack of high reliability organising. The higher ranked captain interrupts the co-pilot at a point where, maybe, the plane could still have been saved. When the aircraft begins to stall, the crew is alerted by a stick shaker, which physically shakes the yoke that pilots use to control pitch and roll. This is an unmistakable cue to immediately apply full power and if possible push the nose down to recover. The co-pilot immediately responds by advancing the throttle, but the captain interrupts him before he completes this action, saying "I have". The auto-throttle then again moves the throttle levers back to the idle position, which again cuts all engine power. At this point the aircraft cannot be saved anymore. The pilots now switch the autopilot and autothrottle off, and the captain advances the throttle to full power. He battles his way down a couple of hundred feet where the aircraft crashes into a wet field. The aircraft breaks up upon impact and slams the nose gear into the cockpit, fatally wounding the pilots. Since no fire breaks out, many passengers survive the accident.

3 QRH: Quick Reference Handbook, which contains all non-normal and emergency procedures.

Nevertheless, the Dutch Safety Board's narrative shows how various imperfections to high reliability organising contributed to loss of control.

1.3.3 Compromised safety barriers

The third explanation for the crash that the Dutch Safety Board's loss of control narrative provides also concerns human factors, building on widely accepted idea that standard operating procedures function as safety barriers against human errors (Reason, 1990; 1997; Reason et al., 1989). The narrative suggests that even with the above reconstructions demonstrating normal accident factors and failing HRO factors, the crash could still have been prevented if the pilots had conformed with standard operating procedures. Applying Reason et al.'s (1989) Swiss Cheese Model, the Board concludes:

The standard operating procedures in aviation are the safety barriers designed to ensure that flight safety is not compromised. [...] As shown by the chain of events during flight TK1951, the importance of these standard operating procedures must not be underestimated if the flight is to be undertaken safely.

(Dutch Safety Board, 2010, p. 8)

Both Schiphol's air traffic controller as well as the Turkish Airlines' flight crew violated critical procedures. First, the chain of events described above would not have occurred as it did if the air traffic controller would have conformed to normal procedure. Because the controller fell back on a shortcut that had become routine practice for the controller, but not for the entire flight crew, the crew got 'trapped' by the tricky interaction between the faulty radio altimeter signal and the automation software.

Second, as they passed 1000 feet altitude, the Turkish Airlines procedure said they should have made been ready with the landing checks or made the decision to abort the landing. If they would have been ready with the landing checks, they would have been free to monitor the instruments, they would have noticed the speed dropping, and they would have been prepared to take control. A second decision point to go around, which could have saved them, was at 500 feet, which also passed without getting called. Had they aborted, the Dutch Safety Board concluded, the subsequent chain of events would not have unfolded and there might not have been a fatal crash that day.

The report therefore concludes that if air traffic control and the flight crew had followed all standard operating procedures, this accident would not have happened. Therefore, the narrative continues, even though these factors happen routinely across the world, the importance of standard operating procedures should not be underestimated. This implies that certain operational professionals involved, possibly indicative of problems within their organisational cultures, had underestimated the importance of standard operating procedures. Indeed, the Board's recommendations reflect this implication: "In light of the deficiencies uncovered in this investigation, Turkish Airlines should adjust its safety programme" and the air traffic control organisation

“LVNL⁴ should harmonise its procedures for the lining up of aircraft on approach [...]. LVNL should also ensure that air traffic controllers adhere to the VDV⁵” (Dutch Safety Board, 2010, p. 86).

1.4 RE-READING THE BLACK BOX

The Dutch Safety Board’s reconstruction may appear to demonstrate sound logic and a healthy common sense. Responsible operators of safety-critical technologies need to be vigilant for any technical anomalies and they need to stick with the procedures. However, Dekker’s (2009) report suggests that one can take issue with the way it reconstructs the accident as a normal accident, to explain the more technical factors, in combination with instances of failed high reliability organising and compromised safety barriers to explain the human factors. The main issue is that it makes it look like human operators and their organisations have control over socio-technical systems, which they really may not have.

1.4.1 Illusion of control

If the Turkish Airlines crash was a normal accident, then this cannot only serve as an explanation of the technical factors causing the crash. The theory after all describes socio-technical systems, which are comprised of technological systems – such as the normally operating auto-throttle, autopilot, radio altimeter, and the buggy sensor equipment – *as well as* the humans operating these systems. In fact, ‘operator’ might be a confusing word to begin with. Cognitive anthropologist Edwin Hutchins made this point in his influential study of flight deck operations, when he analysed in detail how an entire cockpit, rather than the pilots alone, remembers its speeds (Hutchins, 1995b). In the flight operation there are various speeds that indicate limits, such as the speed at which an aircraft stalls, that depend on situational factors like weight, atmospheric pressure and temperature, and flap settings⁶. Various procedures and the continuous process of scanning instruments trigger pilots to set these speeds, which serves as a memory on which they subsequently rely. Literature that follows this type of analysis time and again points out why errors and complex accidents cannot be reduced to something a human operator does or fails to do (Henriqson, van Winsen, Saurin & Dekker, 2011a; Salmon, Walker & Stanton, 2015; 2016). The human operator, after all, is immersed in the very control process that the normal accident theory describes: he or she cannot rise above it. Nevertheless, the Dutch Safety Board’s loss-of-control narrative does precisely this. It narrates a normal accident, which it then reduces to technical factors of a dangerous

4 LVNL: Luchtverkeersleiding Nederland, the Air Traffic Control organisation of the Netherlands.

5 VDV refers to a Dutch acronym for the *Rules and instructions* for flight controllers.

6 Flaps are inboard, trailing edge parts of the wing that can fold downwards to increase lift and drag, thus enabling aircraft to approach more steeply and touch down at lower speeds. With flaps selected in the up-position, the aircraft stalls at a higher speed than when flaps are deployed.

situation that could have been contained if the organising had been highly reliable and the operators would have used the safety barriers appropriately.

In his human factors analysis, which extensively cites the above, as well as other research, Dekker (2009) contradicts the view that the evidence suggests failing high reliability organising and compromised safety barriers on the part of the Turkish Airlines crew. He provides the analysis of the 'trap' and then sticks to the reconstruction of the accident as a normal accident from the point of view of the crew. Important in this regard is that he rejects the idea that the flight crew's procedures could have acted as safety barriers:

The data from continued approaches suggest that crews do not primarily interpret situations in terms of stabilized approach criteria, but in terms of their ability to continue the approach. Soft and hard gates (e.g. 1000 feet, 500 feet), when set in context of the end of a flight at a busy, major airport on a scheduled flight become norms against which to plan and negotiate the actual approach vis-à-vis the air traffic and weather situation, not iron-fisted stop rules for that approach. (Dekker, 2009, p. 108-109)

In support of this conclusion, Dekker cites research that suggests that pilots gradually commit to landing, because they look at a broader picture. He makes a plausible argument that due to the trap, the Turkish Airlines flight crew could not have seen the complex interaction coming, based what they could reasonably have known from training and instruction manuals. Dekker thus concludes:

A large amount of scientific research and, perhaps even more importantly, studies sponsored and conducted by regulatory aviation safety agencies and independent aviation safety boards from across the world (FAA, 1996; BASI, 1998; CAA, 2004) have pointed for years to the insufficiency of automation training standards, the difficulty of relying on human monitors with normally very reliable automated systems, and the possibly devastating effects of subtle automation failures. TK1951 may have been a surprise for the aircrew involved; it can hardly come as a surprise to the industry. (Dekker, 2009, p. 120)

1.4.2 A dangerous contradiction

Dekker's analysis of the Turkish Airlines flight crew's actions not only deconstructs common assumptions about aviation safety cultures; in case of the air traffic controller, Dekker's analysis seems to help the Dutch Safety Board's narrative to reify these assumptions. While Dekker's report elaborately reconstructs the flight crew's work process, such a reconstruction is missing on the part of the air traffic controller. The controller deviated from normal procedure by directing the aircraft on a short line-up for runway 18R, thus contributing to the 'trap' that caught the flight crew off guard. Such shortcuts make sense in a busy, complex airport such as Schiphol that is constantly under pressure to increase its capacity while running into various limits that prevent this. Dekker's narrative however suggests that the air traffic controller should have either

followed procedure or coordinated the shortcut with the flight crew. In his own words, his analysis “[s]hows the consequences of ATC [Air Traffic Control] not previously announcing or coordinating a short and high turn-in for final approach, so that the flight crew has no chance to properly prepare” (Dekker, 2009, p. 6). However, LVNL, the Dutch Air Traffic Control organisation, responded that their air traffic controllers were authorised to interpret the procedure flexibly and that no comments had been received earlier on this particular short line up practice (Dutch Safety Board, 2010, p. 56-57). Because of this, LVNL argues that there is no cause for changing the procedures or enforcing greater compliance with their ATC rules and instructions, referred to as the VDV:

Air Traffic Control the Netherlands has indicated that executing a turn-in manoeuvre between 5 and 8 NM⁷ for runway 18R at Schiphol airport as it occurred with regard to flight TK1951 occurs in more than 50% of all approaches for this runway. In addition, pilots sometimes ask for a short line up. LVNL is, therefore, of the opinion that aligning aircraft within the 8 NM is a normal situation. Air Traffic Control the Netherlands is also of the opinion for this same reason that aircraft crew do not have to be asked whether they can or wish to accept such a line up. Air Traffic Control the Netherlands states that air traffic controllers may broadly interpret the procedures for lining up aircraft as mentioned in the VDV. Air Traffic Control the Netherlands has also indicated that no feedback has been received the past few years that this mode of operation has led to a higher risk. Air Traffic Control the Netherlands, therefore, does not see any reason to intervene with regard to the current mode of operation and procedures. (Dutch Safety Board, 2010, p. 56-57).

The board did not take this response well. They recommend procedural discipline and harmonising the rules and procedures because safety must be guaranteed by unambiguous instructions and procedures (Dutch Safety Board, 2010, p. 57):

Air traffic control is responsible for among other things promoting the most extensive safety possible with regard to air traffic in the Amsterdam Flight Information Region. Air traffic controllers need to get unambiguous instructions. Interpreting the regulations in the above-mentioned manner is, therefore, a contradiction. When it emerges that the regulations are not workable, they must be reviewed.

Furthermore, after concluding that the deviating practice regularly used by LVNL controllers disagrees with the way aircraft are designed, which are taken into account in the guidelines of the International Civil Aviation Organization (ICAO), the safety board recommends:

The Board deems it important that the procedures in the Rules and instructions air traffic control are brought in line with the ICAO guideline that an aircraft shall be enabled to be established in level flight on the final approach track prior to intercepting the glide path.

7 Nautical Miles (1 NM=1.852 km)

The VDV should also reflect how controllers actually work and LVNL will have to make sure that air traffic controllers work as prescribed in the VDV.

1.4.3 Deviance or professional discretion?

The safety board's view on LVNL's role might reflect common sense and a justified worry about flight safety. Perhaps LVNL was on a slippery slope and taking its responsibility for safety less seriously than it should. It would not be surprising, given the rapid growth of the airline industry and the pressure to accommodate more and more flight movements.

The board's rendering of LVNL's role in the crash actually resonates with an influential risk study on organisational deviance, which sociologist Dianne Vaughan (1997) defined as "routine nonconformity" with organisational safety standards. Vaughan studied the events within NASA leading up to a catastrophic Space Shuttle crash in 1986. NASA attempted to shift from the Apollo era space exploration towards a 'cheaper, faster, better' culture to provide routine access to earth orbit. So doing, certain technical anomalies, which at first prohibited launching the Shuttle, sometimes got accepted through a formal 'waiver' process, which gradually became routine, and finally became the norm. Doing so, the large and complex NASA organisation developed ambiguous launch criteria and was unable to see the increasing risk that it thus had accepted with regard to Space Shuttle operations.

However, while this makes sense in retrospect, it is harder to identify dangerous deviance before it causes an accident. Despite the extensive analysis, a similar process led to another lost shuttle in 2003 (Vaughan, 2005). Indeed, the assumption that ambiguities in rules and procedures *inherently* imply a lack of safety commitment may be problematic. In the case of the Turkish Airlines crash, while the board concludes that LVNL's procedures are unworkable, that is not what LVNL seems to be saying. LVNL seems to simply recognise the professional discretion that its controllers normally have and should have to accomplish the task of air traffic control. Indeed, the practice-based view of highly skilled technical work (Orr, 1996) and of HRO operations (Bigley & Roberts, 2001) as a methodical, continuous improvisation, makes it hard to see how there could not be regular deviations from rules and procedures.

From this point of view, the Dutch Safety Board does not seem to provide conclusive evidence of all the necessary organisational factors that are claimed to contributed to the crash. Rather, the investigation relies on problematic assumptions about what routine deviations with rules and procedures say about the organisation that normalises these deviations. This apparent gap in our current understanding of safety cultures leads me to three main themes, which guide my subsequent studies.

1.5 RESEARCH THEMES AND CHAPTERS

My critical reading of the Turkish Airlines crash led me to the overarching conclusion that to gain further insights, I needed to look at practices in their normal operational and

organisational context rather than in the context of an accident. To guide this research agenda, I derive three themes, which are: risk context (chapter 2), organisational deviance (chapter 3), and modelling emergent safety culture processes (chapters 4 and 5). I shortly outline each theme and indicate in which chapter the theme is further investigated.

Each chapter was developed through exposure to various scientific and expert communities. Further information and background regarding this development is provided in Table 2 below. Chapters 2-5 have earlier been published elsewhere as a book chapter (chapter 2), journal paper (chapter 4), and conference proceedings paper (chapter 5); chapter 3 is currently under review for an organisation scientific journal.

1.5.1 Risk context

By contrasting Dekker's (2009) report with the final report of the Dutch Safety Board I argue that the black box read-out is subject to some interpretive flexibility (Star & Griesemer, 1989). While the safety board reconstructs the Turkish Airlines crew's actions as failed high reliability organising, which also compromises organisational safety barriers, Dekker's reconstruction suggests a normal accident due to dangerous software technology. The board and Dekker seem to agree on the danger of normalising routine deviations in the case of air traffic control. However, I argue that this conclusion is built on inconclusive evidence because it relies on problematic assumptions about underlying organisational processes of normalisation.

Such interpretive flexibility with regard to the risk posed by deviations from the norm can also be found in the context of aviation safety cultures. This is illustrated by the investigation process. Shortly after the crash, a story emerged that on the crash site, while the disaster relief was being deployed, a member of the Dutch Safety Board scooped up the black boxes before the public prosecutor could get his hands on them (Springelkamp, 2009, 24 April). The black boxes contain valuable recordings of aircraft instrument and control input data as well as a higher fidelity recording of the final half hour of talking in the cockpit. In the Dutch news, aviation safety expert professor Ben Ale, again from Delft Technical University, pointed out that there is "a certain tension" between the safety board and the public prosecutor, who simultaneously launched a criminal investigation (Slager, 2009, 27 February). The public prosecutor's job is to establish culpability. In contrast, the safety board is responsible for establishing causes in order to improve safety, preferably avoiding blame games that tend to harm constructive relations within society, thus striving for a 'just culture' (Dekker & Breakey, 2016; Reason, 1998). The very different logics and responsibilities of the legal versus safety investigation spheres often conflict, which led to the development of the Dutch Safety Board as a separate, impartial institution. Notably, Pieter van Vollenhoven is recognised for his public work in shaping the safety board while Sidney Dekker is an outspoken academic promotor of just culture in aviation, health care, and other sectors.

While in the ideal case, safety cultures might be insulated from these contradictions, I wondered whether, and if so how, the 'tensions' in reality manifest themselves in a context where contrasting risk perceptions exist, and what the impact might be on work

in the cockpit. In **chapter 2** I investigate this question based on fieldwork I subsequently conducted in the circles of Dutch aviation authorities and experts, who actively give shape to the just culture policy, as well as fieldwork 'inside' the safety cultures of several organisations. I elaborate a bit more on engineering approaches to risk management and the contrasting perceptions of risk that result from applying normal accidents and high reliability organisations as normative ideal types. Then I develop a framework to interpret observations of everyday tensions in the work of airline pilots in terms of these contradictions of the Dutch risk context. This might help retrieve the nuances and complexities of these contextualised practices, rather than, so to speak, putting them back in the box, as I argue public risk debates tend to do.

1.5.2 Organisational deviance as a case of professional expertise

My critical reading of the Turkish Airlines investigation led me to question the implied idea that deep-seated ambiguity regarding safe standards signify a dangerous lack of safety commitment. Could it be that routinely recurring deviations from standards, which the safety board identified at LVNL, are a necessary and helpful aspect of professionals, if their work is in reality better characterised as a methodically prepared and executed improvisation? Indeed, Dekker's comment on pilots' tendency to deviate from the stabilised approach criteria suggests that deviations from standards are not so much the norm, but certainly normal. Is it even possible to operate a complex system without routinely recurring deviations from standards?

I further investigate these questions in **chapter 3** through an in-depth study of deviations observed in airline pilots' expert work practices, guided by the question: how does deviance become normalised in reflective safety-critical work practices, and what are the consequences for risk management? I would have also found it interesting to conduct this study within the air traffic control organisation. However, when I approached them I mentioned the Turkish Airlines report, which according to a source in my informal network immediately closed the doors for me. I later conducted a few interviews within ATC but overall decided to change research focus. Given the sensitivity of the subject, and the limitations this presented to obtaining access, I chose to further study deviations from standards in airline pilots' work practices. Through my informal network, I had better access to the airline pilot community and being a private pilot myself I also had a better grasp of the basic technical challenges. Based on the resulting study in chapter 3, written together with my PhD supervisors Jeroen Wolbers, Frank de Bakker, and Peter Groenewegen, I elaborate the debate on organisational deviance and argue that the positive consequences of this process are understudied. Drawing on various fieldwork data I then present a process model that helps explain how and why deviant practices, despite their apparent fragility, may be crucial for organisations when they seek to defer to operational expertise.

1.5.3 Modelling safety culture

It is interesting enough to open the black box of aviation safety cultures through social science fieldwork observation and interviews. However, the topic also invites engagement. The Turkish Airlines crash investigations show that the normative concepts that describe and prescribe safety commitment sometimes lead to contradicting conclusions. This indicates a need to translate the more descriptive social science research on complex social and organisational processes to the engineering communities who actually design these processes (Leveson, Dulac, Marais & Carroll, 2009). Otherwise, the more counterintuitive knowledge gained on operational expertise, such as provided by the previous theme on deviance, risks getting ignored. Engineers after all tend to either eliminate humans from the system or use simple ('elegant') models that eliminate what we know about 'deviant' processes. Also, it might be said, social scientists tend to criticise engineers' models without offering alternatives.

In **chapter 4** I provide such a translation by taking up an interdisciplinary research challenge with computer scientists in the field of artificial intelligence. Although our research approaches were very different, I was delighted to find a common ground with Alexei Sharpanskykh, who specialises in modelling social and organisational processes. We attracted funding to hire two research assistants with their own expertise, Colin Mols from the aviation management domain and Jan Bim from AI/computer science, to form a research project around aviation safety culture. Our project initially used ethnographic data earlier collected by a colleague, Sytze Kingma, and his master student Ahmed Atak. They collaborated on an insightful article that revealed how the safety culture within the aircraft maintenance organisation where Atak worked varied significantly in different episodes of the organisation's development (Atak & Kingma, 2010). Because we were able to interview them both, as well as members of the company that Atak had since left, we saw an opportunity to translate some of the interesting findings to a formal multi-agent modelling methodology. Settling on the maintenance case study, we formulate the research question: how does the commitment to safety of maintenance technicians emerge and develop under social and organisational influences? Our approach then enables us to develop mathematical representations of some mechanisms by which safety commitment emerges from a (mathematically speaking) complex system of agents, and provide interesting nuance in the light of more normative debates on safety culture. The normative safety culture literature after all relies on linear models like the SCM, which support a more general, problematic assumption that there is a linear relation between management safety commitment and commitment to safety observed on the work floor.

Based on the article and additional interviews and sources we model the power and influence relations between more junior and more senior aircraft maintenance technicians—a generic term used by Atak and Kingma for an actually more diverse group of specialisations—under influence of a separate maintenance and safety management department. Computer simulations with this model then allows us to pattern-match the results with the original description, which provides validation of the model. However, we also point out that because organisational safety cultures are context-specific, the

model should not be seen as generally applicable or predictive, but rather as a useful exercise with potential for further development.

Chapter 5 demonstrates this potential when we apply the methodology to the case of a safety culture change programme at a ground services organisation, focusing mostly on the operations at Schiphol airport platform. In this project Alexei Sharpanskykh and I collaborated with Robert Jan de Boer, at the time lector of the Aviation Engineering school of the Amsterdam University of Applied Sciences. Ground services represented an undervalued aspect of the company's safety culture as occasional workplace accidents as well as flight safety occurrences demonstrated. Applying Line Oriented Safety Audits (LOSA), a method developed for safety culture in the cockpit (Helmreich, Klinect & Wilhelm, 2017, May), ground safety management had found routine deviations from platform safety procedures. They interpreted this as a worrying lack of safety commitment, but had trouble convincing the work floor to comply with the procedures. An interdisciplinary research team, which now encompassed supervisors and students from three universities, of which I was the social science supervisor, was invited to study and work on the problem.

The main question was: how can 'safety 2' analyses of organisational deviance incorporate bottom-up processes? This question addresses a key safety debate on conventional 'safety 1' analyses versus the 'new view', or 'safety 2' analyses. Safety 1 approaches, such as the SCM, which have a top-down perspective on safety rules and standards, often identify human error as the main hazard and turn to compliance as a crucial tool for safety management (Hale & Borys, 2013). In contrast, safety 2 approaches suggest a bottom-up perspective of rules as they acknowledge that safety standards need to be applied in complex sociotechnical contexts (Dekker, 2006). While deviance is also seen as an organisational hazard, safety 2 scholars suggest identifying and managing these hazards through sociotechnical system analyses (Hollnagel, 2012; Leveson, 2011). As chapter 5 reports, we first tried and then ended up criticising an existing engineering safety analysis approach called STAMP (Systems Theoretic Accident Model and Process) (Leveson, 2011), but we also provided an alternative by applying and extending the method developed in chapter 4. This allows me to return to the central research question in **chapter 6** and discuss the role of deviations from standards in committed safety cultures and what this insight contributes to theory and practice.

Table 2. Overview of dissertation chapters

Chapter	Research theme and question	Data	Participation in science and expert communities
1: Introduction	Introduces the central research question: What role do deviations from standards play in committed safety cultures?	- Dutch Safety Board's (2010) final report of the investigation of the crash of Turkish Airlines flight TK1951 on 25 February 2009. - Sidney Dekker's (2009) human factors analysis of the crash of Turkish Airlines flight TK1951 on 25 February 2009. - Interview with accident investigation expert John Stoop (December 2011). - Several Dutch and international news media articles from 2009 to 2020.	Passenier, D. Erosion of and by safety barriers. Deskilling, danger and decoupling in the aviation industry. Presented paper at <i>Risk & Uncertainty Sociology Conference</i>, Amsterdam, January 2013. "The safety solution. Thick descriptions from the annals of organizational bullshit." Presented paper at <i>Organizational Ethnography Symposium</i>, Amsterdam, August 2013. Learning without judgment: A constructionist approach to error culture in aviation accident investigations. Presented at EAWOP conference, Münster, 2013. "Politics of improvisation". Master Thesis, 2012. VU Amsterdam. Invited lecture at the Human Factors in Aviation Group, Schiphol, The Netherlands, March 2012.
2: Tension in the air	Investigates and illustrates the risk context: How do contrasting risk perceptions manifest themselves in the societal context of airline risk management processes, and how do these social manifestations impact regular work in the cockpit?	Fieldwork in the aviation industry (2011 – 2016): - interviews with aviation (practitioner) experts and authorities - observations of (practitioner) expert meetings - observations of work in the cockpit	Chapter published as: Passenier, D. (2018). Tension in the air: behind the scenes of aviation risk management. In: Gephart, R.P., Miller, C.C. & Helgesson, K.S. (eds.) <i>The Routledge Companion to Risk, Crisis and Emergency Management</i> (pp. 296-311). Taylor and Francis. Presented earlier version at <i>Massey Aviation School</i>, Palmerston North, New Zealand, March 2017.

Table 2. Continued

Chapter	Research theme and question	Data	Participation in science and expert communities
3: Deviance in airline cockpits	Studies organisational deviance as a case of professional expertise: ■ How does deviance become normalised in reflective safety-critical work practices, and what are the consequences for risk management?	Fieldwork in the aviation industry (2011 – 2017, partly overlapping with fieldwork for chapter 2): ■ interviews with aviation (practitioner) experts and authorities ■ observations of (practitioner) expert meetings ■ observations of work in the cockpit ■ observations of work in flight simulators	Currently under review. Passenier, Wolbers, de Bakker & Groenewegen. First revision as submitted to <i>Organisation Studies</i> in January, 2019, titled: Deviance in airline cockpits: how professionals manage organisational risks. Earlier versions: Passenier, D., Wolbers, J., de Bakker, F., and Groenewegen, P. Deviant airline pilots: why we need them. Presented at <i>European Group for Organisation Studies (EGOS) Colloquium</i>, Copenhagen, 2017; and at <i>European Theory Development Workshop</i>, Zürich, July 2017. Passenier, D. F., de Bakker, F. G. A., Groenewegen, P., Wolbers, J., & Catz, E. (2016). Up in the Air: The Construction and Management of Risk by Commercial Airline Pilots. In <i>Academy of Management Proceedings</i> (Vol. 2016, No. 1, p. 17488). Briarcliff Manor, NY 10510: Academy of Management. Passenier, D. F., de Bakker, F. G. A., Groenewegen, P., Wolbers, J., & Catz, E. (2016). Up in the Air: The Construction and Management of Risk by Commercial Airline Pilots. Presented at <i>European Group for Organisation Studies (EGOS) Colloquium</i>, Athens, July 2015.

Table 2. Continued

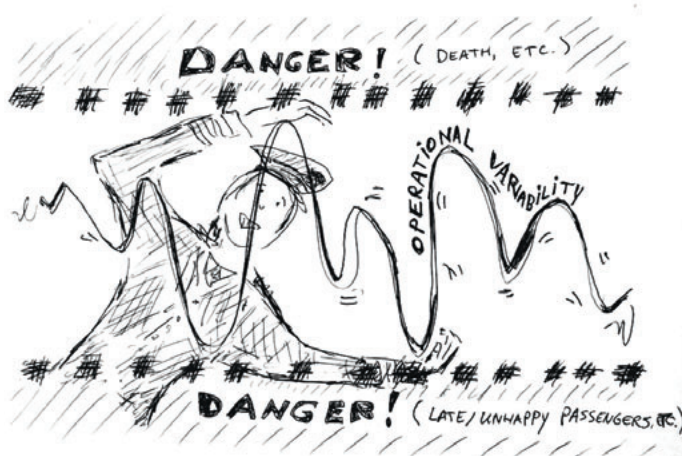
Chapter	Research theme and question	Data	Participation in science and expert communities
4: Modelling safety culture as a socially emergent phenomenon: a case study in aircraft maintenance.	Develops new methodology to model safety culture as emergent processes:	■ Atak & Kingma's (2010) paper on safety culture in an aircraft maintenance organisation	Published as: Passenier, D., Mols, C., Bim, J., & Sharpanskykh, A. (2016). Modeling safety culture as a socially emergent phenomenon: a case study in aircraft maintenance. <i>Computational and Mathematical Organization Theory</i> , 22(4), 487-520.
	■ how does the commitment to safety of maintenance technicians emerge and develop under social and organisational influences?	■ Additional interviews and documents on aircraft maintenance practices and processes (2012)	Earlier versions: Mols, C., Bim, J., Passenier, D., & Sharpanskykh, A. (2013). Modeling safety culture as a socially emergent complex systems phenomenon: a case study in aircraft maintenance. In <i>Proceedings of the Fourth International Air Transport and Operations Symposium</i> , Delft, the Netherlands.
		■ Agent-based simulations and virtual experiments	
			Passenier, D., Mols, C., Bim, J., & Sharpanskykh, A. (2013). Understanding crises: Investigating organizational safety culture by combining organizational ethnography and agent modeling. <i>Proceedings of ISCRAM conference</i> , Baden-Baden, Germany.

Table 2. Continued

Chapter	Research theme and question	Data	Participation in science and expert communities
5: When to STAMP? A case study in aircraft ground handling services.	Applies the novel methodology in, and contributes to, practice: ■ how can 'safety 2' analyses of organisational deviance incorporate bottom-up processes?	■ STAMP data collection and analysis by bachelor thesis student projects (2013-2014) (supervised by R J de Boer, HVA) ■ Ethnographic data collection by 4 master thesis student projects (2013-2015) (supervised by me) ■ Agent simulations and virtual experiments by master thesis student project (2015) (supervised by A Sharpanskykh, TUD)	<u>Published as:</u> Passenier, D., Sharpanskykh, A., & de Boer, R. J. (2015). When to STAMP? A case study in aircraft ground handling services. <i>Procedia Engineering</i>, 128, 35-43. Presented at the international STAMP Workshop, Amsterdam University of Applied Sciences, September 2015.
6: Discussion	Answers the central research question: ■ What role do deviations from standards play in committed safety cultures?		Passenier, D. Wing it, swing it: how improvising in extreme contexts could inform digitalising organisations. Accepted at the <i>Organization Studies Summer Workshop</i>, Mykonos, May 2019, and presented an earlier version at the <i>KIN Summer School</i>, Amsterdam, June 2018. Passenier, D., Pool, D., Rankin, A., Sharpanskykh, A. Preparing to be unprepared: training for resilience. Presented paper at the <i>7th REA symposium</i>, Liege, June 2017. Invited lecture on macho culture in aviation maintenance for the <i>Human Factors in Aviation Group, Amsterdam</i>, March 2016.

CHAPTER 2

TENSION IN THE AIR



ABSTRACT

In this chapter I address the debate whether irregularities in safety-critical organisations are accidents waiting to happen, or that they are a normal part of risk management. I present a series of vignettes from diverse qualitative field studies in commercial aviation. The vignettes reveal how contrasting risk perceptions of safety-critical processes emerge between actors operating in the societal context of airline companies, contributing to a negotiated order that seeks to satisfy the contrasting risk perceptions. I argue that manifestations of the negotiated order impact regular work in the cockpit through subtle social tensions, as exemplified by the humour, emotions and stress that I describe in the vignettes. I discuss the implications of my findings for the influential risk debate between High Reliability Organisations and Normal Accidents, which tend to arrive at opposing interpretations of irregularities in inherently hazardous processes. In contrast, I argue that studying social tensions emerging in regular work settings can provide a range of more nuanced risk management interpretations of irregularities.

2.1 INTRODUCTION

On July 25, 2015, Air Traffic Control (ATC) radio communication went viral on YouTube (ATC audio, n.d.) featuring a Dutch airline jet that encountered a wind shear—an abrupt change of wind direction. One of the pilots was heard exclaiming “Scary!” and “Speed, speed, speed!” The air traffic controller warned the pilots that they were accidentally broadcasting their private talking over the radio frequency, but for some reason the captain was heard on the radio again, coaching the co-pilot: “You’ve flown really well, I just wanted to say that.” The aircraft made a go-around and then landed low on fuel, having already diverted from another airport due to bad weather. While this information might typically only have ended up in an anonymous reporting database, the cockpit scare now spread via YouTube to national news media and even debates in parliament (AD, 2015, 30 July). Despite the upheaval, the Dutch Safety Board subsequently responded that there would be no investigation, because the event was too regular to learn anything new (AD, 2015, 2 September).

The wind shear scare demonstrates common, contrasting risk perceptions. The public perceived the scary looking event as an accident waiting to happen. The common expectation is for the authorities to take control and investigate the matter: could the incident be due to technical or human error; is anyone to blame (Dekker, 2004)? In contrast, the event may appear regular from the point of view of highly experienced safety-critical organisations, whose core operational processes are inherently hazardous. Through risk management, these organisations can reduce, but not eliminate the likelihood of damage and loss (LaPorte & Consolini, 1991), so the close call might be classified as an acceptable risk (Vaughan, 1997).

The inherent social tension between safe and scary risk perceptions can have consequences when perceptions of different actors are opposed, such as directly after a reported incident. Organisational relations may be damaged when managers blame individual operators for incidents, perhaps in order to avoid legal consequences (Dekker, 2007), while safety-critical organisations rely on good internal relations to continually improve safety (Cox, Jones & Collinson, 2006). These discussions, however, remain rather abstract while we have limited understanding of the way safety-critical organisations regularly interact with their societal contexts. Seminal empirical studies focus on incidents (Vaughan, 1997; Weick, 1990) or their aftermaths (Brown, 2000; Gephardt, 1993; 1997; Maguire & Hardy, 2013), rather than any impacts that these societal interactions might have on the regular work process.

In this chapter I therefore present empirical evidence of social tensions occurring in day-to-day operations in the Dutch commercial aviation industry. In aviation, contrasting risk perceptions might surface more sharply than in other safety-critical industries, such as oil and gas (Hudson, Parker & van der Graaf, 2002, January), because passengers are often physically confronted with disturbances like windy weather. Thus, contrasting perceptions of aviation risk frequently emerge as these scares enter the public arena through news and social media. Yet the impact of these media hypes on the regular work

done within the privacy of the cockpit usually remains opaque to outsiders. I therefore ask: *How do contrasting risk perceptions manifest themselves in the societal context of airline risk management processes, and how do these social manifestations impact regular work in the cockpit?*

I continue this chapter by reviewing the relevant risk management literature, followed by the choice of settings and methods I used to collect, analyse, and present qualitative data from the Dutch aviation industry. I then present my findings in a series of vignettes and discuss the implications for the debate on risk perceptions.

2.2 RISK MANAGEMENT IN A SOCIAL CONTEXT

2

Risk management can refer to any organised attempt to exercise control over uncertainties (Power, 2008), but I limit my discussion here to safety risks. I first describe how risk management literature depicts the way managers and government officials can design routines for operating safety-critical technologies, and coordination processes between operators. However, the operation may look messier in practice than on paper, which fuels debate between opposing perceptions of whether such messiness is risky.

2.2.1 Risk management by design

Risk management can refer to an administrative office occupation, as well as a real-time operational activity performed by operators like pilots. In the literature, the administrative occupation dominates (Maguire & Hardy, 2013). The administrative risk management process first identifies risks retrospectively by investigating reported incidents and accidents, or prospectively by projecting those risks on future operations. Second, risk managers design and implement mitigating measures. Third, risk management systems monitor and provide feedback on the effectiveness of these measures.

Risk management methods are anchored in accident models from which control systems for safe work practices are inferred (Hollnagel, 2012; Leveson, 2011; Reason, 1997). These control systems look technical, but a major concern is with human actors. Hazards originate in technical processes like flying jet aircraft, but engineering progress has made the hardware, like jet engines, highly reliable. Thus, the most unpredictable factor in risk management is the human factor (Reason, 1990) or rather its complex interaction with software and hardware (Leveson, 2011).

Two broad approaches to human factors risk management can be identified. The first reasons that human errors are sadly inevitable and sometimes cause accidents, and therefore develop organisational safeguards to contain the effects of errors and thus prevent accidents (Reason, 1990; 1997). A checklist, for example, can function as a safeguard by catching a mistake made earlier, and help the operator correct their mistake. In aircraft, the landing checklist item reminding pilots to lower their landing gear before landing is a good example. Organisations can audit such safeguards by using functional methods such as Line Oriented Safety Audits (LOSA). LOSA is a popular tool by which

observers act as “fly on the wall” in the cockpit, check flight crews’ compliance with procedures, and note errors and violations during several flights (Klinect & Wilhelm, May 2017). However the underlying assumption, that errors and violations indicate hazards to be fixed, seems problematic when organisations have already attained very high safety levels (Amalberti, 2001). Certain procedure violations for example may be expressions of professional expertise.

The second approach (Woods, Johannesen, Cook & Sarter, 1994) reasons that hazards can be managed by redesigning the socio-technical system from which errors emerge (Rasmussen, 1997). A socio-technical system represents safety-critical processes consisting of interacting human and technical elements, such as an aircraft consisting of technical elements, and a flight crew and computers controlling the aircraft. An established origin of human error lies in ergonomic design choices of the hardware. A famous example from WW II was the design solution to B-17 bombers that kept getting damaged when the landing gear was raised while the aircraft was on the ground (Stanton et al., 2010). Pilots kept making this mistake because the landing gear toggle switch looked exactly like another switch that they had to operate after landing. By differentiating the landing gear actuation design, pilots no longer made the same mistake.

The design of complex organisational systems can also create hazardous situations. The formalised coordination processes between pilots and air traffic controllers, for example, is partially automated, enabling detailed planning of aircraft movements; but occasionally complex, unforeseen interactions emerge, causing dangerous situations. Various regulatory agencies ultimately influence the design processes by which the risks of systems like global air transport are managed; Rasmussen (1997) therefore extended risk management thinking to the societal level. New risk management methods (Hollnagel, 2012; Leveson, 2011) now challenge managers and administrators to think about complex interdependencies and redesign organisational systems so that hazards do not emerge or can be jointly monitored and managed.

However, like the original design, the redesigned organisation also functions differently in practice. Human operators are usually confronted with many unaccounted operational variabilities, even in routine technical operations (Suchman, 1987; Orr, 1996). Such variation requires operational personnel to respond adaptively (Weick & Sutcliffe, 2007), although it may be hard to appreciate what actions are required from them: technical work tends to look messy in practice (Schulman, 1993). Because risk management methods tend to select on the dependent variable (Dekker, 2004), and infer bad outcomes from messy looking work, messy looking work is often treated as an accident waiting to happen.

2.2.2 Normal Accidents Theory

Sociologist Charles Perrow (2011) coined the term Normal Accidents to explain why messy looking work processes are accidents are waiting to happen. Two characteristics of socio-technical systems compromise control over hazardous processes. The first characteristic is interactive complexity, which refers to the innate tendency of system

elements to interact in unforeseen ways. The second characteristic is a tight coupling between these elements, denoting strong interdependencies between operational processes and little time, or few alternative courses of action, for operators to respond to unforeseen events. Thus, the messy system will inevitably produce unexpected situations where operators do not have enough time or courses of action to respond. Subsequently, because the system is tightly coupled, one small failure may immediately cause other failures, and the failure, rippling through the system, might end in catastrophe.

Despite several criticisms (Leveson, Marais & Carroll, 2009; Weick, 2004), Normal Accidents Theory (NAT) remains popular to describe accidents waiting to happen. Although its risk predictions are not entirely accurate (Leveson et al., 2009), there is broad agreement on the following central point. However advanced professionals' abilities are to deal with messy processes, some safety issues cannot be resolved unless the socio-technical system is redesigned. When the political momentum to accomplish costly and disruptive redesigns is lacking, the prospect or actual occurrence of a catastrophic accident can amass such momentum (Turner & Pidgeon, 1997).

The Normal Accident frame is further strengthened by the influential risk theories of Dianne Vaughan's (1997) *normalisation of deviance* and Scott Snook's (2000) *practical drift*. These established, influential theories point to messiness as indicating a slow process of degradation. The degradation process is hard to see while one is immersed in it because the messiness has become normalised, by way of cultural blindness or groupthink (Vaughan, 1997). The dangers only manifest themselves when the inevitable accident happens. Retrospective analyses then reveal how the purpose behind risk management systems gradually shifted, allowing deviations from standards to become the norm and blinding organisations to dangerous incompatibilities between diverse organisational units.

2.2.3 High Reliability Organisations

In contrast, the High Reliability Organisation (HRO) concept suggests that safety-critical organisations can continually progress without accidents (LaPorte & Consolini, 1991; Roberts, 1990). HROs impressed social science scholars because HROs operate inherently dangerous technologies low-risk (LaPorte & Consolini, 1991). Social psychological processes contributing to this phenomenon are summarised as 'chronic worries' about risks (Weick & Sutcliffe, 2007), and continuous learning, tweaking, and improvement (Roberts, 1990; Schulman, 1993; Weick & Sutcliffe, 2007). These characteristics were observed in a range of technical work contexts, such as air traffic control (LaPorte & Consolini, 1991), nuclear power plants (Schulman, 1993), and aircraft carrier deck operations (Weick & Roberts, 1993).

The HRO perspective is further elaborated by systems theories emerging from engineering disciplines (Leveson et al., 2009), labelled Resilience Engineering (Hollnagel, Woods & Leveson, 2006). Resilience Engineering suggests that the way in which operational variabilities are handled explains why most operational processes are performed safely (Leveson, 2011; Hollnagel, 2012; Woods et al., 1994). From a Resilience

Engineering standpoint, it is impossible to design frictionless planning systems, complete system operating instructions, or unambiguously purposed management systems. These views resonate with influential science and technologies studies such as the work of Lucy Suchman (1987) on situated action, and Susan Leigh Star's work on boundary objects (Star & Griesemer, 1989).

To handle unexpected, but systematically occurring variabilities, HRO operators develop professional, experiential expertise that entitles them to make safety-critical decisions in the daily operation (Roberts, 1990; Weick & Sutcliffe, 2007). Their knowledge and experience can make a difference between life and death, but they are not infallible (Weick & Sutcliffe, 2007). Instead, HRO members humbly accept their human limitations and make an effort to learn from failure. To accomplish this, the organisation has to protect them from the age-old tendency of the society, in which they operate, to punish someone for a failure (Turner & Pidgeon, 1997). Societies confronted with catastrophe tend to seek a scapegoat to release all the public emotion and political stress.

Weick (1987) therefore argues that the precondition for a constructive organisational culture in HROs is that they are relatively secluded from their societal context. This portrays HROs as creating their own 'bubble' in society, within which professionals can perform their work by their own, expert professional ethics, undisturbed by the anxieties from the surrounding society. The resulting culture of high reliability (Weick, 1987), or safety culture (Weick & Sutcliffe, 2007), is protected by translating erratic public pressures for safety into rational, incremental process improvements characterised by high levels of formalisation (LaPorte, 1996).

However, the inside of the bubble looks messy, because HRO risk management is not strictly centralised (Schulman, 1993). In order to facilitate continuous learning, Schulman (1993) argued that HROs foster "conceptual slack", or "a divergence in analytical perspectives among members of an organisation over theories, models, or causal assumptions pertaining to its technology or production processes" (Schulman, 1993, p. 364). Schulman's study of a nuclear power plant revealed how "much of the formalisation at the plant is meant to document and reinforce an elaborate balance, even fractionation, of administrative power" (Schulman, 1993, p. 358). HROs thus manage risks through a negotiated order where zealous proceduralisation of technical work processes and office politics come together.

Schulman's (1993) work on HROs is relevant in the context of today's globally intensifying accountability practices (Power, 1997), within which conceptual slack is often perceived as a risk and a liability (Dekker, 2011b). This trend indicates that HROs' negotiated orders involve interaction with actors in their societal contexts, which suggests that HROs are not always isolated bubbles within society. I therefore continue to show how, in the case of commercial aviation, the negotiated order of high reliability manifests itself at the societal level and how that order impacts regular, safety-critical work processes in the cockpit.

2.3 METHODS

Based on seven years of research (2011-2017) in the Dutch aviation industry, I developed five vignettes that demonstrate regular social tensions in airline risk management. The vignettes, adopting three levels of Rasmussen's (1997) multi-level view of risk management, answer the central question in two main ways. First, vignettes 1 and 2 illustrate how contrasting risk perceptions manifest themselves in a negotiated order in airline's societal contexts. Vignette 1 describes a debate emerging between professional and public risk perceptions at the societal level. Vignette 2 shows how actors negotiate within this common tension at the administrative level. Second, vignettes 3 through 5 describe impacts of this negotiated order on work done in the cockpit, at the level of the safety-critical work process. I look at the impacts represented by pilots' social responses to risk management systems such as flight data monitoring; their involvement in the negotiated order that standard operating procedures represent; and the social influence they exert in negotiating between different planning systems.

The first two vignettes derive from data collected by investigating and participating in two interconnected aviation networks (see Table 3). First, I participated in an industry network consisting of a cross-section of aviation professionals. Second, I interviewed members of a governance network consisting of the aviation authorities, government, and industry management. Third, I conducted two rounds of in-depth interviews with airline pilots, who represented a subset of the industry network. In total I participated in 9 seminars and conducted 47 interviews; I recorded and transcribed interviews or made notes in case recording was not allowed or impractical.

The last three vignettes are based on two consecutive flight observations with a flight crew flying back and forth between two European cities. I made these observations from the back seat of the cockpit, called a jump-seat. I observed the pilots at work in the middle of a regular workday; they had more flights scheduled that day that I did not observe. During the flight, I was able to engage in conversations with them about topics that came up because something happened. Meanwhile, I made notes with pen and paper and occasionally took a photo or a short video. After the flights, I wrote down and analysed the events I had observed and checked my interpretations in two rounds with one of the observed pilots. In developing the vignettes, I compared them to the data from interviews and documents that I had collected and continued to collect for another year (see Table 3).

In the cockpit, I was able to make detailed, in-depth observations due to the extensive preparatory study of the technical and social aspects of pilot work. Earlier, I was trained as a private pilot to fly general aviation aircraft such as the popular Cessna 152. I also followed introductory aerospace engineering courses. This background allowed me to make an analytical jump to the level of large, complex, multi-engine, multi-crew airline jet operations. I performed a first flight observation in which I refined the observation technique. For this flight, I prepared myself by flying for one hour in a fixed flight simulator of that aircraft type. I analysed aircraft operating manuals and studied multi-crew

coordination techniques before entering into the second flight observation, reported here.

In the final analysis phase, I compared different data content thus gathered. For example, to develop the fourth vignette, I compared procedure variations reported by various interviewees. It emerged from these stories that procedure variations involved confusion, fuelling industry-wide debates about contrasting risk perceptions. Thus I was able to relate tensions I found in the societal context with subtle social expressions of humour, emotions, and stress in the regular cockpit work setting.

Table 3. Data collection and analysis

Time frame	Type of data	Data source	Content
2011-2017	Participation in 9 seminars, ethnographic interviews	Aviation professional industry network: ■ Airlines ■ Maintenance ■ Ground services ■ Air traffic control ■ Research ■ Oversight ■ Government	Emerging risk-related topics relevant to aviation professionals
2011-2012	12 interviews, 1 hour long on average	Aviation professional industry network: ■ Airline captains, co-pilots ■ Pilot trainer, examiners, managers ■ Retired pilots ■ Human factors training entrepreneurs ■ Flight simulator technology entrepreneurs ■ Aviation contract researchers ■ Aviation psychologists ■ Aviation consultants	Contrasting risk perceptions and their implications for regular work in the cockpit
2013-2015	20 interviews, 1 hour long on average	Aviation governance network: ■ Safety managers ■ Airline officials ■ Air traffic control officials ■ Aviation judiciary ■ Aviation police ■ Aviation inspectors ■ Pilot union member ■ Government officials ■ National & EU government bodies	Manifestation of contrasting risk perceptions in interactions between airline companies and their societal context

Table 3. Continued

Time frame	Type of data	Data source	Content
2011-2017	15 in-depth 1-4 hour long interviews, of which 7 were recurrent with the same interviewee	Airline pilots: ■ Captains ■ Co-pilots ■ Trainers, examiners, managers ■ Retired pilots	Impacts of contrasting risk perceptions emerging as social tensions in the regular work of airline pilots
2015 - 2016	Jump seat observations of 2x 2 consecutive flights to/from European cities, about 1 hour per flight and about 1 hour turnaround time for each set of flights.	Cockpit work environment of short haul jet aircraft: ■ Captains ■ Co-pilots ■ Flight attendants ■ Ground services ■ Air traffic controllers ■ Aircraft systems ■ Weather ■ Traffic ■ Airports ■ Airspaces	Impacts of contrasting risk perceptions emerging as social tensions in the regular work of airline pilots
2011 - 2017	Various documentation	■ Aircraft Operating Manuals ■ Navigational charts ■ Policy documents ■ Accident investigation reports ■ News media reports	Textual representations of contrasting risk perceptions

2.4 TENSIONS IN AIRLINE RISK MANAGEMENT

2.4.1 Vignette 1: Journalist ignores difference between ‘emergency’ versus ‘precautionary’ landing

The first vignette describes how, in a heated debate, a journalist rejected the arguments of aviation professionals to distinguish between an ‘emergency’ and a ‘precautionary’ landing. This occurred in a seminar organised by a Dutch aviation professionals network, exemplifying a cross-section of industry professionals. A few prominent journalists were invited to share their views on how they reported on aviation. The safety manager of a major aviation organisation shared the stage to enable a debate between the media and the industry. The audience was occupied by members of the industry network and by students in journalism.

Tensions rose in the room when a journalist from the popular newspaper *Telegraaf* took the stage. He talked about an occasion when a KLM aircraft, flying across the Atlantic Ocean, had made a precautionary landing in the UK due to unexpectedly strong headwinds. The flight crew thus managed to stay well within their safe fuel margins and there was never any danger to the passengers and crew. A *Telegraaf* journalist traveling on board, however, immediately contacted the editorial staff to report an “emergency

landing” due to low fuel. As soon as this news came out, a storm erupted in the news media to which KLM had to respond.

The discussion in the room now unfolded about the question if it was right for the *Telegraaf* to use the phrase “emergency landing” if this was factually incorrect. The journalist held on to his standpoint and said that he would not hesitate to use the phrase emergency landing again. He argued that he could not expect from his readership to tell the difference between an emergency and a precautionary landing.

Tensions escalated in shouting anger amongst the aviation professionals in the audience as the journalist went on to argue that his job was to report something newsworthy. Aviation professionals in the audience charged the journalist for fabricating news, which could have negative consequences for aviation professionals, organisations, and ultimately flight safety. However, the journalist continued that his professional ethic was to report something newsworthy in a language that his readership would understand.

“I actually liked the *Telegraaf* journalist,” an aviation researcher told me afterward. “At least he was honest.” The researcher, an active member of the industry network that had organised the seminar, was more appalled by the story of another journalist. This journalist had spent years investigating to try and prove a pilot guilty of an accident. The researcher found this kind of investigative journalism similar to the *Telegraaf*’s example in that it fabricated aviation news, but in a more destructive way. From the industry perspective, fabricating news about guilty pilots amounted to witch hunts, or calls for justice when there is no justice to be served.

This vignette demonstrates how contrasting risk perceptions manifest themselves in emotional debate about the way unusual events are portrayed and serve vested interests. One could sense the tension in the atmosphere that the emotional disagreement caused, which could perhaps be better understood when placed into the broader societal context. These were no idle semantic games, as a horrifying case from nearby Germany demonstrated. After investigators acquitted an air traffic controller who was on duty when two aircraft crashed mid-air over Überlingen, Germany, the controller was murdered by a relative of crash victims. The relative had felt that justice had not been served, and had taken matters into his own hands. Thus, members of the authorities and the industry could sense urgency to negotiate a position in risk debates that satisfies contrasting perspectives, as is demonstrated by the next vignette.

2.4.2. Vignette 2: Air traffic controllers’ alleged sensitivity to the prospect of prosecution

The second vignette illustrates how it emerged that, according to the Dutch aviation judiciary, air traffic controllers were more sensitive to the prospect of prosecution than pilots. This shows how actors in the aviation industry and the authorities are aware of contrasting risk perceptions and sometimes actively manage the resulting political sensitivities.

The observation took place in the office of a safety manager of a Dutch ATC organisation, just as I sat down to have an interview with the manager. The phone rang;

it was the aviation judiciary. A Dutch aircraft had accidentally overrun a taxiway and hit the grass while taxiing in freezing weather. Nobody was hurt, but in aviation, such a small event potentially becomes the site of an extensive investigation because it could have been worse. The airport where it happened was controlled by the safety manager's ATC organisation, so they also became part of the investigation. The judiciary was at this stage judging if the incident could have been caused by someone's intention or gross negligence, which would require him to start a formal investigation.

Now on the phone with the judiciary, the manager expressed dismay with the fact that the aviation police were visiting his organisation. The judiciary replied that the police were only conducting a preliminary investigation, but the manager felt that the line between preliminary evidence gathering and full-on prosecution was blurry. "Any evidence that they might gather now can be used to prosecute our employees later," he explained to me, after hanging up. From the manager's point of view, the judiciary did not live up to the kind of hesitancy to prosecute that they had mutually agreed on before.

What had happened? The reason for the incident was unclear at this stage, but it was tempting to speculate that the pilots were maybe taxiing too fast; this was a pattern I had heard about from pilots. If the pilots were speeding, however, it was unclear to me how the ATC organisation could be blamed. Could they be blamed for putting pressure on pilots to taxi faster than the speed limit? It seemed unlikely to me, but it was all speculation at this point—I had no access to data of the incident.

A few weeks later, I talked to the judiciary and asked him to clarify what had happened. He told me that to his mind, there was no direct cause for worry for the ATC organisation. Instead, his perception was that air traffic controllers were overly sensitive to the prospect of prosecution; more so than airline pilots. He said that members of the ATC organisation would still reference a 1990s case where a Dutch air traffic controller had been prosecuted. The judiciary found it hard to understand why the case resonated so strongly that, in 2015, it still caused hostile sentiments amongst Dutch air traffic controllers towards the judiciary. The judiciary pursued a policy of hesitancy to prosecute (see Dekker, 2007, EESC, n.d., and ICAO, 2016, 25 August, for elaborations on this policy of 'Just Culture'), enabled by maintaining rapport with various crucial industry officials like the ATC safety manager. By keeping in touch on a regular basis, the judiciary cultivated a knowledge basis to judge if a reported incident could be left to an organisation's own investigative process.

The vignette exemplifies how emotional disagreements emerge in daily risk management activities dealing with the political sensitivities of risk, and that considerable energy is spent to maintain a dynamic, negotiated order. The tensions erupting in the phone call between the safety manager and the judiciary illustrate the tensions arising in this work. The judiciary and the safety manager did not give any impression that the incident, and the disagreement it had caused between them, seriously threatened their relationship. These tensions seemed to be part of the game.

The negotiated order may also impact the regular safety-critical work processes in airlines. In the following vignettes, I focus on the airline cockpit work process and

a selection of events and conversations unfolding there on a regular working day. The first impact is a social response of pilots to their company's risk management systems.

2.4.3. Vignette 3: Flying 30 knots over the speed limit

The third vignette shows how a flight crew senses, anticipates and responds to managerial risk perceptions on their actions as they reflect on a deviation within what they perceived as a grey area of the rules. The observation took place in the cockpit of an aircraft that had just taken off and was climbing to cruise altitude, presently passing around 3000 feet altitude. I noticed that the speed indicator read 270 knots, instead of the 250 knots I expected. The co-pilot, as if anticipating my question, explained that: "Nine out of ten times we will fly maximum 250 knots [463 km/h] below Flight Level 100 [an altitude of 10,000 feet or 3 km]. But if the captain agrees, we can consider to go a bit faster."

Speeding below 10,000 feet was deemed to be one of the 'grey areas' where, according to some pilots whom I interviewed, the rules are not as fixed as they look on paper. This grey area differs from speeding on the taxiways of airports, which I allowed myself to speculate about in the previous vignette. Speed limits exist in certain parts of the airspace. Pilots I interviewed said that speeding often happens in the airspace between the ground and 10,000 feet, where a 250 knots speed limit applies. In this airspace, aircraft usually are either climbing away or descending on approach to airports. The reason for the speed limit is to keep these dynamic traffic flows manageable and prevent mid-air collisions between aircraft. However, pilots argued, sometimes exceeding the limit by 20 or 30 knots (37-55 km/h), would not endanger flight safety and could help. Speeding could sometimes straighten out the flow of traffic or simply help a flight catch up from an earlier delay, so that it could be on time for an arrival slot.

Back to the cockpit. Shortly after the co-pilot clarified the current speed—by now, reading 280 knots—an unusual warning popped up on one of the computer screens. "Speed limit exceeded." We were now passing through 6500 feet and both pilots said they had never seen this computer warning before. The co-pilot quickly cancelled the warning, joking that he did not want to be summoned to the office. The captain added that the office would probably get this message, in view of their extensive flight data monitoring. "You don't want to know what they are checking. The reversers you were pulling on landing, your flaps settings, everything."

It sounded like the pilots felt uneasy about being monitored, so I asked if there was any truth in the co-pilots joke. The captain replied that they did not have to fear being summoned because that only happened if one "experienced something", some kind of incident. The current situation would not qualify: "Flying 30 knots faster won't matter if you hit someone." Perhaps to make sure that I would not misunderstand his joke, the co-pilot concluded the conversation by stating that he had "complete confidence in the reporting culture of the company. It's really all about learning."

This vignette illustrates how pilots may anticipate and respond to the negotiated order embodied by their risk management system. The impact described here is subtle and of no direct consequence for the flight I observed, but it illustrates how pilots

may anticipate and respond socially to technical risk management systems. The social response here consisted of ironic and laconic talking about the system, possibly revealing some ambiguity in the company management's perceived intentions behind the system.

2.4.4. Vignette 4: “Quick reset” instead of following the SOPs

The fourth vignette describes how a novice pilot responds to a captain's order to deviate from the aircraft's standard operating procedures. Besides variations on air traffic rules like speed limits, described in the previous vignette, I also found that routine variations on technical systems operating procedures sometimes surface in the regular work I observed. The topic of performing variations on system operating procedures arose when one of the covers of the emergency rope, above the captain's head, suddenly fell open mid-flight. The emergency rope is intended for escaping out of the cockpit after a crash. The before start-up checklist required checking the rope on every flight, as I had seen the captain perform on the ground. Evidently, the captain suggested while closing the cover again, opening and closing the cover regularly had weakened the closing mechanism.

A conversation then arose about how in aircraft little things tend to break; and how the formal procedure for dealing with small system failures may differ from the informal norm. The co-pilot then shared his experience of becoming socialised in the culture of pilots flying the current aircraft type. In his initial training, he learned to strictly revert to the books whenever a failure occurred. Then, as he began participating in the operation, he was a little shocked to find that for many failures, the only accepted response was a simple, “quick reset”. That is, many failures would be remedied by simply turning the failed system off and on again. The co-pilot learned that the informal norm for a quick reset was more authoritative in practice than the formal procedure to which he was accustomed.

The background of the quick reset practice was that earlier generations of pilots were routinely faced with small system failures. They had learned that the formal procedure for many failures—taking out the Quick Reference Handbook and following the checklist—was unnecessarily cumbersome. Pilots found that in many cases a quick reset did the trick, and they began spreading this practice informally. The practice thus spread as seniors conveyed operational experience to juniors. Eventually, the quick reset practice found its way to “the office”, which decreed through an email communication that resets were allowed under certain conditions. The co-pilot added that he had missed the email, which was sent after he had already gotten used to the informal practice. Later on, he had heard about the formal change from a colleague.

This vignette thus illustrates how pilots socially participate in the negotiated order represented by Standard Operating Procedures (SOPs). Pilots participate in creative socialisation processes by which informal operational norms are created and maintained. A new member's experience of slight shock and confusion demonstrates the process when he gets exposed to the social norm that the informal routine prevails over the formal procedure. The differences between formal and informal practices may cause

confusion at first, for how does one know which parts of the books are authoritative, and which are not? When the informal norm is adopted in an amendment of the SOP, it turns out that pilots are not merely recipients of the negotiated order but also, as a collective, participate in the process of negotiation.

2.4.5. Vignette 5: A flight crew's frustration about a controller communication

This final vignette shows how, while taxiing to the runway, one of the observed flight crews got frustrated by a delay, which from the crew's perspective should have been communicated earlier by the ground controller. The flight was planned in detail, as always, but also encountered this contingency to which the pilots had to respond in a coordinated manner. Whereas coordination may sound like a neat, technical process, it can look tense, even angry, in practice. The following illustrates the coordination between air traffic controllers and the flight crew, taking the point of view of the latter. Even on a short flight in Europe, flight crews may pass through several, slightly differently organised ATC planning systems, with different customs and accents in English. The pilots on this flight had already spent some time talking about the annoyances that the different airport planning systems caused, before the following events happened.

When it was time to depart for the return flight, everything looked well. The weather was perfect and the passengers had boarded without incident. The ground crew had put some fuel in the wrong tank but it would be possible to correct this in-flight. While taxiing out from the gate, the flight crew was confident that they would arrive on time at the destination, until they spotted an ominous row of waiting aircraft. The captain requested an expected take-off time and the air traffic controller replied: "We will call you back." The captain cursed, sensing trouble. "How do they not know yet?"

A few minutes later, the ground controller returned on the frequency and politely informed the flight crew that "delay is one-niner minutes." The captain replied with a neutral "roger" but the mood in the cockpit instantly flipped to anger. The captain had just promised the passengers that they would be on time; now, they might have suddenly incurred about twenty minutes delay. "Ridiculous," the co-pilot exclaimed. "Why not let us wait at the gate so we don't have to stand here burning fuel?" In addition to the expected delay, the fuel management situation had suddenly changed. The co-pilot quickly calculated that their fuel reserve could now get below their expected Take Off Fuel (TOF). The number was written on a piece of paper clipped to the inside of the cockpit. Would they even have enough fuel to depart, by the time they would be allowed to take off?

The pilots continued to decompose the TOF-number to arrive at the minimally required amount of fuel to arrive safely at the destination. With a delay of about 20 minutes, they concluded, there would still be enough fuel to arrive at the destination well above minimum fuel required by law. There might however not be enough fuel left to divert without issue to another airport, in case of bad weather or a runway obstruction at the destination, for example. Even if they would have to divert, there would still be plenty of nearby airports in range, but the flight crew might have to declare an emergency.

Declaring an emergency is legally required below 30 minutes of fuel remaining. Once an emergency is declared, a formal investigative process will start and the event will be thrust into the public arena.

Diverting was an unlikely scenario, because the weather was good and the destination was unlikely to get unexpectedly closed at arrival. Talking it through, the captain reasoned that if something unforeseeable happened, they could “commit” to the destination. Confronted with this phrase, an air traffic controller could become more willing to find a way and let an aircraft land on a closed airport. “Committed” would essentially communicate the impending need to declare an emergency, thus preventing the situation where one has to come out and actually do it. Having calculated and reasoned it through, the pilots felt reassured. They continued to wait in line for take-off and the rest of the flight proved to be routine. Flying a bit over the speed limit, the pilots later even managed to catch up some of the delay and got their passengers to the destination on time.

The vignette demonstrates how anger and frustration can mark pilots’ preparation to negotiate contingent planning with ATC. Anger and frustration emerged first from the pilots’ lack of influence on the ATC planning system in which they operated, which pushed them towards the limits of their fuel planning. They responded by re-asserting their fuel planning and re-evaluating the safety and accountability risks associated with the landing phase of the flight, preparing a way to implicitly negotiate with ATC on arrival. Since the flight continued without incident, they did not need to exert this influence and their efforts never escaped the confines of the cockpit.

2.5 DISCUSSION

The five vignettes I presented in this chapter show what dynamic risk management looks like as a socio-technical phenomenon, embedded in a social context where contrasting risk perceptions exist. Contrasting risk perceptions manifest themselves in a negotiated order in airline’s societal contexts. I described a debate emerging between professional and public risk perceptions at the societal level, and subsequently showed how risk management actors negotiate contingent positions within this common tension at the administrative level. These observations demonstrate interactions between professional members of aviation High Reliability Organisations (HROs) and their societal context. The actors invest in negotiation because failing to do justice to either of the contrasting risk perceptions can have damaging consequences to aviation organisations.

I subsequently demonstrated how the impacts of the negotiated order of aviation HROs are visible at the level of the safety-critical work process. I looked at three manifestations of the negotiated order in HROs: the application of risk management systems in regular flight operations; social norms guiding variations on SOPs; and formal jargon used to negotiate contingent planning. The impacts of these manifestations of the negotiated order were visible, first, in how pilots responded socially to ambiguity in technical risk management systems by laconic and ironic talking. Second, I showed

pilots' feelings of shock and confusion when getting involved in the negotiated order through socialisation and learning how to perform variations on SOPs. Third, I highlighted pilots' anger and frustration when they were facing frictions in the negotiated order represented by different planning systems, and engaged in contingent planning to re-assert their position towards ATC by committing to the destination.

2.5.1 Social tensions in commercial aviation HROs

Developing empirically rich description of social tensions could further aviation safety debates about the meaning and consequences of observed irregularities. Often irregularities are reduced to forms of either human error or technical failure (e.g. Reason, 1990). In contrast, my observations reveal social tensions between actors engaging in risk management at different levels—society, administration, and hazardous work process—in the form of disagreement, ambiguity, and strains in the relationships between them. These social tensions become visible in emotions, humour, and stress, and provide a window into the regular irregularities, or the negotiated orders, that characterise aviation HROs on a daily basis. What the consequences of these social tensions are is a complex matter and subject to debate.

Going back to the wind shear scare described in the introduction, it seems obvious that the emotion of fear is an indication of danger and therefore demands action from actors who share some responsibility for the HRO risk management process. However, in light of the evidence presented in this chapter, the reader might appreciate the complexity of interpreting the risks associated with emotions like fear, and of arriving at a proportionate response. I demonstrated shared responsibilities between authorities, administrators, and operational personnel, and showed how they interact to subtly negotiate and re-negotiate an order that works. Much of their investments in this process may never be seen by higher authorities or outsiders to the professional community or even the single work space. For example, the efforts of the observed flight crew, to prepare for the highly unlikely prospect of negotiating with ATC, would never have escaped the cockpit if I had not been there to write about it here.

The approach to investigate and describe social tensions in depth may add an actor-perspective that is often lacking in functionalist aviation safety analyses. Functional safety analysis methods, such as LOSA (Klinect & Wilhelm, 2017) are useful because they do allow aviation HROs to gain insight in their own operational practices. LOSA could have found deviations as described in vignettes 3 (a speed deviation) and 4 (an aircraft operating procedure deviation). LOSA would probably label the former two as a type of error – a human-caused hazard – and then suggested a course of action, such as promoting compliance with speed restrictions and harmonising SOP with informal practices. While these are not necessarily bad ideas, the aviation industry is already immensely regulated and it is probably impossible to eradicate grey areas from sociotechnical systems (Amalberti, 2001; Suchman, 1987). I therefore agree with resilience engineering scholars (Hollnagel et al., 2006) that for cases like the above, error labels are probably overly negative and fail to do justice to the operational reality in which

deviations are performed. My approach might therefore usefully complement existing functionalist approaches. In contrast to a LOSA observer, I was not a “fly on the wall” to check for non-conform behaviours but engaged actively in conversations with the pilots, before, during, and after the flight, to learn how professional expertise comes into play in everyday practice (vignettes 3-5). Instead of focusing only on line operations, I also contextualised these practices in the society that shapes and impacts social interactions (vignette 1), which led to the interesting suggestion that political sensitivities might surface differently within different groups of aviation professionals (vignette 2).

2.5.2 Contextualising HRO practices in and beyond aviation

Developing a practice approach that seeks to contextualise (e.g. Nicolini, 2012) may be useful to understand how risks are managed by HROs both within and beyond aviation. By zooming in (Nicolini, 2009) on irregularities seen in everyday work settings in aviation, this chapter already provided some up-close glimpses of people regulating, managing, and working with hazardous technologies in aviation HROs. This approach contributes to research in HRO domains, which due to their “preoccupation with failure” (Weick & Sutcliffe, 2007) often focus on human error but lose a sense of context and lived experience that the vignettes reveal.

Loss of context is an important limitation to the use of safety tools like flight data recorders, or ‘black boxes’, from which often human errors emerge as culprits of aviation accidents (e.g. Dutch Safety Board, 2010). Airline captain Sullenberger makes an important point in this respect, as quoted in the movie *Sully*: “[If] you are looking for human error, make it human.” Dekker (2004) furthermore argues that we should not be looking for error, but a more neutral vocabulary about operational variabilities. Adding to Sullenberger and Dekker, I argue that since human action is social, we should add social texture to the debate about HROs. However, in contrast to the ‘neutral’ technical language promoted by resilience engineers, I suggest a more descriptive language of social tensions to translate relevant insights in everyday practice across HRO risk regimes.

A social perspective, which acknowledges the various ambiguities and emotions that people experience in everyday practice (e.g. Nicolini, 2012), suggests that irregularities in HROs are more than hazards to overcome. In contrast, from a functionalist perspective, irregularities are predominantly seen as unwanted hazards. We then tend to only see conflicting risk perceptions between aviation professionals and journalists (vignette 1) as dangerously undermining HROs; we could characterise negotiations between industry and authorities (vignette 2) as potential failures of oversight; and we might judge operational deviations (vignette 3 and 4) and emotionally charged coordination (vignette 5) as messy and weak examples of human involvement in high-tech systems. In contrast, from a social perspective, even if these examples do indeed reflect certain hazards inherent to HROs, they also reveal important, perhaps necessary work done in and around HROs. The social perspective then shows us how aviation professionals and journalists may learn about each other’s different points of view (vignette 1); how

politically sensitive negotiations are conducted between actors who represent different regimes of HRO risk management (vignette 2); and how highly skilled, reflective practices (Schön, 1983) are performed by aviation professionals (vignettes 3-5). Indeed, similar strains and stresses are observed in HROs outside aviation, such as how professionals demarcate and mobilise their expertise in nuclear power plants (Schulman, 1993; Roe & Schulman, 2008) and crisis response (Wolbers, Boersma & Groenewegen, 2018). This suggests that reliability-seeking sectors, such as hospitals, should also foster their own negotiated orders, instead of merely copying aviation's focus on proceduralisation, standardisation, and discipline (Kortleven, Putman & Waaijer, 2017).

I do not mean to argue that the presence of a flourishing negotiated order makes HROs immune to normal accidents; on the contrary, HROs still operate inherently vulnerable, hazardous systems that continue to evolve and sometimes produce hazards in new and unexpected ways. Rather, my argument is that negotiated orders are not inherently dangerous or deviant (Vaughan, 1997), and that we lack conceptual tools to distinguish hazardous social processes from safe ones. I further develop this line of thinking in the next chapter (3). Furthermore it may be fruitful to investigate and systematically compare social tensions in different types of HROs and bridge the opposing HRO and NAT viewpoints, which tend to get stuck in caricatures (Leveson et al., 2009; Shrivastava, Sonpar & Pazzaglia, 2009; Rijpma, 1997; 2003). The caricatures are as follows: if a safety-critical organisation is successful, we perceive an HRO; if the organisation is involved in an accident, we see evidence of a normal accident (Rijpma, 2003). Getting stuck in these opposing frames of mind does not lead to new insights about risk management. Instead, studying a range of vulnerable HRO conditions might open up the debate between NAT and HRO scholarship. An example of such work is found in Atak & Kingma's (2010) longitudinal, auto-ethnographic study of an aircraft maintenance organisation's negotiated order. When the organisation experienced rapid growth, the competitive strain was reflected in heightened social tensions between technicians, client pilots, and managers of the company. In this phase, Atak and Kingma (2010) argue, the aircraft maintenance company was more vulnerable to failure, because managers pushed technicians to compromise safety margins. With such an analysis it becomes possible to debate under what conditions HROs become more vulnerable, without needing to jump immediately to the inevitable accident waiting to happen.

Furthering the risk debate in this manner is a cross-disciplinary challenge, because different scientific disciplines specialise in different levels of the risk management process (Rasmussen, 1997, p. 185). An example can be found in the attempt of Passenier, Mols, Bim and Sharpanskykh (2016; chapter 4 in this dissertation) to translate Atak and Kingma's (2010) qualitative explanation of social tensions into a formal agent-based model. Applying the approach in a ground service organisation (Passenier, Sharpanskykh & de Boer, 2015; chapter 5 in this dissertation), this cross-disciplinary research led to new insights in the negotiated order at the work process level (Sharpanskykh & Haest, 2017).

2.6 CONCLUSION

I presented a study of the airline risk management including how actors in the societal context invest in a negotiated order to satisfy contrasting risk perceptions, and how these negotiations impact the regular work process of airline pilots. Despite available methods, it remains hard to judge if regular but messy or odd-looking events should be seen as risky, and what organisations should do about these risks. Further, cross-disciplinary research on the social conditions under which tensions emerge and modify the negotiated orders in regular technical work could move this debate forward.

CHAPTER 3

DEVIANCE IN AIRLINE COCKPITS



ABSTRACT

Organisational deviance, defined as routine non-conformity, can be dangerous in high reliability organisations when organisational deviance becomes normalised. Classic studies of major accidents, such as the Space Shuttle disasters, reveal that organisations gradually categorise hazardous deviance as 'accepted risk' until the hazards suddenly materialise. In this study, we show that in the case of commercial airline pilots' work practices, deviance is more pervasive than is previously acknowledged and actually stimulates reflective risk management processes. We studied pilots' work practices over a seven-year field study period, employing a combination of methods, including in-depth interviewing and detailed observations of pilots at work in the cockpit. Our study reveals how normalisation of deviance contributes to organisational risk management, when it enables professional intuition through reflective practice. This complements our understanding about normalisation of deviance as a potential hazard, because we show why deviance should be recognised as common and valuable in safety-critical organisations.

3.1 INTRODUCTION

It is a routine afternoon departure, but the flight crew feels the time pressure as they prepare the plane for flight. "It's like top-class sport," says the co-pilot. Rising competition with budget airlines puts pressure on the ground process, as is presently visible in the cockpit. While the captain performs the pre-flight procedure by heart, he manages to cram in a few words to the observer seated on the jump seat behind the two pilots. "I can already tell you..." – his right-hand whizzes across four different levers and switches – "...that I'm not following normal procedure here." The Aircraft Operating Manual confirms this statement, showing a slightly different sequence of checking and switching the position of 85 controls and indicators, a procedure that the captain performs in only a few minutes. On being asked why he deviates from the normal procedure, the captain later explains that this is how he had once learned to do it when he was still a co-pilot. In contrast to the formal procedure, his sequence follows a continuous line across the instrument panels in the cockpit, which, he argues, makes it easier to keep track of all items and therefore less likely he will forget something, even if he performs the process rapidly.

(Cockpit observation, September 2015)

Is it normal to deviate from formal procedures in an industry known for its safety and reliability? Indeed, deviance, generically defined as "routine non-conformity" (Vaughan, 1999, p. 274), is often characterised as a potential hazard in accident investigations. Studies focusing on major crises and accidents, such as aerospace accidents (Oliver, Calvard & Potočník, 2017; Snook, 2000; Vaughan, 1997; Weick, 1990), strongly influence risk management research. This view holds that once deviance is normalised, an accident cannot be far away, so deviance should be prevented at all times (Reason, 1990). This leads to an intensification of control (Power, 2008), involving methods like reporting, auditing, enforcing compliance, and adjusting the rules, based on systematic analyses of hazards (Power, 1997; Reason, 1997).

Studies of safety critical industries show that deviance is more pervasive than we often think, as demonstrated by phenomena like practical drift (Snook, 2000), performance limits violations, and procedure violations (Busby & Iszatt-White, 2016; English & Branaghan, 2012; Reason, 1990). This pervasiveness suggests that deviance might not automatically lead to accidents in safety-critical organisations. Indeed, research shows that approaching unintended deviance in a tolerant and constructive manner benefits organisational learning and performance (Sitkin, 1996) because after-the-fact reflecting on deviance helps shape future responses to real-time danger (Ron, Lipshitz & Popper, 2006). Thus we note a scattering of ideas about deviance in the literature, since it is unclear under what conditions the normalisation of deviance is dangerous, or how deviance could simultaneously be a normal part of reflective practice in ways that might even contribute to safety.

The aim of this paper is to provide a coherent perspective on deviance, suggesting that the normalisation of deviance can contribute to risk management. If risk management

is becoming a dominant template for organisational management (Hardy & Maguire, 2016; Power, 2004), fuelled by growing dependency on high-tech systems with potential for catastrophic failure (Perrow, 2011), then it is important to distinguish better the processes by which deviance can lead to negative *and* positive consequences. We investigated the normalisation of deviance by posing the following research question: *How does deviance become normalised in reflective safety-critical work practices, and what are the consequences for risk management?*

We first review the role of deviance in risk management in extant literature and then present an extensive study of deviance in commercial airline cockpit work practices. Our results indicate that deviance is pervasive in flight operational practices. Reflexive actions may trigger reflective deviations when pilots experience small anomalies. These reflective deviations are extracted from the operation by problematising deviance, after which some deviating practices are normalised in established work practices. By identifying this emergent process of risk management, we make two contributions. First, we contribute by explaining how deviance renders professionals' expert intuitions actionable. Second, we formulate a research agenda for organisations to stimulate reflective practices by which deviance may be normalised. In the following section, we will discuss the debate on deviance in risk management, which provides the basis for our study into cockpit work practices.

3.2 THE ROLE OF DEVIANCE IN RISK MANAGEMENT

Recent decades have seen a proliferation of risk management (Power, 2008). Whereas at first certain technologies, such as aircraft or nuclear power plants, were primarily considered as risky objects (Perrow, 2011), attention has gradually shifted to deviant organisations (Gephart, Van Maanen & Oberlechner, 2009). Risk management nowadays is thus being applied to the organisation of virtually all inherently dangerous human activities, ranging from flying planes (Pélegrin, 2013), to driving cars (Elvik, Vaa, Erke & Sorensen, 2009), providing medical care (Cagliano, Grimaldi & Rafele, 2011), or even mountaineering (Keyes, 2006). Risk management however is also applied to more and more mundane, less hazardous activities (Power, 2008) such as going to school (Binkhorst & Kingma, 2012) or playing children (Christensen & Mikkelsen, 2008). Risk management thus has become increasingly pervasive and controls many aspects of our daily lives.

3.2.1 The normalisation of organisational deviance

Studies on deviance play an important role in the proliferation of risk management, following Vaughan's (1997) seminal research on the Space Shuttle Challenger disaster as well as subsequent influential accident analyses (Dunbar & Garud, 2009; Snook, 2000; Starbuck & Farjoun, 2005; Vaughan, 2005). Organisational deviance in risk management is often treated as a potential danger, but this ignores other possible approaches. On

the one hand, ground-breaking studies into accidents explain that normalisation of deviance fosters less reflective practices, which can unnoticeably drift into complex failures (Snook, 2000; Vaughan, 1997). On the other hand, the same studies show that organisations develop highly reflective practices, of which other researchers (Weick, Sutcliffe & Obstfeld, 2008) claim that they mobilise technical expertise through deviance.

We first examine the argument that deviance fosters dangerous, unreflective practices. The key technical cause for high-tech accidents is 'complex interactivity' (Perrow, 2011) that makes technologies 'unruly' (Wynne, 1988). Complex interactivity means that, either because of unknowns in the core technical process or through complex interactions with unpredictable environments, deviations from normal procedures are regularly necessary. Because such deviations cannot be eradicated, organisations must learn, cope, and adjust their practices and sometimes their formal procedures, guided by strict organisational control systems (Leveson, Dulac, Marais & Carroll, 2009). However, in large, complex organisations, 'structural secrecy' (Vaughan, 1997), the inadvertent isolation of knowledge in dispersed pockets of organisations, may obstruct coordination of these adjustments. Sometimes, therefore, adjusted practices can drift out of control, which can have disastrous consequences. Snook (2000) describes that when a US Air Force squadron in Iraq adjusted its squawk code procedures for radar recognition, another Army Blackhawk helicopter unit had not been privy to these changes, which led to a friendly fire accident because two US Blackhawk helicopters were misidentified as enemy Hind helicopters.

While Snook's analysis reveals the danger of deviance within the military as a consequence of practices that locally drift away from the standard procedures, deviance can also be found in a complex interplay between intuitive and reflective risk assessments. Accident analyses of other complex organisations such as NASA have revealed in detail how more risks gradually become accepted when decision-makers, faced with little more than someone's strong intuition of danger, reject this intuition in favour of what is considered 'hard' evidence (Vaughan, 1997). However, what is considered hard evidence is subject to normalisation. In her study of the Space Shuttle Challenger accident, Vaughan (1997) demonstrated how deviance became normalised by NASA and the contractor that produced the failed rocket booster joints for the Space Shuttle. By 'normalised,' Vaughan means *"that behavior the work group first identified as technical deviation was subsequently reinterpreted as within the norm for acceptable joint performance, then finally officially labelled an acceptable risk. They redefined evidence that deviated from an acceptable standard so that it became the standard"* (Vaughan, 1997, p. 65). The accidents that occur as a consequence of such normalisation of deviance cause deep crises that make organisations problematise deviance, wanting them to reassert control (Maguire & Hardy, 2013; Turner & Pidgeon, 1997).

In a similar vein, in the infamous incident at Tenerife airport where two Boeing 747s crashed into each other, a Dutch captain muted the feelings of his co-pilot and flight engineer that something was amiss (Weick, 1990). The Tenerife accident, however, rather than serving as a crisis with only a temporary effect on risk management, as was seen in

the case of NASA (Boin & Schulman, 2008; CAIB, 2003; Vaughan, 2005), contributed to a lasting integration of more risk-averse attitudes in commercial aviation's professional safety culture which now pays more attention to intuitions of danger. Crew Resource Management (CRM) training was developed over decades, teaching co-pilots to 'speak up' against captains, accept errors as part of their normal work, and develop skills to manage and learn from these errors while remaining constantly aware of the danger (Helmreich, Merritt & Wilhelm, 1999). Today, these views are common sense amongst pilots and developing the skills to approach deviance constructively constitutes an important part of the socialisation process into the professional pilot communities of commercial airlines.

3.2.2 Reflective practices in High Reliability Organisations

The same studies that point out how normalisation of deviance caused accidents, also note the extensive reflective practices by which organisations approach deviance. A popular explanation of the Challenger accident was that it had been illegally launched due to malevolent procedure violations within NASA. When Vaughan tried to confirm this popular notion, she found that violations of procedures hardly exist as such. In contrast, the organisation has extensive rule systems for creating workarounds in order to continuously learn to work with the technology. Schulman (1993) refers to a 'negotiated order' by which such complex bureaucracies maintain a certain order whilst continuously debating changes to established practices. NASA employed bureaucratic control like 'waivers', defined as "*a formalized procedure that, upon approval of the technical rationale behind the request, allows an exception to some internal rule*" (Vaughan, 1997, p. 57), by which the normal operation could continue through adjusted practices.

In other words, under very specific conditions, deviance is normal, accepted, and even valued in high-tech organisations. Even unintended errors, such as when forgetting an item in a lengthy procedure or entering wrong values in a computer, are valued to the extent that they can provide information about design weaknesses in systems and procedures (Reason, 1997). Deviations from procedures can trigger reflection on work practices that is instrumental for both learning (Thomas, 2003) and adapting to varying operational contexts (Haavik, Kongsvik, Bye, Røyrvik & Almklov, 2017). However, these positive roles of deviance are often pushed to the background when researchers are looking for ways to explain how an accident occurred. The psychological mechanism of 'hindsight bias' makes it hard to read anything else but a catastrophic plot in operational deviations, even if the basis for the inferred causal explanations is weak (Dekker, Cilliers & Hofmeyr, 2011). Hindsight bias affects accident investigations (Dekker, 2004) as well as the identification of future risks (Dekker, 2004), implying that the danger of deviance may often be overestimated.

Indeed, Vaughan (1999) states that while organisational deviance may be considered in the light of positive and negative consequences (cf. Merton, 1949), her work focuses on negative consequences. It therefore comes as no surprise, examining the literature on High Reliability Organisations (HROs), that we find that deviance can also contribute

to safety (Fraher, Branicki & Grint, 2017; LaPorte & Consolini, 1991; Roberts, Stout & Halpern, 1994; Schulman, 1993; Weick & Roberts, 1993). HROs conduct operations safer than one might expect based on the severe hazards inherent to their processes. In commercial aviation, for example, safety currently hovers around 0.08 accidents per million flights, with 2017 striking a record of zero fatal accidents (Young, 2018). An important aspect of such successful HRO risk management concerns non-conform behaviour to handle risks that emerge real-time in the operation (Weick & Roberts, 1993). Work practices in HROs therefore rely on often quick, critical judgments made by local technical and experiential experts, which sometimes may go against the formal lines of the more traditional bureaucratic system, such as formal authority and decision trees. These practices are reflective (Fraher et al., 2017; Schön, 1983) because they rely on a supportive safety culture where professionals develop a sharp technical intuition (von Meier, 1999), which, due to diverse expertise bases, regularly leads to debate and epitomises useful ‘conceptual slack’ in the organisation (Rochlin & von Meier, 1994; Schulman, 1993).

The resulting debate suggests that HRO professionals manage risks through reflective deviance, which seems to imply that unreflective deviance is dangerous. The basic assumption is that routinised action, on account of its automaticity, saves resources like time and energy, and risk management implies intervening in these processes by making them more reflective. Putting risk management into practice is therefore often seen as a trade-off between working thoroughly, by complying with organisational procedures, and working efficiently, by deviating and taking more intuitive shortcuts (Hollnagel, 2009). However, the assumption that costly, slow reflection implies a trade-off with efficient, fast reflexes, has been extensively challenged (Dreyfus & Dreyfus, 2005). Indeed, it turns out that fast ‘*reflexive*’ processes operate in parallel with slow ‘*reflective*’ ones (Lieberman, 2007) and both processes “literally compete for control” as people act (Hodgkinson & Sadler-Smith, 2018, p. 487). That is, we now understand that intuitive forms of normalised deviance, such as quick, habituated shortcuts and workarounds that people locally develop to speed up their process, goes together with reflection and deliberate control.

In sum, we thus signal a scattering of ideas about the role of deviance. On the one hand, scholars argue that normalisation of deviance can make organisations unreflective about the dangers of deviance, with catastrophic consequences as a result (Snook, 2000; Vaughan, 1997). On the other hand, scholars investigating these same complex organisations tasked with safety-critical operations, find that while deviance is in some ways normal (Schulman, 1993), these organisations’ work practices are unusually reflective and wary of danger (Fraher et al., 2017; Weick et al., 2008). These different theoretical positions motivate our research, because while contrasting views have been duly noted (Leveson et al., 2009; Rijpma, 2003), we argue that there is need for a more coherent perspective. To restore coherence between these two risk approaches we investigate what a normalisation process looks like by which the intuitions of danger are not trivialised, as seen in the NASA and Tenerife disasters, but acted upon.

3.3 RESEARCH DESIGN

When we started to examine deviance in commercial airline cockpits and the question of whether and how deviance might be normalised, we aimed to uncover a complex set of activities that was not well-defined ex-ante. We therefore followed the logic of zooming in and out of the phenomenon of interest (Nicolini, 2009) and employed an engaged practice-approach (Barley & Kunda, 2001; Nicolini, 2012; Van de Ven & Johnson, 2006). We characterise our approach as engaged because we studied and gave voice to practitioners, and in particular under-represented voices, such as advocates for new safety approaches, that contradicted dominant discourses, such as the risk discourse that emphasises compliance. Our approach qualifies as a practice-approach because we studied deviant aspects of cockpit work practices as well as pilots' reflections on these practices, enabled by the reflective nature of these practices.

Based on our theoretical framework, we distinguish three elements in reflective processes: reflexive action, reflection-in-action, and reflection-on-action (Hodgkinson & Sadler-Smith, 2018; Schön, 1983; Yanow & Tsoukas, 2009). Through interviews, we first tapped into pilots' ongoing reflection-on-action, such as when talking with colleagues about challenging work situations over lunch or coffee (Orr, 1996). These reflections guided us to grasp reflection-in-action, i.e. split-seconds of thinking and deliberating that happen while an action in the cockpit is unfolding, predominantly relying on pilots' fast reflexive action. The example in the introduction, where a pilot comments on his routine deviation while he performs it, illustrates how both the observer and the pilots identified situations of reflection-in-action. To retain our independent analysis, we regularly compared and triangulated different sources, and discussed the emerging interpretations within the research team.

3.3.1 Research setting

The three elements of reflexive action, reflection-in-action, and reflection-on-action occurred in different domains in our research setting. First, there are individual flight crews' reflexive actions, taking place mainly in cockpits characterised by meticulous, continuously updated technical designs, maintenance, and operational support. Flight crews operating them, in case of the short-haul flights we studied, usually consisting of two pilots who often do not know each other but can smoothly work together because of their intensive training and extensive standardisation. With technological advances, processes that in the past relied on crews' deliberate reasoning and calculating, under pressure of the ongoing operation, are now distributed between human actors and technical systems. In today's automated cockpits, most visible actions by human operators, therefore, are reflexive actions, such as making a quick judgment by eye. Knowing how technical systems work, procedures are designed, and flight crews are trained, therefore is essential to understand the meaning of what, to an untrained observer, might seem like mindless actions.

Reflection-in-action is seen when pilots in the operating environment discuss how to adjust to contingencies. In order to be able to intervene, pilots do not just monitor if dials are pointing “in the green” and react when the system tells them to do something, but rather prospect, by scanning if the readings make sense in terms of the underlying – often quite complex – system logics and the expected flow of unfolding events. The slightest deviations that emerge in the process trigger a sense that something is off and requires attention, i.e. reflection-in-action. Pilots activate themselves by using tools like checklists and scan flows across the instruments to keep checking if the readings make sense. Sometimes cues that something is off are easy to spot and the required responses well-rehearsed; at other times cues are not that obvious, which can be confusing or even threatening. Therefore, pilots experience a strong norm of providing constant feedback to keep everyone as well-informed as possible.

After the flight, as well as during low-workload periods in the cockpit, deviations from the normal process also trigger reflection-on-action. Pilots take the planned process such as provided by the trained and written procedures very seriously. They often discuss their experiences in convoluted legalistic and technical jargon amongst each other informally, in training sessions, and by entering even mundane deviations and anomalies from planned processes in centralised safety reporting systems. There, these data are analysed and used to distil safety lessons that are communicated back to pilots or other parts of the operation, or serve as input for complex procedure redesign processes. Updates are offered continuously, but the updating process may involve many parties, including regulators and aircraft manufacturers. Safety information can also lead to modifications in the continuous flight simulator training cycle that pilots are subject to during their entire career.

The flight simulator hence is another setting where we find all three elements. All flight training on a new type of aircraft starts in realistic (moving) flight simulators and trains reflexes to the point that trained pilots can immediately start flying the real aircraft operationally. From novice pilot to experienced captain, pilots’ expertise typically develops in stages, where at first they are still highly aware of all procedures, but not necessarily know how to apply them in complex situations yet, while senior pilots may have forgotten about certain procedural details but know exactly how to handle complex situations. Half-yearly recurrent flight simulation training keeps these reflexes sharp, guides pilots to reflect-in-action, and triggers them to also reflect on their actions.

While these work processes and safety systems are very similar across the globe, there may be differences between countries. Our study took place in the Netherlands, a member state of the International Civil Aviation Organization (ICAO, 2018), falling under the jurisdiction of the European Aviation Safety Agency (EASA, 2018) and EU and Dutch aviation law and regulations. By focusing on one national context we could involve many key positions in relevant social networks; this gave us ample insight in typical social phenomena observed globally in aviation.

3.3.2 Data collection

The first author gathered different types of qualitative data by approaching research participants and building relations with aviation professionals in the Netherlands between 2011 and 2017, as part of ongoing research in aviation (see Appendix 3A). With about 170 hours of General Aviation (GA), non-professional, flight experience, and having completed one year of aerospace engineering course work, this author was uniquely prepared for this study. Because pilot training starts in GA aircraft, the first author could draw on a shared background in terms of basic flying principles and a common understanding of the existential value of standard procedures. The data reflect pilots' current experiences as based in the four different airline companies where they worked, as well as previous experiences in several other companies inside and outside the Netherlands. In total, sixteen interviews were conducted in the first, exploratory phase. Participation in a professional aviation network, as well as interviews with key governance actors, helped form a deeper understanding of the type and origin of discussions surrounding deviance and risk. The first author participated in nine professional seminars, presenting and conducting workshops on two occasions. From 2015 onwards, the first author developed a dialogue through seven consecutive interviews with an airline captain with an academic safety background, which allowed us to start zooming in on deviating work practices. Throughout the process, all authors discussed the data being collected to challenge informant choices as well as initial interpretations of what informants were saying.

Based on personal invitations by this captain in 2015, and a co-pilot in 2016, the first author conducted observations in cockpits of two different aircraft types and companies. For the first observation, the first author studied the aircraft procedures and took an hour of flight simulator training to get a sense of flying a large two-engine jet, as well as of the complex cockpit crew coordination materials and procedures involved. After the observation, notes were transcribed and the captain was interviewed to check the accuracy of the observations, elaborate upon them and connect them to earlier conversations. For the second observation, one year later, the knowledge gained from the first observation transferred well enough so that no further training was needed. The debriefing interview sufficed to understand the deviations in this case, what motivated them, and how they connected to larger debates in the professional community of pilots, flight instructors, and CRM trainers on the normalisation of deviance. The observations helped refine the reflexive dimension of our analysis, as it gave access to events that pilots might not necessarily want to be known. The debriefing interviews underscored the value of these observations, such as when the co-pilot was shown a series of photos made of him slightly mixing up a short sequence of fuel tank switching actions. He joked: "I kind of hoped you hadn't seen that," commenting that he was impressed by the level of detail of the field notes.

Finally, the first and second author together conducted observations in five seven-hour flight simulator sessions, followed by a debriefing interview to examine our observations and five further interviews to challenge and inform our interpretations. Even though the flight simulator setting might inspire conforming behaviour, we noted

some interesting deviations and discussions about these deviations. One part of each flight simulator session was particularly useful because it was not concerned with training but with 'just' observing how pilots normally fly. In the span of about 80 minutes, a regular flight process was simulated from preparation to parking. The instructor's role was to operate the simulator and play all the other actors that pilots normally encounter on a regular flight, such as cabin crew, air traffic controllers, ground service personnel, and maintenance and operational back offices offering assistance in case something was wrong. Instructors would also comment during the simulation flight on actions to help us understand what happened and take note of something that we could pick up on in the coffee break afterwards.

Simulator flights are much less complex than real flights, for example because the instructor can only play one actor at a time; yet the observed simulated flight was packed with small failures that required pilots to act in non-normal ways, which triggered non-standard actions. The training practices we observed, such as how instructors engaged with different crews' performance of non-standard actions, further corroborated our interpretations of how reflective practices take place. We transcribed our notes and checked our interpretations in interviews with the instructors as well as the company's safety and training managers.

3.3.3 Data Analysis

The data provide a rich set of empirical examples of how deviance occurs when risks are managed in cockpit work. To this end, we began unpacking our deviance examples by coding elements of reflective processes as we found them in the empirical examples. We developed the coding scheme through an iterative process (Gioia, Corley & Hamilton, 2013). We first labelled the empirical examples shown in Appendix 3B with first-order concepts that formulated aspects of reflexive action, reflection-in-action, or reflection-on-action. We grouped the examples to different risk-prone processes, such as take-off, landing, failure management, and fuel management. In this grouping, deviance is still implicit: some examples are one-off deviations, which according to our definition is not necessarily deviance; other examples concern routine deviations, and thus constitute deviance. Some examples show explicit reflection-in-action, such as the example of adapting the standard procedures for selecting flaps to non-normal snow conditions (#I.1 in Appendix 3B). Other examples show reflection on an earlier performed action that failed to accomplish a goal, signalling a lack of reflection-in-action, such as when one flight crew in a simulator session forgot the after-care process of a cabin injury accident (#S.11 in Appendix 3B).

From this process of examining different empirical examples and counter-examples, we developed second-order themes that were theoretically informed and that described the normalisation of deviance. As we began to gather a larger volume of data, the different examples and counter-examples of deviance, we realised, could all be interpreted in terms of potential negative as well as positive consequences. Indeed, the informants interviewed in intermediate stages of the analysis process provided commentary on the

possible mechanisms and the positive and/or negative consequences. They generally suggested that these are not mutually exclusive processes; the positive normalisation processes usually are not differentiated from the negative ones. This analytical process resulted in a coding scheme consisting of six second-order themes: reflexive action, experiencing small anomalies, reflective deviations, problematising deviance, normalising deviance, and established work practices.

We went through several iterations before arriving at the two aggregate dimensions of deviance and normalisation, which connected the different second order themes. In addition, we realised that the deviance and normalisation processes operated at different levels of analysis. We identified that deviance occurred at the operational level, whereas the normalisation process occurred at the organisational level. Throughout this process, all four co-authors independently reviewed the evolving coding scheme to assure a balanced interpretation, develop our understanding of the operating mechanisms and tease out different explanations of deviance and normalisation. We realised that a perspective on positive deviance consequences was important, complementary to the already strong discourse on negative consequences. This led us to develop a data structure of deviance normalisation (see Figure 1), which we will explain in the findings.

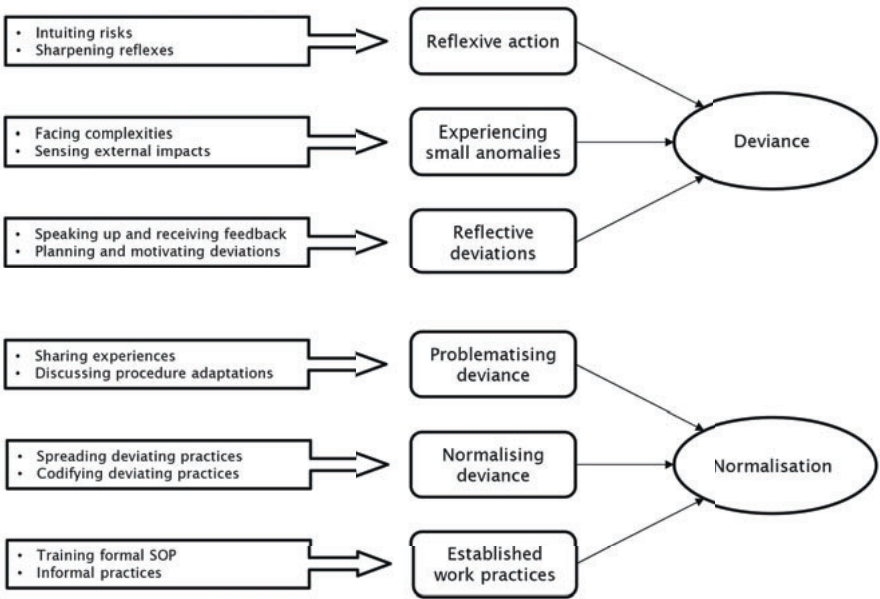


Figure 1. Data structure

3.4 FINDINGS: NORMALISATION OF DEVIANCE IN COCKPIT WORK PRACTICES

Our analysis of cockpit work practices revealed that the normalisation of deviance is a bottom-up process consisting of *deviance* and *normalisation* as two distinct parts, which link the operational and the organisational level. Through this process pilots are able to strike workable balances between safety and efficiency and manage complex safety risks.

3.4.1 Deviance

In this section, we first unpack the emergence of *deviance* in the regular flight operation as pilots recognise and act on various cues. This process consists of *reflexive action* followed by *experiencing small anomalies*, which may trigger *reflective deviations* as shown in Figure 2.

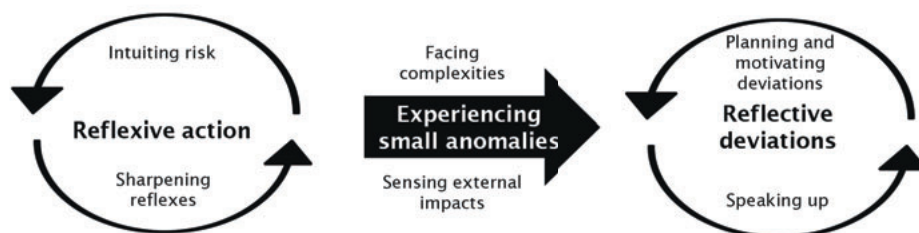


Figure 2. Deviance process

Reflexive action. Reflexive action is predicated on a continuous stream of cues. Many cues are recognised from previous experience and training and trigger pilots' well-rehearsed reflexes. Because not all cues can be covered by training, and pilots have varying experiences and backgrounds, there is some variation in what cues pilots recognise as well as what the cues signify to them. Therefore, when presented with the same cues, pilots may intuit different degrees and types of risk, as we observed in the flight simulator exercise. Only one of the five crews faced with the identical conditions decided to bring additional fuel for their flight. The weather conditions were so close to the legal limits that this crew thought that they risked having to wait before the take-off runway for the weather to clear up and consequently run low on fuel for the flight.

Cues like certain weather conditions therefore may signify a risk, or an opportunity, and pilots develop their sensitivity to these cues by sharpening their reflexes, sometimes in non-standard ways. A co-pilot argued that within limits, he regularly experimented with different techniques because it expanded his sense of what he could do with the aircraft. We for example observed him select flaps instead of airbrakes, when Air Traffic Control (ATC) requested him to expedite his descent. He argued this was a way to increase drag and thus descend faster, without making the aircraft buffet as much as the speed brakes did, thus benefiting passenger comfort. Such small experiments might trigger the emergence of (slightly) deviating practices.

Table 4. Reflexive action

1st order	Empirical reference	2 nd order
Intuiting risks	■ of dirty runway + tailwind, which triggers a “red flag” (#I.17); ■ when hearing that the weather conditions are close to minima (#S.2; #S.4)	Reflexive action
	■ when sensing familiar engine vibration (#S.8) ■ of deviating from stable approach criteria (#S.12) ■ of a co-pilot who fails to anticipate wind conditions while flying (#I.5)	
	■ by self-training a mental trigger to do an extra check on air pressure (#I.9) ■ is induced while vacating the runway: feeling the anti-skid operating confirms a “red line” for accepting “dirty runway” conditions (#I.17)	
	■ by dimming lights as a sure reminder to close the window after checklist says so, but before taking off (#O.6)	
Sharpening reflexes	■ when using hand grip to remember clearance received (#I.7) ■ by levelling off just above clouds and bleed off airspeed before descending into clouds and possible turbulence (#O.15) ■ by manually flying around clouds to avoid turbulence (#O.14) ■ by trying flaps instead of airbrakes to expedite descent smoothly (#O.12)	
	■ by trying a fuel management sequence and correcting mistake (#O.3) ■ by dipping one wing to make the plane “sit” more comfortably (#O.17)	

Experiencing small anomalies. Faced with certain cues, pilots may judge these to be (slightly) anomalous. Experiencing anomalies often means facing complexities intrinsic to the flight process, such as we observed when a flight crew inadvertently triggered a navigation system warning. They conducted their pre-flight process very fast in order to depart on time, but this meant that the system was not yet ready when the crew entered a subsequent process. The crew did not know about this complex interaction and therefore did not understand why the light had come on and gone off again. They called the ground mechanic on duty who helped diagnose the anomaly, after which the crew felt confident that the system was, in fact, operating normally.

Pilots can also experience anomalies due to some external event that impacts the operational process, such as we observed when flight crews in the simulator experienced vibration due to simulated ice accumulating on the engine’s turbofan blades. This example shows that the source of the impact may not be immediately apparent. One captain, who had previously experienced the vibration in real life, immediately recognised the sensation caused by the simulator, and directed his team process straight to the associated Quick Reference Handbook (QRH) procedure. In contrast, other crews were more surprised by the vibration. In view of the weather conditions reported, they thought that ice formation was unlikely and it subsequently took one of these crews more time to diagnose and resolve the problem.

Table 5. Experiencing small anomalies

1st order	Empirical reference	2 nd order
Facing complexities	■ interrupting the engine start checklist in complex airport (#I.9) ■ triggering a system warning when performing start-up very fast (#O.11) ■ triggering critical fuel when taking time to handle problems (#S.4) ■ requiring crews to prioritise, inducing forgetfulness (#S.11)	Experiencing small anomalies
Sensing external impacts	■ of personal problems that may reduce pilot's sharpness (#I.10) ■ of short/rugged airfields on landing (#I.11) ■ of tailwind and dirty runway on landing (#I.17) ■ of low visibility and unserviceable runway lights on fuel safety margin (#S.2) ■ of volcanic ash on engines (#S.1) ■ of ice on engine turbofan blades (#S.8)	

Table 6. Reflective deviations

1st order	Empirical reference	2 nd order
Speaking up and receiving feedback	■ when given nonstandard command to handle both radio and failure (#I.6) ■ when operations centre hesitates to accept extra fuel (#S.3, #I.2, #I.4) ■ by joking about co-pilot's fast taxiing (#O.16) ■ by raising question, triggered by error in captain's briefing (S.7) ■ by inviting feedback, saying "if you're not happy, we don't go" (#S.1) ■ by adjusting leadership style to co-pilot's expertise-level (#O.4; #S.5)	Reflective deviations
Planning and motivating deviations	■ by taking a moment to discuss the timing of a non-normal procedure (#I.1) ■ by briefly reasoning through contingencies when fuel goes critical (#S.4) ■ by recalculating the expected fuel available on take-off after getting delayed while taxiing, weighing the risks, and deciding to "commit" to land on the destination airport because it is unlikely to close down (#O.2) ■ by silently weighing risks before transgressing speed limit (#O.13) ■ by shortly explaining a nonstandard solution to a resisting co-pilot (#I.6) ■ by discussing whether to continue the flight as planned, divert, or return because of some problems incurred during flight (#S.10)	

Reflective deviations. Small anomalies trigger pilots to reflectively deviate by speaking up and receiving feedback, and planning and motivating the deviation. Flight crews may show contrasting responses to small anomalies, which surface when pilots speak up. Speaking up when one sees a higher ranked crew member do something strange

or incorrect is found extremely important, if very difficult –even in the supposedly egalitarian culture in the Netherlands– because it is not self-evident that higher ranks will be receptive to feedback. Procedures help co-pilots to speak up, such as by simply calling an anomalous reading (“speed!”) rather than saying the captain is doing something wrong (“you are going too slow!”). Captains may however consciously invite feedback by adjusting leadership styles to the perceived expertise-level and attitude of the co-pilot. The more novice co-pilot might benefit from a more directive captain to structure the overwhelmingly complex, fast-pacing operation, but since novice pilots might also be less assertive, captains may explicitly give co-pilots space to voice contrasting viewpoints.

Reflective deviations are furthermore planned and motivated. Sometimes there is plenty of time to discuss the plan and motivation of the deviation. Often, however, there is little time for explicit deliberation and split-second reflections may at first appear rudimentary or even absent. In the simulator we observed how a captain, despite rearranging and extending his final approach to make more time to configure the aircraft for landing, did not manage to reduce enough speed before reaching 1000 feet, at which point the SOP stipulates that a ‘stable approach’ should be established. The co-pilot asked if they should go around, but the captain replied “no” and continued steering the plane down in silent concentration. Because of low fuel and several failures incurred earlier, the captain explained afterwards that he instantly felt that going around presented a bigger risk than deviating from the stable approach procedure. Indeed, the instructor congratulated him on making a good and fast decision that demonstrated operational expertise.

3.4.2 Normalisation

In this section we unpack the process of *normalisation* that occurs when pilots extract their reflective deviations from the operation. In this process, pilots first engage in *problematISING deviance*, and may *normalise deviance* by informally spreading deviant practices or codifying them into established work practices, as shown in Figure 3.

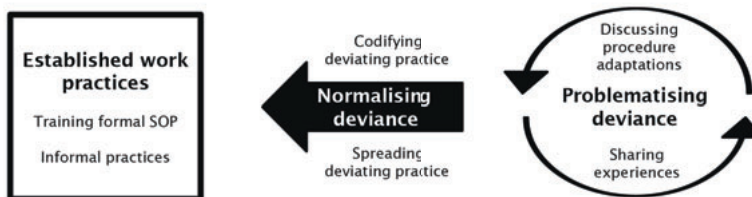


Figure 3. Normalisation process

ProblematISING deviance. Pilots extract deviance from the operation by problematising deviance when they are sharing experiences or by discussing procedure adaptations. Sharing experiences of noteworthy deviations may problematise a particular situation where it was not obvious how to apply the SOP, or debate pilots’ responses to such situations. The captain in one of our flight observations, for example, told a ‘war story’ about a co-pilot resisting an urgent request because it was non-conform the SOP. In mere

seconds, the captain had to explain the deviation before the co-pilot understood and would go along. The point of this story was to demonstrate that being a good pilot means sometimes deviating from procedures to deal with a complex situation. By sharing such experiences, pilots may question each other's abilities to handle complex situations in line with SOPs and take a position in larger questions of what it means to be a professional pilot.

By discussing procedure adaptations, pilots may subsequently problematise the SOP itself. Pilots for example debated about the extent to which speed limits could be violated to gain flexibility without endangering flight safety. We observed this process in informal discussions arising in breaks of the simulator sessions, where pilots debated whether fast taxiing was worth the risk. Pilots may also disagree with the aircraft operating manual about what the safest procedure is and develop their own deviating practice, as was the case for automatic landings on an aircraft that has two independent autopilot systems. Normally, pilots flew with only one of the autopilots engaged and the other functioning as backup. However, for automatic landings the manual prescribed selecting two autopilots, because only with two systems engaged could the aircraft perform an automatic go-around. In order to prepare for this eventuality, the two systems combined would always start trimming up the nose around 400 feet altitude. If in this situation, for whatever reason, the pilot should have to decide to overrule the autopilot and take manual control, he or she would have an 'out of trim' aircraft that was less controllable at a very critical low altitude and speed. One of our informants found out that to prevent this risky eventuality, many of his colleagues chose to select only one autopilot, which would mean that an automatic go around was not possible, but they would in any case never have to face an out-of-trim aircraft. Consequently, they would have to be ready to disengage the autopilot and perform the go-around manually if needed. Discussing such a procedure adaptation thus involves critically examining reasons for deviating and techniques by which to accomplish the goal of the SOP and the underlying company policy, such as landing safely under varying weather conditions or flying passengers timely to their connecting flights.

Normalising deviance. We found that in some cases informal deviating practices were normalised because, after ample problematisation, they were found to offer better solutions to practical problems than the existing SOP. A deviating practice can then spread informally in the operation such as by captains' instructions to novice co-pilots. One co-pilot for instance said that he was instructed to deviate from the SOP in the case of various small system failures. When he was about to find the relevant Quick Reference Handbook procedure after a failure occurred in flight, he was briskly told to just reset the system. After his initial shock, the co-pilot learned that this was standard practice in his type division for several of the small system failures that the aircraft routinely suffered.

When the deviating practice that has emerged from practical experience in the operation is found to offer a better solution than the written procedure, the organisation may undertake a formal process by which the practice is codified into a modified SOP. Because modifying SOPs involves many different regulatory bodies and organisations,

airlines may be hesitant to start the process. In the case of the 'quick reset' deviating practice, the organisation eventually codified this by formulating certain conditions under which this practice was allowed. The type division's chief pilot communicated the modification by email to all pilots, which our informant co-pilot had actually missed, but was told about by a colleague in the operation.

Table 7. Problematising deviance

1st order	Empirical reference	2nd order
Sharing experiences	■ by telling war story about co-pilot resistance (#I.6) ■ by voicing distrust in aircraft checklist design (#S.9) ■ triggered when the emergency rope cover falls open in flight (#O.10) ■ of generic failure procedures in other companies and type divisions (#I.14)	Problematising deviance
Discussing procedure adaptations	■ of leading nonstandard autopilot practice (#I.18) ■ when new SOP no longer specifies quantitatively when to select runway turnoff lights (#I.20) ■ of risks involved in making reverse thrust a non-normal procedure instead of the normal procedure (#I.21) ■ needed to comply with the rules of a complex airport (#I.9) ■ by debating whether the time gained by fast taxiing is worth the risk (#I.6) ■ by debating stable approach deviations (#S.13)	

Table 8. Normalising deviance

1st order	Empirical reference	2nd order
Spreading deviating practice	■ when co-pilot is told to do a "quick reset" instead of following procedure (#I.13) ■ by commenting that briefing "flex temp" as per SOP signifies a lack of independent thinking (#O.5) ■ by explaining tricks to use grey area and get some flexibility in loading (#I.3)	Normalising deviance
Codifying deviating practice	■ when management endorsed the "quick reset" under certain conditions (#I.13) ■ when late passenger seating becomes the standard procedure (#I.15)	

Established work practices. Finally, the normalisation of deviance modifies established practices. Established practices could be modified when normalised deviance codified in formal SOP modifications are adopted by training programmes or simply passed on by instructions such as the earlier mentioned email from the chief pilot. Normalisation of deviance however probably modifies established practices more often in informal ways, because many deviating practices involve only slight deviations that are informally accepted, or they have become a norm only within a certain part of the organisation. Because of the extensive data monitoring that occurs in airlines it seems increasingly

difficult to hide deviating practices from company management, although plenty of deviance remains difficult to survey. Most normalised deviance as such appears to fall within “grey areas” that are generally left to pilots’ professional discretion, such as personally preferred deviations from the standard scan-flow described in the introduction.

Table 9. Established work practices

1st order	Empirical reference	2 nd order
Training formal SOP	■ ingrains emergency reflexes like following TCAS commands (#S.7)	Established work practices
	■ ingrains the “normal procedure” as basic reflex while giving “non-normal” options for varying conditions such as short runways (#I.21)	
	■ helps to enter emergency checklist despite overwhelming noise and stress (#S.9)	
	■ in one company’s captaincy training course means knowing when to deviate (#I.12)	
Informal practices	■ when leading failure handling practice is to perform a quick reset instead of following QRH (#I.13);	
	■ when working around automation-induced risks of an automatic landing (#I.19) or switching off automatic thrust to prevent over-speed (#O.9)	
	■ when non-normal becomes treated as normal procedure, such as when pilots stopped briefing flex temp (#O.1; #O.5)	
	■ when routinely chopping the start-up checklist in two parts to comply with ATC procedure in a complex airport (#I.9)	
	■ in case of personally preferred scan-flows (#O.7) or use of paper when digital tools are being introduced with early design flaws (#O.8)	

We have thus returned to the premise of the normalisation process, because pilots heavily rely on the structured, routine scan-flow of cockpit instruments and controls to spot anomalies and deviate as necessary. As cited in the introduction, the captain we observed at work in the cockpit argued afterwards in the debriefing interview that for him personally, his deliberately deviating scan-flow allowed him to spot anomalies better, thus contributing in a small but critical way to the management of organisational risks.

3.5 DISCUSSION

Our study of airline cockpit work practices indicates an emergent process by which professionals deliberately act on anomalous cues and reflectively engage in the normalisation of deviance to manage organisational risks. Although positive roles of deviance in HROs have been noted (Roe & Schulman, 2008; Schulman, 1993; Weick & Roberts, 1993), the possibility that normalisation of deviance may contribute in a positive

way to risk management has thus far remained relatively unrecognised because of the emphasis on accidents in risk studies (e.g. Gephart, 1993; Oliver et al., 2017; Turner & Pidgeon, 1997), characterising the normalisation of deviance as a complex organisational path towards failure (Snook, 2000; Vaughan, 1997). We argue that the risk literature has thus incurred *hindsight bias* (Dekker, 2004), seeing deviance mainly as a potential danger, while the need for deviating is only recognised in incidental cases (e.g. Weick & Roberts, 1993). In contrast, because we studied regular work practices rather than failures, we removed hindsight bias from our analysis, enabling us to make two main contributions to the risk literature that formulate positive consequences of deviance and normalisation. First, as shown by the *deviance* processes in Figure 4, at the operational level, pilots act reflexively as they recognise cues in the ongoing and highly standardised flight process. Experiencing small anomalies triggers reflective deviations by which professionals give voice to diverse expert intuitions. Second, as shown by the *normalisation* processes in Figure 4, at the organisational level, such experiences are regularly extracted from the operation by the ongoing problematisation of deviance. Some procedure adaptations are eventually normalised when consensus is reached for how to handle certain anomalies in established work practices.

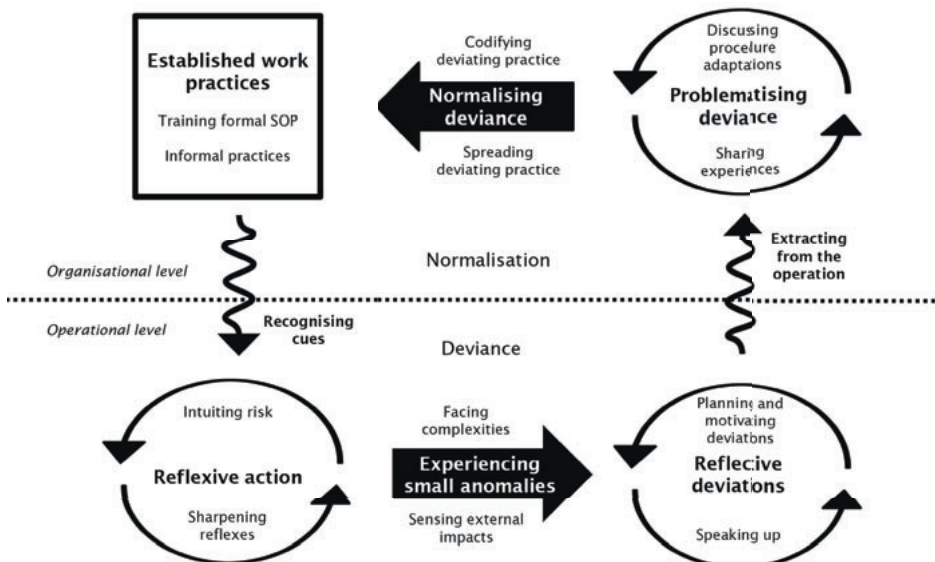


Figure 4. A model of the normalisation of deviance emerging from regular work practices

3.5.1 Deviance in operations

Our cockpit study shows how operational deviance responding to small anomalies does not necessarily lead to failure but instead to reflection. Researchers usually warn against deviance such as shortcuts and workarounds to deal with regularly encountered

small anomalies, because organisations presumably cannot control the risks induced by professionals deviating (Reason, 1990; 1997). Indeed, our model shows how within the loop of reflexive action, individuals or groups may develop deviating practices that are not shared or tested by the organisation or authorities (cf. Snook, 2000). Yet, we contribute by showing that reflexive action is not only imperative for professionals' ability to know when to deviate, but, triggered by the experience of small anomalies, professionals can also share diverse expert intuitions by reflectively deviating.

By explicating these deviance processes, we connect research on human factors in HROs with risk research on organisational deviance. Scholars argue that speaking up, receiving feedback, planning, and motivating deviations in-action are critical professional skills to avert accidents (Helmreich et al., 1999; Helmreich, Klinect & Wilhelm, 2017; Nevile, 2004; Sur, Schindler, Singh, Angelos & Langerman, 2016; Weick, 1990). Our study adds that these skills imply and sustain useful deviance in HRO operations, because deviating from SOPs is a structural rather than incidental phenomenon, which interacts with the inherent complexity of HROs' socio-technical systems and their environments (Perrow, 2011; Snook, 2000; Vaughan, 1997).

Our study thus begins to answer a crucial question from risk scholars who, after decades of asking how human errors trigger accidents, now ask "why the behaviours that usually make things go right occasionally make things go wrong" (Hollnagel, 2014, p. 77). Scholars studying socio-technical processes are thus shifting from a focus on reliability, which seeks to eliminate dangerous variations and errors, to resilience, which in turn seeks to capitalise on the richness and diversity of behaviours in such systems (Hollnagel, Woods & Leveson, 2006; Roe & Schulman, 2008). Our study adds that HROs capitalise on the diversity of expert intuitions with operational experience (Dreyfus & Dreyfus, 2005; Hodgkinson, Langan-Fox & Sadler-Smith, 2008; von Meier, 1999), if professionals engage in a communicative process through reflective deviations that renders their intuitions intelligible to a wider audience.

Since our study implies that organisations who seek to eliminate deviations may undermine intuitive expertise, further research is needed to understand how organisations may facilitate and stimulate reflective deviance. Research has shown that reflective practices may be stimulated by way of standard briefing procedures that require professionals to reflect afterwards or interrupt the operational process to reflect on potential threats and upcoming situations that might induce them to err (Helmreich et al., 2017; Ron et al., 2006). Our study in contrast shows that many anomalies arise dynamically and unpredictably from the complexity of high-tech systems and the uncontrollability of the environment. Therefore, we suggest that the main question for further research is how to rearrange an ongoing, largely reflexive process (Hodgkinson & Sadler-Smith, 2018) under pressure of time and danger in order to engage in meaningful reflection-in-action (Yanow & Tsoukas, 2009).

3.5.2 Normalisation in organisations

Our cockpit study suggests that the normalisation of deviance is not necessarily a dangerous path of increasing risk-taking, because normalisation can also signify a reflective process by which a risk-averse organisational culture is sustained and developed. Seminal risk studies showed that when deviance is normalised, organisations gradually expand the scope of acceptable risk, until a catastrophic accident occurs (Snook, 2000; Turner & Pidgeon, 1997; Vaughan, 1997). In contrast, our study shows that on the condition that problematisation of deviance examines the risks and benefits of deviating practices, normalisation codifies and spreads deviating practices that embody useful lessons drawn from operational experience. Thereby our study complements, rather than contradicts, the view that normalisation of deviance is potentially dangerous, because there is no guarantee that the right lessons are drawn when a group normalises its deviance (Snook, 2000). Indeed, our study serves to set a research agenda by which we can better recognise the normalisation of desired and undesired organisational deviance in HROs.

Our study first triggers the question at which point problematisation of deviance from and by operational professionals should be followed up by an organisational response. Established thinking suggests that an organisation managing risks as critical as flight safety should quickly extract emerging deviance and swiftly codify or correct deviating practices (Helmreich et al., 2017, May). However, our study raises the question whether immediate correction or codification does not cut short the useful problematisation of deviance by which professionals learn and develop their expertise. If organisations were to accept the premise that professionals should develop and test their own thinking and intuition by problematising deviance, then a logical organisational standpoint would be that in various routine situations, non-conformity is tolerated based on professional grounds (EESC, n.d.). This position, taken by scholars who promote “resilience engineering” (Hollnagel et al., 2006), drives the question whether and how organisations can develop a ‘just culture’ (Dekker, 2007) that capitalises on professionals’ intuitive expertise (Dreyfus & Dreyfus, 2005) and discourages scapegoating when incidents happen (Perrow, 2011).

Second, suggesting to better discern the normalisation of *desired* deviance prompts the question: desired *by whom*? The NASA Space Shuttle accident studies revealed a gradual shift towards commercialisation, changing the safety culture developed in the age of Apollo moon missions because many stakeholders with a diverse range of interests collectively tolerated increasing risk-taking (Vaughan, 1997; 2005). Our study in commercial aviation similarly addresses a politicised safety-critical business where the operational professionals we observed and interviewed actually represent a stakeholder group that promotes risk-averseness, even if they acknowledge that they regularly bend the rules inspired by a company policy of timely flight service. We need a better understanding of how organisations may give room to and provide platforms for such professional groups to problematise deviance by making explicit what deviance is desired by whom and why.

Third, our study raises the question how professional risk and safety cultures can have sufficient influence to keep organisations on track when commercially driven organisations regulate their own risky processes by managing compliance (Vaughan, 1990). This implies a change of perspective from existing compliance-based risk management to managing deviance. The dominant view is that HRO professional cultures are risk-averse because they are compliant with organisational standards, while in other cultures, such as in the banking industry, professionals show risk-taking behaviour through deviance, even after the global financial crisis (Palermo, Power, & Ashby, 2017). In contrast, our study suggests that in order to understand how professionals in risk-averse cultures are able to manage organisational risks, we need to understand better how these cultures uphold risk-averseness exactly by perpetuating the normalisation of deviance. Further research needs to develop and test these informal mechanisms and investigate them empirically in HRO safety cultures as well as other risk-managed organisations, such as banks and accounting firms.

Finally, our study shows that we need more context-sensitive research on the normalisation of deviance in more cultural and regional contexts than Western Europe. Current thinking on safety culture suggests that certain cultural characteristics, such as the reportedly steeper hierarchy and stronger emphasis on seniority in Asian countries, could inhibit dissent (Liao, 2015). Our study suggests dissent to be crucial for the reflective normalisation of deviance. Especially considering the growth of Asian markets, as seen in commercial aviation, there could be much to gain in furthering research on the positive consequences of deviance and normalisation in these cultural and regional contexts.

3.6 CONCLUSION

Our study reveals how normalisation of deviance contributes to organisational risk management, when it enables professional intuition through reflective practice. This complements our current understanding about normalisation of deviance as a potential hazard, because we show why deviance should be recognised as common and valuable in safety-critical organisations. With growing organisational dependency on high-tech systems with a potential for large-scale, complex failures, HROs as well as other risk managed organisations could benefit from facilitating the process where professionals develop, detect, and learn from deviance.

APPENDIX 3A: DATA COLLECTION

Phase	Data source	Duration	Content
2011-2012 Exploring cockpit deviance	Engineering researcher	1 hour	Levels of automation, cockpit interface design
	Aviation psychologist	3 hours	Aviation safety culture, errors, speaking up, CRM, SOP design versus practice
	Airline captain / instructor / ret. navy pilot	4 hours	Checklist design, coordination challenges, discretionary space, fuel management, failure management, risk management, CRM
	CRM trainer / ret. airline captain / ret. air force pilot	2.5 hours	Economic pressure on turnaround process, checklist deviations, skill training, CRM
	Captain / instructor and co-pilot / instructor	1.5 hours	Automation surprise, workarounds, changing procedures, skill development
	Airline captain / PhD student in management	1 hour	Improvising in cockpit work, office politics surrounding applied safety research
2012-2015 Exploring Dutch aviation networks	Human factors specialist / former captain	2 hours	Risk management methods and practices, non-normal procedures, compliance
	Accident investigation expert / researcher	1 hour	Conflicting conclusions in accident report, B737NG failures, stable approach violations
	Nine aviation human factors seminars	35 hours	Compliance, professionalism, public versus professional risk perceptions, safety culture
	ATC safety manager (2x)	2 hours	Relationship with judiciary, SOP redesign
	Two aviation inspectors	3 hours	History of Dutch oversight, current practices
	Aviation judiciary (2x)	2 hours	Relationships with industry, other judiciaries
2015-2017 Dialogue on work practice	Two government officials	3 hours	Rule-making process Europe/Netherlands
	Seven consecutive interviews with captain / instructor / safety expert	10 hours	Normal checklist deviations, underspecified procedures, error management, safety audits, safety policies, deviations in training

Phase	Data source	Duration	Content
2015 First cockpit observation	Two sectors, turnaround	4 hours	Observing work and ethnographic interviews
	Debrief interview with captain	1 hour	Checking transcript and interpretations, elaborating on practices observed
2016 Second cockpit observation	Two sectors, turnaround	4 hours	Observing work and ethnographic interviews
	Debrief interview with co-pilot	1 hour	Checking transcript and interpretations, elaborating on practices observed
2016-2017 Flight simulator observations	Captain / safety manager, co-pilot / safety staff	1.5 hours	New safety policy and regulations, pilot skill training and evaluation practices
	Captain / training manager	1 hour	Design of the flight training and evaluation, pilot skill database, flight training process
	Five simulator sessions including classroom (de)briefing and breaks	35 hours	Observing training practices in (de)briefings and training part, observing regular work practices during one-hour evaluation part
	Debrief interview with two captains/flight instructors	2 hours	Checking observations and interpretations of the simulation trainings observed
	Captain/flight instructor	3 hours	Background of flight training practices and regulatory developments
2017 Member-checking our interpretations	Human factors specialist	1 hour	Training policy and current challenges
	Captain / safety manager, co-pilot / safety staff	1 hour	Risk management techniques used, formal and informal training practices
	Team meeting company training management	1 hour	Discussing the tentative interpretation of the flight simulator observations
	Captain / training manager	1 hour	Training practices, evidence-based policy

APPENDIX 3B: EMPIRICAL EXAMPLES

Risky process: Take off	
Cockpit observations	
Remember one is “fooling the computer”. By entering higher ambient temperatures than actually present, pilots are said to “fool the computer” because this makes it “think” the weather is so hot that it needs to reduce power on take-off to prevent damage. Knowing this logic is important because the ‘flex temp’ take-off procedure, while reducing wear on the engine, also introduces the risk of accidentally entering the wrong numbers and crashing on take-off due to an insufficient thrust setting. This explains why pilots have to always to cross-check the numbers and remain aware of the fact they are carrying out a non-normal procedure. For routes using long runways, flex temp is actually standard practice, so it is easy to forget about its risks, as demonstrated by some crashes (#O.1, 2016)	
Interviews	
Adjusting take-off checks to snow. In snow conditions, a captain selects the required wing flaps setting for take-off just before take-off instead of at the moment of taxiing out. This non-normal procedure reduces the risk of snow getting stuck in the exposed wing flap mechanisms while taxiing, which could render the flaps inoperable. However, the non-normal procedure also introduces the risk of forgetting to select flaps and crashing on take-off. To overcome this risk, the crew needs to shortly discuss and agree any specific point that will trigger them to set and check the correct flap setting. (#1.1, 2011)	
Simulator observations	
Noticing volcanic ash meteorology report. One of the crews thinks that the volcanic ash in the evaluation flight scenario is so unlikely that it must be a ploy of the scenario designers to trick them. This impression impacts their decision making in two ways. First, when during taxiing, a warning comes on implying that the Auxiliary Power Unit (APU) is now unusable, the captain opens discussion if they should continue. In the remote possibility of engine failures due to volcanic ash in the air, it would be better to have the APU available. The crew laughs that this means they should not go, but then the captain argues that if this were a normal operation, they would continue. He checks with his co-pilot if he is happy with the decision, saying: “if you’re not happy, we don’t go.” The co-pilot says he is happy so they continue. Second, while focusing on volcanic ash, which in fact will not be a part of the evaluation part, the crew had missed the NOTAM report “runway centre lights unserviceable”. When they enter the runway, they notice that the centre lights are off and realise they do not know if this allows them to take off. While standing still and blocking the runway, they cancel their own take-off clearance, look up the rules, and re-acquire clearance about 30 seconds later. (#S.1, 2017)	

Risky process : Fuel management

Cockpit observations

Formulating low fuel decision rules. Waiting on the taxiway, a crew commits to the destination because they are made to wait and are burning fuel before take-off. If something should block the arrival runway, they will likely not have enough fuel left to divert without being legally bound to declare an emergency, because in that case they will likely start using their last 30 minutes of fuel reserve. (#O.2, 2016)

After mistake, restoring fuel flow. Then, to avoid a fuel imbalance arising between left and right wing tanks, the co-pilot switches tanks. Doing the procedure by heart, he mixes up the sequence of actions needed to do so, which triggers an alarm because of causing a lower fuel pressure to the engine. In a quick reflex the co-pilot selects the cross-feed pump that restores fuel flow and cancels the alarm. (#O.3, 2016)

Interviews

Holding one's ground for extra fuel. Captain explains that if he wanted to bring additional fuel to deal with potential delays, he has experienced opposition from his management in times when the fuel prices were higher. (#I.2, 2011)

Knowing tricks to stay within legal limits. Knowing about small margins, like the round-off errors that cause a difference between the fuel on the official weight and balance sheet and fuel actually on board, and rules of thumb to estimate fuel consumption, help pilots negotiate situations such as when they unexpectedly receive more cargo or passengers that does not seem to fit according to the official calculation, but actually does. These informal "tricks" are passed on informally in the operation. (#I.3, 2015)

Economic vs. safety reasons for fuel. Captain argues that unlike today, in the past pilots did not have to take fuel costs as much into account when requesting additional fuel. (#I.4, 2015)

Simulator observations

Bringing extra fuel, anticipating delays. Anticipating bad weather might cause them to wait for the weather to get within limits before take-off, one crew out of five elects to bring additional fuel. As a consequence, this crew is not low on low fuel when they land, in contrast to the other four. (#S.2, 2016-2017)

Be assertive when requesting extra fuel. Pilots in the simulation training argue that they have to be quite assertive when they ask for additional fuel for safety, because the operations control centre does not always immediately understand or agree with their request. (#S3, 2016-2017)

Fuel indications reaching critical range. For four out of five crews who did not bring extra fuel enter their final approach phase, the fuel readings jumps to yellow, triggering crews to take note of entering a critical range where, if they have to divert, they have to declare an emergency. Entering this range is a consequence of the flights taking slightly longer than planned because crews take time to deal with a number of small problems along the way. Pilots comment afterwards that entering this range in the final minute or so is actually quite normal in real flights. (#S.4, 2016-2017)

Risky process: Crew coordination	
Cockpit observations	
Adjusting leadership style to expertise. Captain adapts his leadership style to the competent skill-level of the co-pilot by allowing more deviations and initiative, while joking to the cabin crew about the co-pilots' fast and rough taxiing style (#O.4, 2015)	
Skipping briefing item that is too routine. Crew skips "flex-take-off" briefing item because it is so routine to perform flex take-offs that they think it does not make sense to brief it anymore; briefing items should be focusing attention on nonstandard conditions. The captain mentions that it is actually annoying if co-pilots keep mentioning the item, like how they are taught in training and how it is written in the procedure. (#O.5, 2016)	
Interviews	
Attention: fails to anticipate crosswind. Captain checks if his co-pilot corrects for crosswind when aligning with the runway localiser for landing, which, if he doesn't, will signal that the captain needs to pay extra attention to the co-pilot (#I.5, 2011)	
Resisting non-standard command to do RT. Captain tells a "war story" where a co-pilot protested the captain's quick non-standard order to handle radiotelephony (RT) as well as a failure that arose during a complicated approach. The co-pilot forced the captain to motivate the non-standard order to handle RT and the failure. The captain knew by heart that the failure procedure was very short, while the captain also needed to focus on landing the aircraft because of the complexity of the approach and the small fuel margin. By continuing the approach while handling the radio as well, the risk of missing the approach and having to go around could increase. The nonstandard order is a solution to prevent this risk and distribute the workload evenly. (#I.6, ethnographic interview, 2016)	
Simulator observations	
Varying leadership/followership. Instructors discuss the observed variations between captains "CRM"-styles: to have CRM skills is described as holding back a lot, looking "almost lazy", having a "very calm CRM" that takes the co-pilots needs into consideration. Less attention to CRM is associated with more directive captaincy styles, which may demand more assertiveness from the co-pilot. (#S.5, 2017)	
Respond to TCAS warning. In the skill-training part, the flight crews are taught to react without thinking to a TCAS commands that go off when they are on a collision course with another aircraft. The few pilots who experienced such a command in real life have no problem recognising the cue and immediately follow it. Some of the pilots who have not, need to repeat the exercise to get it right. (#S.6, 2016-2017)	

Risky process: Error management	
Cockpit observations	
Dimming lights as memory aid. Co-pilot dims the light of one of his screens when keeping a window open during taxiing in hot weather, after the checklist prescribes windows closed. Routine scanning past the dimmed screen later reminds the pilot to close the window just before take-off. (#O.6, 2016)	
Knowing about a faster scan flow. Captain performs scan flow in the way he once learned from an 'old grey head', namely a continuous line. The prescribed scan flow jumps back and forth between panels, which the captain argues makes it easier to forget or miss something in the pre-flight and start-up procedures (#O.7, 2015)	
Using notes for memory and backup. While several planning tasks that happen continuously throughout the flight are now digitalised with a company-distributed tablet, there are still several problems in the design of the tablet, so that for some tasks, the captain prefers to keep using the old paper systems. (#O.8, 2015)	
Interviews	
Using hand grip as memory aid. A captain always folds down the hand grip, that is intended to help pilots to get seated in their chairs, as a memory aid indicating that landing clearance has been received. (#I.7, 2011)	
Check cabin pressure drop after take-off. Captain uses the after-take-off checklist item "air packs on" as a memory trigger to keep monitoring the cabin pressure and check if it decreases as expected during climb. There is no written checklist item for this check, which the captain argues introduces the risk of failing to notice anomalous cabin depressurisation, if it should occur. (#I.8, 2015)	
Impossible to follow start-up procedure. Captain has timed a procedure with some colleagues to demonstrate that the company's start-up procedure contradicts an ATC rule that one needs to start push-back within 10 minutes of receiving clearance. In order to comply with both, one would have to perform the start-up process faster than humanly possible. A solution is to break the start-up procedure in two parts, but one could argue this solution introduces a risk of pilot errors. (#I.9, 2017)	
Personal problems may reduce sharpness. From a safety perspective it is important to realise that many things impact and interact with each other in ways that can sometimes drive you close to the limit of failure, because you never know exactly where that limit lies. For example if someone has problems at home, they might be less sharp and you cannot rely on them as much or you have to be ready to help out more than usual. (#I.10).	
Threat and Error Management (TEM). Pilots have recently learned to include "Threat and Error Management" in their process. When appropriate, pilots should reflect on factors that could induce errors or threats. For example, checking if your colleague is doing OK when he or she looks worn down is important because they might be more susceptible to errors. Briefing the particulars of a rugged airfield with a short runway could help anticipate potential threats such as overrunning the runway. In practice, multiple pilots argue, "TEM-ing" often becomes a dreary routine briefing item that has limited value because many threat and error conditions arise unexpectedly. (#I.11, 2015-2017)	
Simulator observations	
Pointing out error in landing briefing. During a final briefing before landing, the co-pilot interrupts the captain to point out that he seems to be wrong about the expected taxi procedure. The captain then realises that he had he had mixed up the layout of the airport, and concludes that he is actually landing on another, shorter runway than he thought. They quickly estimate the numbers and conclude that the available landing distance should still be sufficient. After the exercise, the instructor points out to the co-pilot that he did well to speak up but that he should have interjected earlier, when the captain was reasoning that they were on approach to the longest available runway. (#S.7, 2016)	

Risky process: Failure management	
Cockpit observations	
Deviate to overcome autopilot errors. The pilot flying has to sometimes switch off a part of the automatic system to manually reduce thrust and prevent the system from over-speeding the aircraft. (#O.9, 2016)	
Drawback of rope checking procedure. The cover of the emergency rope, which can be used if the pilots need to climb out the windows, spontaneously falls open. The captain argues that because the checking procedure requires one to open and close it before every flight, the mechanism is now so worn that it hardly holds the cover anymore. (#O.10, 2016)	
Fast pre-flight triggers warning. During the pre-flight procedure, a warning light illuminates that the flight crew does not understand. When the ground mechanic is brought in, the light is off again. The mechanic trouble shoots the cause of the light and they conclude that it went on because they executed a sequence faster than normal. (#O.11, 2015)	
Interviews	
Captaincy check requires deviation. In a company, candidates for captaincy exams are expected to deviate from an emergency procedure. When an engine fuel leak warning goes off, the procedure is to switch off the engine, but the examiner will program a lower fuel loss rate than to be expected in this failure mode. The candidates are expected to figure out that the leak is actually in the wing, which means that they should keep the engine running and switch tanks. (#I.12, 2017)	
Chief endorses “quick reset” practice. For many years, an informal practice developed where failures that should normally be handled by reverting to the Quick Reference Handbook (QRH), were resolved by a “quick reset”: simply switching the system off and on again. A co-pilot explains how he was at first a bit shocked to find this to be the norm when he began flying in the operation. In a recent email, the type division chief formally endorsed this practice for specific conditions. (#I.13, ethnographic interview, 2016)	
Considering generic failure training. Pilots discuss whether they should have a type of generic risk management process to resolve acute failures like they had elsewhere. When such a procedure is well-rehearsed, it allows crews to fall back on shared reflexes by which they can structure a complex failure by diagnosing the problem, weighing options and risks, executing the resulting plan, and checking if the plan works as expected. However, it is hard to design such a procedure before even considering to invest in training it. (#I.14, interview, 2017)	
Simulator observations	
Vibration procedure by the seat of his pants. One of the captains performing the evaluation flight literally feels by the seat of his pants that they are experiencing high vibration in one of the engines, which triggers him to immediately enter the checklist associated with ice on the turbine blades. Unlike the other crews, some of whom first do not think it is ice on the blades, this captain remarks that he has experienced the ice/vibration in real life, which allowed him to instantly recognise the sensation created by the simulator. (#S.8, 2016)	
Co-pilot learns about “scary” checklist. One of the co-pilots performing a double engine failure exercise, does not make it to the runway. The instructor explains that he needs to essentially manage his emotions by forcing himself into the checklist, despite stress caused by the noise of the ram air-driven electricity generator and fear of having only one shot at landing with both engines lost. The co-pilot first objects that he does not trust the design of the checklist, but after more explanation concludes that he did not understand the system logic behind the checklist. (#S.9, 2016)	

Risky process: Passenger service delivery	
Cockpit observations	
Co-pilot tries something unusual. Co-pilot uses flaps instead of the nominal use of air brakes to expedite descent. He argues that on this aircraft, lowering flaps produces less vibrations than air brakes do, so his non-standard technique improves passenger comfort. (#O.12, 2016)	
Knowing when to exceed speed limit. To reduce their delay and prevent passengers to miss their connections, a crew exceeds a maximum speed by 30 knots, which triggers an unexpected warning from the flight management computer. The pilots comment that they consider the risk of this violation to be negligible so they believe the company is fine with it. (#O.13, 2016)	
Flying around the clouds. Deviating slightly from instructed vector, to fly around clouds while climbing to cruise altitude, and prevent hitting the turbulence that is present in clouds. (#O.14, 2016)	
Bleed off airspeed before entering cloud. While descending, by adjusting the rate of climb in the mode control panel, a co-pilot levels off just above a cloud deck to bleed off some airspeed before entering the cloud, which normally contains turbulent air. This way, he reduces the time passengers will experience turbulence as well as the stress on the aircraft caused by turbulence. (#O.15, 2015)	
Commenting on fast taxiing. As the co-pilot taxis away from the gate, he uses slightly more thrust than the captain did on the previous flight, which seems to cause a low, subtle scraping sound and vibration, indicating that the wheels are slipping slightly on the asphalt while the aircraft is turning. The captain comments humorously on the intercom to the cabin crew that what they are feeling is the co-pilot's "unique taxiing style" (#O.16, 2015).	
Interviews	
Late passenger seating becomes standard. A company procedure once required passengers be seated once descent from cruise altitude (somewhere between 25,000-40,000 feet) begins. However, because it takes a long time to descend, this caused discomfort and for short haul flights often meant that passengers hardly had time to get out of their seats. The leading practice therefore is to see passengers seated roughly before descending through 10,000 feet. At first, this is called a "checklist error" in CRM training exercises, to the annoyance of some pilots. Then, the company procedure is changed to fit the leading practice. (#1.15, 2017)	
Debating if fast taxiing is worth the risk. Pilots discuss whether taxiing faster than the speed limit is worth the risks. It seems that many pilots feel it as their responsibility to assure passengers make it to their connecting flights, but some more senior pilots object that the gains are minimal while one comes closer to making damage such as slipping outside the taxiway, hitting lights and getting stuck in the grass or soil next to the taxiway. (multiple ethnographic interviews, #1.6, 2017)	
Simulator observations	
Discussing point of no return. At several points in the flights, flight crews discuss whether to continue the flight after encountering an anomaly. A power generator system that breaks before even taking off triggers them to see if they are allowed to continue in a reduced configuration and check if the necessary equipment is present at the destination airport to restart the engine for the (hypothetical) return flight, for which crews variously involve the company operations centre and maintenance department. In flight, they consult with a cabin crew member if they should return, following a serious injury caused by turbulence. They all reason that since they are already half way, and the injury can be taken care of at the destination, they should commit to the flight destination: whatever happens, they cannot return. (#S.10, 2016)	
Remember the cabin. A crew experiencing high workload towards landing forgets to do after-care of an earlier turbulence incident in the cabin. The captain remarks afterwards that he kind of forgot about the existence of the cabin because of the simulated setting. Indeed, other crews were more involved or explicitly decided to focus on system failures or flying. For the crew who forgot, the experience in the sim is debriefed as a reminder to integrate the cabin in an already demanding flight management process (#S.11, 2016)	

Risky process: Landing

Cockpit observations

Dipping wing to prevent hard landing. Captain dips one wheel during the flare, which is a tailwind landing technique. There is no tailwind for which the techniques are required to land safely, but the pilots argue that this makes the plane “sit” easier when it manifests a tendency to float and drift over the runway, which can lead to a hard landing. (#O.17, 2015)

Interviews

Triggered by “red flag” of dirt on runway. When ATC offers a non-standard tailwind approach the captain declines because he read earlier that the runway is dirty. Dirt on runways is a “red flag” for him, a trigger to pay attention to risks. Now, in combination with dirt on the runway, he feels that the higher ground speed caused by tailwind could cause the plane to skid and become uncontrollable. After he lands and exits the runway, he notices that the runway is in fact slippery at the point where he would have touched down, had he accepted the tailwind landing. This makes him realise that the combination of dirt and tailwind is a “red line” that he does not want to cross. (#I.17, 2015)

Debating nonstandard autopilot use. ‘For an automated approach, the SOP says, “engage the other autopilot”, but we never do that, except when it is bad weather. So apparently, whenever we are flying under normal visibility conditions, we execute every approach incorrectly. Then we should ask ourselves, why do we never do that?’ ‘Actually I flew with someone recently who did engage the other autopilot. I asked “why, you’re not landing it automatically are you?” and he said “no, but then it doesn’t intercept the localiser so aggressively.” When you use two autopilots, the two systems start averaging.’ (#I.18, 2011)

Investigating nonstandard autopilot use. Pilot interviews colleagues and analyses the auto-land procedure in detail to explain how risks are reduced by using only one instead of two autopilots in low visibility conditions. Engaging the second autopilot has the advantage of allowing for an automated go-around, but in order to do so, it trims the aircraft to a high nose-up attitude when passing 400 feet. The disadvantage of this situation is that the aircraft is ‘out of trim’ and as such less controllable in a very critical final phase of the flight, should the pilot want to take manual control. (#I.19, 2015)

Impact of changed manuals. When a company discontinued its customised manuals and instead started using the less detailed manuals provided by the aircraft manufacturer, many discussions arose between pilots to informally establish a common practice. The topics could be as detailed as determining the exact point at which to select the runway turnoff indicator when intending to vacate the runway just after landing. While the customised manuals used to specify this distance quantitatively, it is now left to pilot discretion. Some pilots now wonder why they always had to follow these highly specified procedures in the first place and what changed that they no longer have to do so. (#I.20, 2011)

Idle-reverse becomes normal procedure. Because using full reverse thrust to slow the plane down after landing wears the engines, and because most airports in the route network of a company have long enough runways that do not require reverse thrust, the company changes its policy to make idle-reverse thrust the normal procedure instead of the non-normal. A pilot debates the wisdom of this move because he worries that by making idle-reverse the default reaction, someone in the future might forget to apply reverse thrust in the rare but critical case when it is needed to slow down. By switching policy on what is normal and non-normal procedure, he argues that a risk-averse reflex is being replaced by a less risk-averse reflex. (#I.21)

Risky process: Landing

Simulator observations

Deviating from stable approach criteria A captain makes a quick decision to violate his company's stable approach procedure, because in view of several non-normal conditions, he deems the risks of complying greater than the risk of deviating. The airplane has suffered multiple brake failures and the QRH suggests that in this condition they should not raise the landing gear after lowering it. They are also low on fuel. Together, this seems to make for a complicated go-around with some never before experienced unknowns that might introduce a risk of running out of fuel before landing. Even though the captain extended his final approach leg to give himself more time to stabilise, he is still slowing down as they come up on 1000 feet. The co-pilot asks: "go around? The captain immediately answers "no" and silently continues to fly the plane down to the runway, reaching stable approach a few hundred feet lower than intended. (#S.12, 2016)

Debate on stable approach violations. Afterwards the instructor comments that he is happy to see that the captain was able to make such a quick and sound judgment call. However, in the following interview, he also comments that the experience should make one reflect on how not to arrive in such a condition in the first place, even if measures were already taken to prevent the situation. The background of that comment is that stable approach criteria are seen as an important safeguard against failed landings, as emphasised by the internationally operating Flight Safety Foundation. (#S.13)

CHAPTER 4

MODELLING SAFETY CULTURE AS A SOCIALLY EMERGENT PHENOMENON: A CASE STUDY IN AIRCRAFT MAINTENANCE



ABSTRACT

Safety culture is often understood as encompassing organisational members' shared attitudes, beliefs, perceptions and values associated with safety. Safety culture theory development is fraught with inconsistencies and superficiality of measurement methods, because the dynamic and political nature of culture is often ignored. Traditionally, safety culture is analysed by survey-based approaches. In this paper we propose a novel, systemic, interdisciplinary approach for investigating safety culture that combines multi-agent system modelling with organisational ethnography. By using this approach, mechanisms of emergence of safety culture from daily practices, operations and interactions of organisational actors can be modelled and analysed. The approach is illustrated by a case study from the aircraft maintenance domain, based on existing ethnographic data. Using the proposed approach we were able to reproduce and explain emergent characteristic patterns of commitment to safety in the maintenance organisation from this study. The model can be used for theory development and as a management tool to evaluate non-linear impacts of organisational arrangements on workers' commitment to safety.

4.1 INTRODUCTION

It is broadly recognised that safety culture plays a crucial role in shaping the safety and performance of operations in safety critical organisations (Reason, 1997) in such areas as air traffic (Mearns, Kirwan, Reader, Jackson, Kennedy & Gordon, 2013), nuclear power plant management (Lee & Harrison, 2000), and railway systems (Jeffcott, Pidgeon, Weyman & Walls, 2006). Safety culture has been defined in a variety of ways (Choudhry, Fang & Mohammed, 2007; Guldenmund, 2010). In this paper, we use the term safety culture as those aspects of organisational culture that may have an effect on safety, which is in line with Hopkins' (2006) primary focus on organisational culture and subsequent analysis of its impact on safety.

Organisational culture is a complex, context-specific phenomenon not easily harnessed in a single definition or theoretical approach (Giorgi, Lockwood & Glynn, 2015). Culture is particularly complex because its members may relate to cultural meanings in ambiguous ways (Kunda, 1992). Organisational members may engage in political ways with cultural elements such as particular basic assumptions, espoused values, technologies, and artifacts (Schein, 1990); and narratives, symbols, and rituals (Geertz, 1973). A culture is therefore not necessarily an integrated and stable whole, but is dynamic and can be differentiated into subcultures or appear to be fragmented (Martin, 2001). This fundamental insight has not yet been thoroughly incorporated into the concept of safety culture.

Current safety cultural analytical approaches and frameworks have acknowledged limitations. They rely on linear models derived from accident research (Reason, 1990). These models, and the assumptions underlying them, are increasingly being criticised for being overly simplistic (Hollnagel, Woods & Leveson, 2006). They offer little insight in the way competing values interact in real organisations, such as the simultaneous challenges to accomplish growth and profitability as well as high safety levels (Antonsen, 2009). Current approaches to safety culture are therefore a-political, while in reality, power plays an important and complex role in the development of organisational safety cultures, as Antonsen (2009) has noted.

In this paper we present a novel, advanced research approach to investigate organisational safety culture as a complex phenomenon, emphasising its gradual emergence in years of mostly normal operations. The approach takes a systemic view on safety modelling and analysis (Hollnagel et al., 2006) according to which safety hazards, accidents and incidents develop from complex, nonlinear interaction between diverse organisational processes. This view fits the social scientific understanding of culture described above.

The paper is organised as follows. In section 4.2, we describe the approach and its components of ethnographic research, multi-agent modelling, and simulation analysis. Section 4.3 describes the process of case selection as well as presenting details of the case study. Section 4.4 describes the model and how it was developed. In section 4.5 we present the simulation results of the model as well as virtual experiments. We conclude in section 4.6 with a discussion about theoretical implications, applications, limitations, and further development of the approach.

4.2 APPROACH

Modelling safety culture necessarily involves an in-depth study of a particular culture, which is usually done by ethnography. Therefore we introduce agent-based modelling and organisational ethnography, as well as how to perform agent-based modelling on safety cultural phenomena and incorporate ethnographic data.

4.2.1 Organisational ethnography

Because of the complexity of culture, organisational culture is typically investigated with ethnography. Ethnography involves making detailed discoveries of local informal processes and practices, understand the experiential reality of cultural members from within, and thus develop ideas about how patterns of interest emerge (Fayard & Van Maanen, 2015). Generally the method of participant observation is preferred. The researcher participates in the everyday life of the cultural group of interest to obtain an insider's understanding, while also maintaining an intellectual distance or preventing to 'go native'. In the case of auto-ethnography, a member of a culture may be trained as ethnographer and enabled to study the culture by reflecting on its common sense meanings with cultural outsiders (Doloriert & Sambrook, 2012). The data that are thus gathered are field notes of observations and conversations, transcripts of interviews and collections of meaningful documents. The analysis process is quite particular to the research context which means there are hardly standard procedures for analysis. The results are conveyed through context-rich, or 'thick', qualitative descriptions (Geertz, 1973).

4.2.2 Agent-based modelling

The emergent nature of cultural phenomena is intuitively congruent with the multi agent paradigm. According to this paradigm, cultural patterns, seen as systemic properties of a multi-agent system, emerge and develop over time from many distributed local interactions of agents that represent organisational actors. Agent modelling can complement ethnographic theory building because it can serve as a formal test of its logic, and lead to new theoretical propositions (Harrison, Lin, Carroll & Carley, 2007).

A specification of a multi-agent system model comprises: 1) A description of agent types and structural relations between them; 2) A specification of local properties of each agent. Such properties comprise both internal (cognitive) properties and behavioural properties, i.e., temporal input-output relations of some complexity; 3) A specification of relations between agents, such as communication and power relations; 4) A specification of the environment.

This definition is in line with the work of Weiss (1999). More details on the specification of multi-agent systems are provided in Bosse, Jonker, van der Meij, Sharpanskykh and Treur (2009) and in Sharpanskykh (2008).

4.2.3 Agent-based modelling of safety culture

The combination of agent modelling and ethnographic data, that our approach implies, is unusual in the sense that it serves theory development. The safety cultural concept of interest, such as commitment to safety, is refined through the ethnographic study. A more complex idea about what the concept means and how it unfolds in practice is thus developed. Modelling then serves to work towards more generic statements by incorporating more social scientific theories. The aim is not to simply model an observed structure or process, but to incorporate much more detailed and conceptually refined observations that can lead to theoretical development.

The process of modelling and validation of the model through simulation requires teamwork between the researchers of the interdisciplinary team. Ethnographic data are used to build an agent model from generic socio-cultural mechanisms that aims to reproduce the patterns found in the ethnographic study. In our team, two ethnography specialists were guiding in the interpretation of the data. Modelling specialists created suitable mathematical representations, implemented and instantiated the model, and produced visuals for interpretation. The tension here is between the ethnography specialists who attempt to contextualise and the modelling specialists who attempt to see concepts and dynamics as more generic. The team must ensure that members are talking about the same concepts and make an effort in understanding some of the principles and details of the other's discipline.

The modelling process involves jointly creating a conceptual model, after which the modelling specialists continue to formalise the model in mathematical equations. To test the model's expressiveness and value to the current literature, we also compared it with another model of power relations (Appendix 4A). Our agent-based model was then implemented in Java. We did not use dedicated agent modelling tools because their conceptual models of agents and specification languages are rather restricted for our purposes (e.g., to the BDI architecture). Furthermore, a lower level implementation runs faster, which is critical for sensitivity (Appendix 4B) and robustness analysis (Appendix 4C), when many runs with many interacting agents need to be performed.

Generating and interpreting simulations with the model serves validation as well as deepening theoretical insights and throwing up new questions. In section 5 we show how we could validate our simulation results by interpreting visualisations of the simulations and making sense of them in terms of the original research question. In addition to reproducing cultural patterns in the original ethnographic study, we performed several virtual experiments. In these experiments we explored the behaviour of the model in different settings and under different conditions that seemed plausible in the given setting.

4.3 CASE STUDY

In this section we describe the process of case selection and present the necessary empirical details of the case itself. The case narrative is the basis for the agent model.

4.3.1 Case selection

Although different sequences are possible, we began by selecting an empirical research domain where a relevant contribution could be made. We chose the aircraft maintenance domain. In this domain daily practices are usually hidden from view in incident investigations, and only the emergent errors or failures are found when an incident or accident occurs. Thus, investigating aircraft maintenance safety culture has the dual benefit of understanding the emergence of safety cultural characteristics over longer periods of time, and of uncovering hidden, 'latent failures' (Reason, 1990) of air transport systems.

Our literature analysis furthermore suggested that the commitment to safety of maintenance technicians and maintenance teams is an essential aspect of safety culture, which presumably has a strong effect on safety of maintenance operations. Commitment to safety is a sensitive topic because organisational members are confronted with dynamic market demands and complex work situations, in which rules and procedures do not always make sense and ambiguities arise (Hale & Borys, 2013; Dekker, 2014). Under the pressure of meeting schedules and satisfying customers, a good safety culture means commitment to safety is ingrained such that it prevents pushing the balance too far towards working quickly and less safe (Edwards, Davey & Armstrong, 2013). What remains relatively under-investigated however is how context and power actually shape such commitment. Thus, the main research question of our case study is: *how does the commitment to safety of maintenance technicians emerge and develop under social and organisational influences?* Below we describe the data collection, and describe the case in terms of its internal power relations and the more complex pattern unfolding over time.

4.3.2 Data source

As a relevant and recent source of data for our study we used the case study on aircraft maintenance safety culture by Atak and Kingma (2010). The first author of this paper performed auto-ethnography, allowing a unique insider's view of safety culture. We conducted additional interviews, literature and materials that helped us understand local social processes, safety cultural practices, and the context and the history of the organisation in question. Furthermore, we modelled the power and influence relations between the agents using theories from social science. To gather missing data required for the model, and gain a thorough understanding of the secondary data, we conducted additional interviews with the authors Atak and Kingma, with a manager still working in the organisation in question, and with domain experts from commercial aircraft maintenance organisations. In addition to the interviews, we used several reports on field studies performed in existing aircraft maintenance organisations in the context of large European projects such as HILAS (2007), ADAMS (Van Avermaete & Hakkeling-Mesland 2001), and TATEM, and smaller PhD projects (Pettersen, 2008; Ward, 2006).

4.3.3 Power relations

The company features professional power relations and dynamics that are common in the industry. At the core of operations are teams of Aircraft Maintenance Technicians (AMTs),

which can generally be subdivided into junior technicians and senior flight engineers. Junior technicians usually do most of the actual handwork repairs, and senior flight engineers usually take on more of a supervisory role such as taking care of planning and drawing up work packages. The ratio of junior to senior technicians that closely cooperate in a team may be somewhere around six to one.

Supervising the seniors is a senior Maintenance Manager (MM), who is responsible for planning in terms of total man hours and work packages for incoming aircraft. The MM thus plays a key role in regulating production pressures that AMTs experience, and to which they may sometimes mount resistance. While the incentive from MM may be to increase speed and efficiency, the Quality Assurance and/or Safety Department (SD) of a maintenance organisation provides a counterbalance.

The SD is there to ensure repairs are carried out in a way that does not harm flight safety as well as occupational safety of maintenance personnel. The SD is much less visible at the work floor than the MM. The SD takes on an advisory role towards management, monitors and investigates incidents, and reports to top management. Whether the SD has the power to assure safe operations then also depends on the CEO's prioritising, which in turn is a response to the economic and operational challenges that the company is facing at a certain point in time.

We refer to Luke's (1974) three faces of power to distinguish different power dynamics resulting from the relations described above. The first face is direct power influences between agents, such as when one agent is able to make another agent do something that it would not otherwise do. This happens for example when a MM holds punitive power over an AMT. The second face is indirect power, such as setting an agenda or refraining from making a decision. When older AMTs use their experiential authority to talk about how things used to be, they exercise this power, as it draws away attention from current demands. The third face of power can be exerted by discourse, rather than individuals. This occurs when a discourse stressing production values takes hold due to changing context, such as the development described below.

4.3.4 Emergent patterns

The aircraft maintenance organisation developed in three distinct phases from birth to maturation in a period of 9 years, beginning in 2001 and running up to 2009. In 2001, the organisation experienced a takeover. First, it had to survive the challenging first phase with many ad-hoc projects and slim margins. Of the initial work force of 35, the company still employed 20 Aircraft Maintenance Technicians (AMTs) that had worked at the company before the takeover. The increasing work pressures led to resistance amongst this old guard while the company grew to employ 60 AMTs. Second, at the start of 2004, the company contracted new customers and grew explosively to a total of 260 employees by 2008. Members of the old guard gradually left the company and resistance diminished. AMTs worked overtime and there were some close calls, highlighting safety had a lower priority than productivity at this stage. Third, in mid-2008, a new technical director led the company into more mature phase. Safety and production goals were

harmonised, the AMTs could develop a sound professional culture and adhering to safety standards became normal.

These three phases correspond to three different perspectives on the organisational culture (Martin, 2001), which is seen as consisting of a safety strand and a production strand. Due to its complexity, any organisational culture can at any time be seen as integrated, differentiated or fragmented, depending on the focus of the researcher. In the case of the maintenance organisation, and in agreement with Martin (2001), one perspective was found to be dominant over the others in each of the consecutive three phases (Martin, 2001, as interpreted by Atak & Kingma, 2010, p. 269):

- Survival phase: *fragmentation perspective* 'highlights ambiguity and a lack of clarity and conflicting or changing meanings in organisations'.
- Development phase: *integration perspective* 'refers to the shared understandings in organisations'.
- Maturation phase: *differentiation perspective* 'focuses on the existence of sub-cultures'.

During the survival phase, the old guard resisted the pressure of Maintenance Management (MM) to increase productivity by reverting to a work-to-rule resistance strategy: extensively complying with all procedures, stalling the company's performance. The company's Safety Department (SD), not very active at this time, was used in this way as a shield against MM's pressure. To new AMTs, however, 'the way we do things around here' was not clear at this stage. Experienced and senior old guard drew new AMTs to collaborate with their resistance, while at other times MM could force decisions. There was little common understanding about the application of procedures. Confronted with ambiguity and conflicting values, the new AMTs' experiences reveal a fragmented culture.

In the second phase, the organisational culture integrated around production values, at the expense of the safety strand of the culture. The company grew to 260 employees, with members of the old guard gradually leaving. The new AMTs continued to use the resistance strategy of the old guard against management pressure, though to a lesser extent. They were working overtime and sometimes even double shifts. Members throughout the company adopted a flexible attitude to safety trying to satisfy rising work demand enforced by MM.

In the final maturation phase, the company culture can be seen as differentiated, with several subcultures coexisting next to one another. MM still focused on productivity yet existed in relative harmony with SD, which was in turn occupied by a new, more proactive team that was granted more influence. AMTs gained autonomy to act on their judgment and sticking to safety procedures became easy compared to the previous phases. Production demands were resolved through planning schemes rather than by pressuring AMTs to work faster, allowing AMTs to develop a professional sub-culture with safety as a solid priority. For a more detailed description of the study we refer to Atak and Kingma (2010).

4.4 THE MODEL

In this section we show how we translated the ethnographic findings to a more general conceptual model, and derive a formal model with specific parameters. We translate our conceptualisation of power relations into a generic set of mechanisms, incorporate the given context of the case, and quantify from mostly qualitative data.

In accordance with the case description, we identified four types of agents: new AMT (a novice technician), old guard technician, MM and SD. The behaviour of the technician agents was the main focus of modelling. MM and SD agents exerted performance and safety pressures on that behaviour, which were driven by conflicting goals and different interests, values and norms. These pressures and the AMTs' response to them were formalised by performance and safety demands and efforts considered in Section 4.4.1. Power and influence relations between the agents are described in Section 4.4.2. The spread of attitudes to performance and safety in shifts of AMTs was modelled as a social contagion process, considered in Section 4.4.3. In Appendix 4A we demonstrate how the proposed model can be related to another well-known agent-based model of power based on social dependencies. This was done according to Burton's (2003) model docking approach.

4.4.1 Demands and efforts

To describe at a high level the execution of maintenance operations by AMTs the following variables are introduced, in line with the essential organisational goals:

- performance demand (*pd*) and performance effort (*pe*);
- safety demand (*sd*) and safety effort (*se*)

All these variables vary from 0 to 1.

The performance demand for a task is an aggregate of the task complexity, the situational complexity of the environment, in which the task is being executed, and of the time pressure. High performance demand is associated with the interval [0.7, 1], average – with [0.4, 0.7) and low – with [0, 0.4).

Several empirical sources indicated that AMTs normally have a high workload and work pressure during the night and in the morning, and a low to average workload and work pressure during the day.

To represent the changes in the performance demand imposed on the AMTs as described in the case study, a correlated random walk is used with fixed mean values for all the phases. These values are linearly interpolated during the transition phases and their values are different for day and night. In the first phase the means are 0.5 and 0.7 for day and night respectively, 0.6 and 0.8 for the second phase, and return to 0.5 and 0.7 for the third phase (Figure 5).

The meaning of performance demand we derived from Atak and Kingma's narrative as well as additional interviews. Zero performance demand means no work needs to be

done at all. At 1, AMTs must disregard all quality and safety rules and precautions and completely exhaust themselves to meet schedules. An average demand of 0.5 means that work can be accomplished at a normal rate and no heavy pressure is experienced. On the threshold of average to high, at 0.7, the AMTs begin to experience that they must pick up pace, skip steps, and work overtime in order to accomplish the work. We took skipping steps at the level of 0.7 as not necessarily harmful for safety and can be done based on expert judgment. Similarly, working overtime can be experienced as doing something out of professional zeal, rather than being exploited. This depends on the context: in the first phase, the latter meanings applied (unsafe violations, exploitation), and in the third phase, the former meanings (safe workarounds, professional zeal). Passing 0.7 towards the level of 0.8 in the second phase, production pressures will begin to affect health and safety negatively after some time. Working overtime becomes working double shifts and skipping steps in procedures to meet schedules becomes routine.

The safety demand indicates the required degree of compliance of an AMT with the safety standards of the maintenance organisation and other regulatory bodies. The highest safety demand ($sd=1$) means that all the safety standards are required to be followed by the word. Multiple interpretations of standards may be possible; then the highest safety demand means that AMTs are required to choose the interpretation that by their professional judgment optimises safety rather than efficiency or AMTs' own interests (cf. Atak & Kingma, 2010, p. 273). The minimum safety demand ($sd=0$) indicates that only a minimum set of strong safety requirements is required to be satisfied. Similarly to performance, high safety demand is associated with the interval $[0.7, 1]$, average – with $[0.4, 0.7]$ and low – with $[0, 0.4]$.

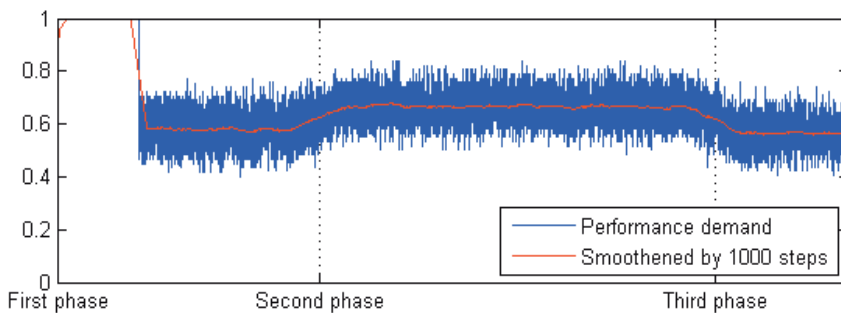


Figure 5. The dynamics of the performance demand during the three phases

The dynamics of the safety demand imposed on the AMTs is defined in accordance with the case study description. For the first two phases a constant safety demand of 0.8, a high degree of adherence to procedures, was specified. In the last phase the safety demand lowered to 0.7 (Figure 6), reflecting the more mature organisation and the autonomy over safety-related decisions granted to a developing professional culture of AMTs.

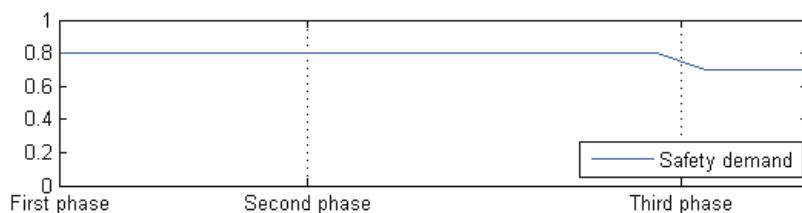


Figure 6. The dynamics of the safety demand during the three phases

When the performance effort reaches a critical value called *critical performance point* (*cpe*), it starts interacting with the safety effort. This assumption is based on several evidences provided in Atak and Kingma (2010), indicating that some safety prescriptions were not followed by AMTs because of a high time pressure (performance demand). It is reflected in the model by the assumption that the higher the performance effort of an AMT agent, the less the maximum amount of safety effort it would be able to deliver. This relation reflects the well-known dilemma between performance and safety goals in safety-critical organisations, and is also in line with observations of operation execution in many maintenance organisations. To formalise such a relation between the performance effort and the maximum amount of safety effort of an AMT (i.e., the limit on safety effort from above), the logistic function $\text{maxsft}(pe) = 1 - 1 / (e^{-w_1 \times pe + w_2})$ with $w_1=25$, $w_2=20$ shown in Figure 7 was chosen. This function determines *cpe* close to 0.7, corresponding the lower bound of the high demand interval. The high steepness of the function reflects that with the increase of *pe* above *cpe*, the maximum *se* degrades rapidly, i.e., every subsequent increase of *pe* by Δpe occurs at a rapidly increasing cost for the maximum *se*. In Appendix 4B, sensitivity analysis results are provided for different values of w_1 and w_2 corresponding to different values of *cpe*.

Note that an AMT may not necessarily contribute the maximum possible amount of safety effort. The AMT's effort is determined as the result of social influences and contagion processes described in the following Sections 4.4.2 and 4.4.3.

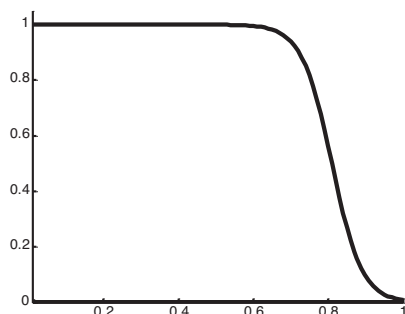


Figure 7. Change of the maximum safety effort (vertical axis) depending on the performance effort (horizontal axis)

The initial values of the efforts were drawn randomly in the beginning of the simulation from uniformly distributed ranges defined as follows: for old guard $se \in [0.7, 1]$ and $pe \in [0.4, 0.7]$; for new AMTs $pe \in [0.5, 0.8]$ and $se \in [0.5, 0.8]$.

4.4.2 Power and influence relations

In the model, MM is the main source of the performance demand imposed on AMTs, and SD is the main source of the safety demand. Besides the MM's and SD's influences, the AMT's commitment to performance and to safety is also shaped by influences from their peer AMTs. Such influences may be exerted explicitly by communication or may be transferred implicitly by observation.

To specify influence relations between agents, the French and Raven's power model (Raven, 1992) was used. This model introduces the following bases of power:

- *reward power*: its source is the ability to control legitimate reward and its strength increases with the magnitude of rewards;
- *coercive/punishment power*: its strength depends on the magnitude of the negative valence of the threatened punishment multiplied by the perceived probability that the punishments can be avoided by conformity;
- *legitimate power* of i over j stems from internalised values in j which dictate that i has a legitimate right to influence j and j has an obligation to accept this influence;
- *expert power* is the ability to administer information, knowledge or expertise to another agent; its strength varies with the extent of the knowledge;
- *referent power* of i over j has its basis in the identification of j with i , i.e., a feeling of oneness of j with i ;
- *informational influence* or *persuasion* is based on an information or logical argument that the influencing agent could present to the target to implement a change.

Different power bases may be correlated. For example, a source of legitimate power may be the value that one must adhere to certain types of expertise, thus enabling an agent's expert power base if the agent holds this expertise. An agent's ability to persuade may further increase his/her standing as an expert. Power bases should therefore not be thought of as independent variables, but conceptual tools to quantify the ethnographic textual descriptions and the sentiments conveyed by them. This necessarily involves some (inter-)subjectivity.

The strength of power-based influence of agent i on agent j is represented by parameter γ_{ij} with the range $[0, 1]$. For each influence relation between the agents from the case study a range of values was identified as shown in Figure 8. The actual influence values used in the simulation discussed in Section 5 were drawn from the uniform distributions defined by these ranges. In the following these influence relations are discussed more in detail.



Figure 8. The influence relations between the agent types in the three phases

According to the case description, in the first phase MM was pushing for production goals. The main power bases involved were strong coercive/punishment power, strong reward power and weak legitimate and expert power. MM had these power bases due to its formal position in the organisation. For example, MM had the ability to control promotion of AMTs and to decide whether or not AMTs with a short term contract would be hired again in the future. The case study indicates that the new AMTs were more influenced by managers than the old guard (0.8-1.0 vs. 0.0-0.2) during the first phase. The old guard used their knowledge of safety regulations to resist the MM's pressure on production goals. Thus the old guard could structurally undermine both strong and weak power bases. This is reflected in high legitimate power between members of the old guard (0.8-0.9) that reduces the power of MM.

The ranges are determined by reasoning from within the specific situations that the agents can encounter. For example, we established a range of (0.8-1.0) power of MM over new AMTs for the following reasons. The influence level of 1.0 means that in some instances, new AMTs do not see how they could resist MM demands at all. New AMTs had weak legitimate power, as they are unaware of behavioural norms like how procedures should be executed, if those norms existed at all. At the same time, MM had very high coercive and reward power over newcomers. In the context of a fragmented culture, where there is no clear norm of 'how to do things', MM can play out any uncertainty about rules and always has the last word. MM may also hold some expert power towards newcomers, as the MM is himself a senior engineer and newcomers may not feel they can question this knowledge.

The lower level of 0.8 on the other hand reflects that in some situations, the legitimacy and expert power base of MM may be undermined by members of the old guard. A top-down management style may also create negative referent power. AMTs identify with one another and MM becomes the out-group, resulting in a desire *not* to behave in a manner seen characteristic of MM. That is, AMTs then resist behaviour such as respecting work packages and trying to meet performance demands. This together creates a lower level that we determined at 0.8, rather than, for example, 0.7, which would be at the threshold of a medium to strong power level. The reason for this is that the power of MM over new AMTs never reaches close to average. New AMTs generally feel at the mercy of MM during the first phase as clear norms are lacking and they have little individual or shared experience to resort to.

According to the case description, the old guard acted as role models for the new AMTs, which is represented by high referent, expert and legitimate power towards new AMTs. In situations where MM is absent, the old guard could pressure new AMTs to do the complete opposite of their instructions, while the lack of norms allows them to come up arbitrarily with instructions that new AMTs should follow. This is reflected in the upper level of 1.0. The lack of an integrated culture may also undermine their own legitimacy; the old guard also does not control MMs reward and coercive power on new AMTs, which together is reflected in a lower limit of 0.8, and thus a range of (0.8-1.0). The role of SD during the first phase was only marginal. SD had very limited legitimate power to influence both new AMTs (0.1-0.2) and the old guard (0.0-0.1) by imposing safety values on them.

In the second phase the size of the old guard was decreasing, by the end of the phase all of them had left the organisation. MM was still the main driver behind the production goals. The MM's influence was still based on the same power bases as in the first phase and additional referent power. In the second phase MM also included former technicians, who were perceived as role models by new AMTs. Besides the new referent power, the legitimate power of MM had increased due to the struggle of the organisation for survival. This created a context in which a discourse about meeting schedules became commonly accepted as the reality to reckon with. From the MM's position, it became easier to argue why tight plans should be met and working overtime should be considered normal. Therefore, the MM's influence strength on new AMTs had increased in comparison with the first phase as well (0.85-1.0 vs. 0.8-1.0). We take 0.85 rather than 0.9 because the effect of legitimate power, while significant, is impacted negatively by the gradual development of new AMTs' experience and knowledge of company rules and business arrangements. This allows new AMTs to develop their own informational and expert power base, and undermine coercive and legitimacy power bases. Yet because the company grows so quickly, we estimated these effects remain very small on average for the duration of the growth phase.

Even though the main focus during the second phase was on production goals, SD became more involved and present in the organisation. However, their behaviour was rather reactive - they responded to occurrences and supported production goals. Their legitimate power had increased a little. SD thus could thus always exert a trace of influence, translating in power level of 0.1. On occasions – such as after an incident or during a safety campaign – influence would be slightly higher, but still very weak, resulting in the range (0.1-0.3).

In the third phase a new proactive SD was formed. Management pressure on production goals was not dominant anymore and AMTs were able to work according to procedures and safety rules. The legitimate power of MM decreased and SD even had coercive and punishment power. For example, in this phase SD was able to initiate the suspension of the license of an AMT who did not work according to procedures. This new power of SD over the AMTs is reflected in the higher influence strength (0.5-0.8). In their turn, the AMTs had more freedom to work according to safety standards and had more

legitimate power against management pressure. Note that there is no mechanism that establishes a new 'old guard' as time passes by and new AMTs become more experienced. This is a theoretical possibility but there were no data to substantiate this process here.

To determine combined influences of groups of agents (such as the management or old guard) based on the individual influences of the group members, the Latane's (1981) dynamic theory of social impact is used. According to this theory, the strength of influence γ_{Gi} of group G of N agents on agent i is determined by:

$$\gamma_{Gi} = N^\beta [\sum_{k=1..N} (\gamma_{ki} / I_{ki}^2) / N], \quad (1)$$

where γ_{ki} is the strength of influence of group member agent k on agent i ; it is defined for the different phases of the case study as discussed above;

$I_{ki} \in [0, 1]$ is the immediacy of agents i and k , i.e., their closeness in space and time; we assume that $I_{ki} = 1$, i.e., the agents interact with each other without intermediate agents.

β is a constant used for compensation for the group size; from empirical studies $\beta = 0.3..0.5$. In our study $\beta = 0.4$.

4.4.3 Modelling social contagion

Provided a demand for performance or safety by an influencing agent, an AMT agent decides to which extent and how fast to satisfy this demand by delivering its performance effort. The AMT i 's performance effort pe_i for the MM's performance demand pd_{MM} is determined by the following social contagion equation (Deffuant et al., 2000):

$$dpe_i = \alpha_{MM,i} \gamma_{MM,i} (pd_{MM} - pe_i) dt \quad (2)$$

Here $\gamma_{MM,i}$ is the influence of MM on i , $\alpha_{MM,i}$ is the rate of change parameter, which depends on the agent's openness to change and the expressiveness of the influencing agent/group. Since MM has a high expressiveness in all phases, $\alpha_{MM,i}$ is taken 0.8.

Similarly the AMT i 's safety effort se_i for the SD's safety demand sd_{SD} is determined by

$$dse_i = \alpha_{SD,i} \gamma_{SD,i} (sd_{SD} - se_i) dt \quad (3)$$

Here $\alpha_{SD,i}$ is taken 0.4 for the first two phases, when SD was rather passive and 0.8 for the last phase with the proactive SD.

The influence of AMT agent j on the performance and safety efforts of its peer AMT agent i is defined by the following social contagion process:

$$\begin{aligned} dse_i &= \sum_j \alpha_{ji} \gamma_{ji} (se_j - se_i) dt \\ dpe_i &= \sum_j \alpha_{ji} \gamma_{ji} (pe_j - pe_i) dt \end{aligned} \quad (4)$$

Here α_{ji} is taken 0.7 in all the phases, reflecting intensive explicit and implicit interaction between the AMTs.

If by applying the equations (2)-(4) a point (pe, se) is obtained that lies above the maximum safety effort function from Figure 7, the closest point on the function is chosen. In such a way mutual inhibition of safety and performance goals is captured.

Furthermore, two additional constraints are defined to reflect that the old guard had used safety as a shield against the productivity push of MM in the first phase and did not deliver performance effort above a certain threshold (pt):

$$\begin{aligned} pe &< pt \\ se &> \text{maxsft}(pt)pe^2 / pt^2 \end{aligned} \quad (5)$$

where pt is performance threshold setting maximal performance the old guard can reach and maxsft is the maximum safety effort function defined above (Figure 7). For our model we have chosen $pt = 0.75$ for new AMTs corresponding to a high performance demand and $pt = 0.5$ for the old guard, which reflects their opposition to a high performance demand. Essentially, the safety effort of the old guard is determined by fitting a quadratic function between $[0, 0]$ and the point on the maxsft curve for the level of the performance threshold.

The frequencies of interaction of the agents are defined as follows. Interaction between AMTs occurs within a shift every 5 minutes and between shifts during shift changes. MM influences AMTs every 10 minutes in every phase, since MM function as supervisors of AMTs and are relatively close to them. The SD's influence on AMTs occurs once a shift in the first phase, five times a shift in the second phase and 15 times a shift in the last phase. This represents the low, indirect participation of the safety department in daily operations at the initial phases towards a more active participation in the last phase.

4.5 SIMULATION RESULTS

In this section we discuss analysis of the simulation results. In particular we show how the model can be validated through an interpretation of the emergent patterns regarding commitment to safety. Validation is here seen as the interpretation of generated simulation data and matching the pattern to the ethnographic description. This validation criterion states that if the simulations create patterns that match the empirical case, then the model must be to some extent correct. With alternative settings, we can check if the results are intuitively sensible and construct hypotheses that can be tested with newly gathered data. We therefore performed simulations using the model from Section 4.4 (discussed in Section 4.5.1) and several variants of this model (discussed in Section 4.5.2).

4.5.1 Simulation results of the proposed model

Based on the model presented in Section 4.4, 100 discrete simulation runs were performed with a static time step representing one minute of time in the real world. The simulation comprises three distinct phases for which most of the simulations

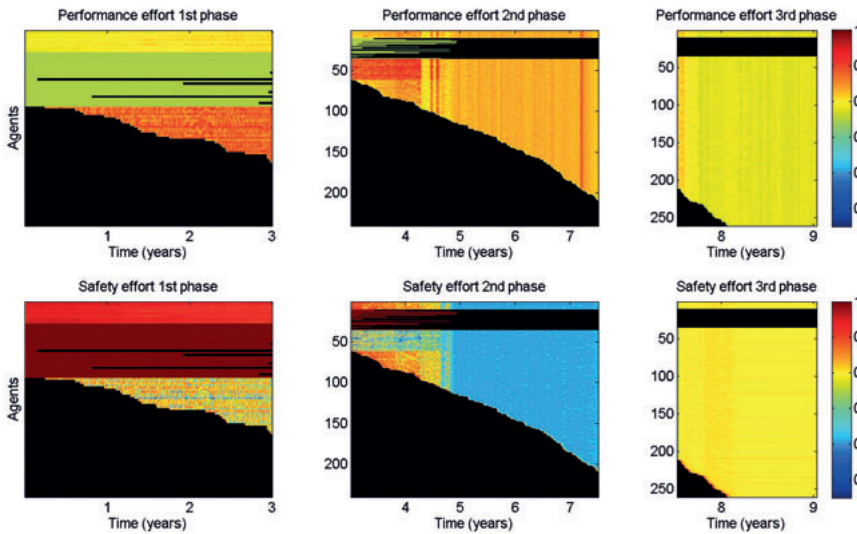
parameters differ in accordance with the case description. In addition, there are two transition phases between the main phases and those parameters that vary between the phases are gradually changed in transition phases. The length of all the phases separately as well as the overall length match the lengths of periods with distinct safety cultural characteristics as identified in the case study.

All agents were put in an agent pool from which they were being selected for shifts. There were three shifts with equal length during one day. The ratio between the size of a shift and number of agents was constant during the whole simulation. Only in the third phase every shift was split into two which worked separately and had no influence on each other. This simulated that some of the AMTs had worked on line maintenance and some on base maintenance. During the whole simulation the number of agents entering and leaving the company is maintained as reported in the case study.

The developed model was validated by comparing the simulation results with the patterns found in the case study (Atak & Kingma, 2010). The simulation results for one random simulation run are represented by graphs of AMTs' performance and safety efforts (Figure 9) provided the MM's performance and SD's safety demands (Figures 5 and 6). The simulation results aggregated over all 100 simulation runs are provided in Figure 10. Commitment can be interpreted as the difference of management demand and AMT performance, but not in all situations. For example, when management demand is very low, equally low AMT performance does not necessarily reflect high commitment. We chose not to include another complex parameter for commitment to safety, but rather interpret commitment straight from the performance and demand graphs.

The rows in the graphs in Figure 9 represent the state of a single agent's safety or performance effort. Efforts range from zero (blue) to one (red). Black corresponds to the value of -0.1, which is an empty row, i.e., the agent is not employed. In the graphs for the first phase, at time point 0, there are 35 agents present, a work force that gradually grows until the 8-year time point in the third set of graphs, where it reaches 260. Old guard AMTs occupy row 15 through 35 in Figure 9. They are gradually leaving the company starting from the first phase to roughly the first year of the second phase. The row representing their efforts abruptly turns black when an old guard AMT leaves, while empty rows below are gradually being filled with new AMTs.

In the first phase, conflicting management demands, resistance strategies and power differences between agents give rise to fluctuating, unevenly distributed safety efforts (Figure 9). This pattern corresponds to the fragmentation perspective, highlighting ambiguity and inconsistent views amongst cultural members. Commitment to safety at this stage reflects the influence of the old guard's 'work-to-rule' resistance against management performance demands, by extensive compliance with safety rules (reflected by very high safety efforts in Figure 9). New AMTs are highly influenced by the more experienced old guard and therefore are greatly drawn in by this behaviour. At the same time new AMTs experience a stronger pull from MM than the old guard does. They work harder than the old guard, compensating to some extent for the work they leave undone due to their resistance to MM (Figure 9).



4

Figure 9. Visualisation of performance and safety efforts of the AMTs during the three phases

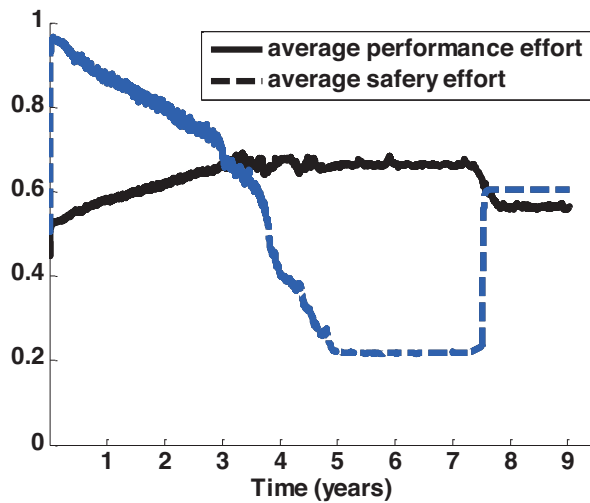


Figure 10. Performance and safety efforts in the three phases averaged over all agents in 100 simulation runs. Standard deviation at each point is less than 0.03

As the core of this resistance—the old guard—leaves the company, it enters a second phase. Commitment in the first phase appears to have been of a superficial character. In the graph, old guard members leaving the company are represented as values that go to -1. As almost all members of the old guard have left, the safety effort graph shows how all the AMTs' safety efforts drop to dangerously low levels (Figure 9).

The transition between the first and second phase is initiated by changing power relations between MM and AMTs and increasing performance demands. The changes accompany the shifting mentalities and arrangements accommodating new, larger contracts (see section 4.4). Old guard AMTs continue to resist performance pressures, but new AMTs are less affected by them than by the increasing persuasiveness of MM. This reflects the observed exertion of power, where AMTs could not ignore the company's economic challenges and MM legitimised its attempts to pressure the work force by reminding technicians of this fact (Atak & Kingma, 2010, p. 271). As more and more new AMTs were recruited and the old guard AMTs' numbers decreased, the old guard AMTs was losing the struggle to resist. When only the last two members of the old guard remain in the company, safety efforts reach a turning point, drop and stabilise at a significantly lower level. Since the phasing out of the old guard is a relatively gradual process, the transition between phase one and two takes a relatively long period to complete.

The safety efforts observed in the second phase, fluctuating around 0.25, can be interpreted as AMTs regularly making shortcuts to speed up the work, also when the flight safety consequences of procedure shortcuts may not be known. Atak and Kingma (2010, p. 275) describe an event, where an incorrect aircraft part had been ordered and MM forces an AMT to install an old part, rather than wait for the correct new part. Another type of practice related to low values of safety could be acceptance of unhealthy working schedules, such as the reported overtime and double shifts that can lead to clouded judgment.

Consistently low safety efforts, significantly lower than demanded by the SD (0.8), can in the second phase be interpreted as revealing low commitments to safety. The uniform distribution of low levels of safety efforts indicates that practices such as those described above are seen as normal and legitimate throughout the organisation. The ethnographic data reveal that 'a new discourse on safety which stressed a flexible and practical attitude' took hold of the organisation at this time and was used to justify deviations from safety rules (Atak & Kingma, 2010, p. 272). AMTs' relatively low power towards MM, and MM's increasing persuasiveness to be flexible with safety standards, gives rise to an organisational culture integrated around production values. This can be observed in the performance efforts by AMTs responding in a uniform manner to fluctuations in managers' performance demands.

In the transition towards the third phase, managerial demands and power relations are harmonised. Both safety and performance demands are lowered, and the SD gains power relative to MM, which loses some power (see section 4.4). The resultant power balance shifts in favour of the SD, signifying the shift towards a serious safety policy by a new CEO, in a more comfortable, mature market position. Safety levels quickly rise to acceptable levels, reflecting the observation that the influence of the new policy was felt 'from the very first day' (Atak & Kingma, 2010, p. 272). Performance efforts remain at a higher level slightly longer, accounting for the work that had accumulated under the previous, higher performance demands and takes some time to complete.

The new balance of power and work pressure allows AMTs' safety efforts to stabilise, yielding an impression of strong, internalised commitments to safety. Safety and performance pressures no longer impose conflicting demands on AMTs, evident when one compares the demand values to the maximum efforts represented in Figure 9. Safety efforts are uniformly distributed amongst the 260 AMTs at a level of approximately 0.6, meaning more than-average concern with safety where standards are normally met and exceptions coordinated. Safety efforts hardly fluctuate, even when performance efforts do (approximately between 0.5-0.55). This stabilisation and uniform distribution signifies a professional subculture of AMTs where safety practices are shared and technicians are given leeway to exercise discretion over safety-critical decisions. Production pressures exerted by management still fluctuate, but hardly perturb the uniformly distributed safety efforts.

To summarise, under the social and organisational influences an emergent pattern of commitment unfolds in the three distinct phases of organisational development. Commitment is first superficial, owing to the old guard's resistance in the context of a fragmented culture in the survival phase. The weakness of commitment shows up in the second phase, when the organisational culture integrates around production values. In the final, maturation phase, commitment takes on the stable character. Such commitment is expected of a more autonomous professional culture in a diversified cultural context where competing core goals coexist in relative harmony.

4.5.2 Results of 'what-if' simulations of model variants

To test the usability and scope of the model, we simulated three variants of the original model from Section 4.4. These variants are each realistic scenarios that could have an interesting impact on the patterns of commitment. The results of these simulations are considered in this section and compared to the simulation results of the original model.

Model variant 1- Weak opposition culture. In the first model variant, in contrast to the original model, old guard represents a loosely connected group, which does not oppose MM strongly. This variant is interesting because it helps illuminate the role of the old guard in the development of the culture. The following changes were made in the original model:

- influence of the old guard on themselves is [0.1, 0.4] (was [0.8, 0.9]);
- performance threshold (*pt*) of the old guard is 0.75 (was 0.5).

Using this model variant 10 simulation runs were executed. The performance and safety efforts averaged over all the agents and the simulation runs of model variant 1 were compared with the simulation outcomes of the original model (Figure 11) by using paired sample t-test with 5% significance level.

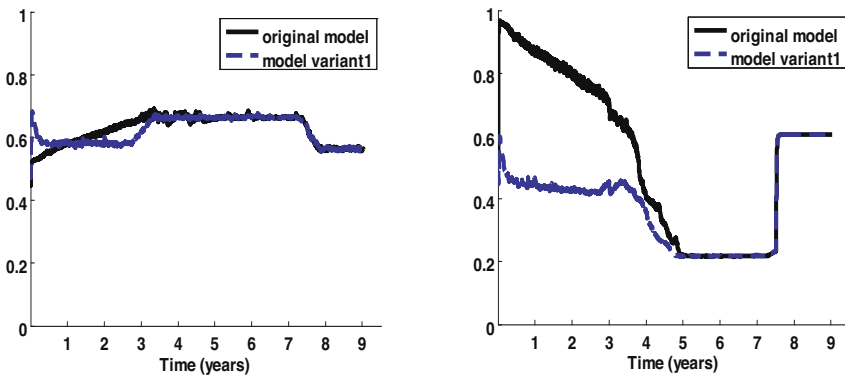


Figure 11. Performance efforts (left) and safety efforts (right) in the three phases averaged over all agents in 10 simulation runs for the original model and model variant 1. Standard deviation at each point is less than 0.05

In phases 1 and 2 significant differences between the models were established both for the performance and safety demands. The null hypothesis of the paired t-test was supported for the phase 3.

The safety effort of the AMTs in phase 1 of the model variant 1 is significantly lower than in the original model. This can be explained by a low opposition of the old guard and a low degree of their mutual reinforcement. Furthermore, it can be observed that because of the loose relations in the shifts in model variant 1, the performance effort is not reinforced by the team members and remains relatively constant throughout each phase. In the original model the performance effort grows steadily in the first phase. In general, tight relations between agents and mutual reinforcement of their states may have positive, as well as negative amplification effects.

After the transition period the behaviour of AMTs stabilises in the second phase in both models. These results show that a resistant old guard may not only have a positive role to play in terms of safety, but also have a less detrimental effect on production than it might seem.

Model variant 2 – Conflict between safety and performance demands. In the second model variant, in contrast to the original model, SD has a high influence on the AMTs during the first and second phase. However, the performance and safety demands are both high and not harmonised, as in the third phase. This is theoretically interesting because it may help to corroborate the managerial insight that pressing on performance is not always helpful.

The following changes were made in the original model:

- the influence of SD over both new AMTs and the old guard is [0.7, 0.9]

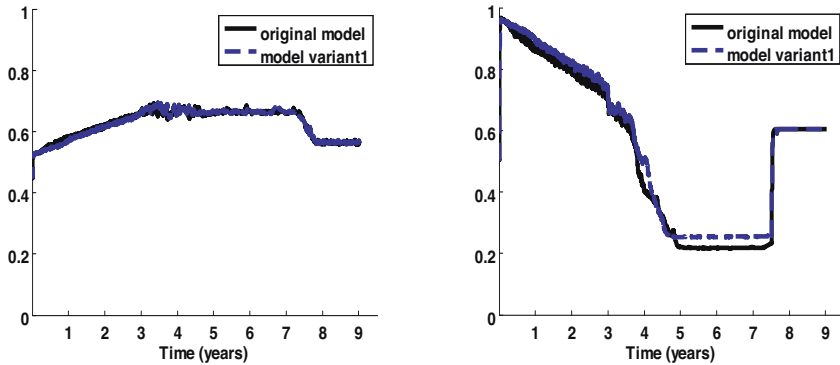


Figure 12. Performance efforts (left) and safety efforts (right) in the three phases averaged over all agents in 10 simulation runs for the original model and model variant 2. Standard deviation at each point is less than 0.05

The paired t-test showed the models have significant differences w.r.t. the performance effort in the second phase and w.r.t. the safety effort in the first and the second phase. It means that the SD's impact on the AMTs is statistically significant, however is not very high in terms of the magnitude (Figure 12). One can conclude that enforcing high safety and performance demands at the same time without their mutual adjustment does not actually help to improve safety.

Model variant 3 – Random composition of shifts. In the third model variant a random composition of the shifts was introduced by a random permutation of the agent pool every time when all the agents were used for the shift composition. This is an interesting variation because it is a strategy used by airline companies, for example, to prevent negative group dynamics in flight crews.

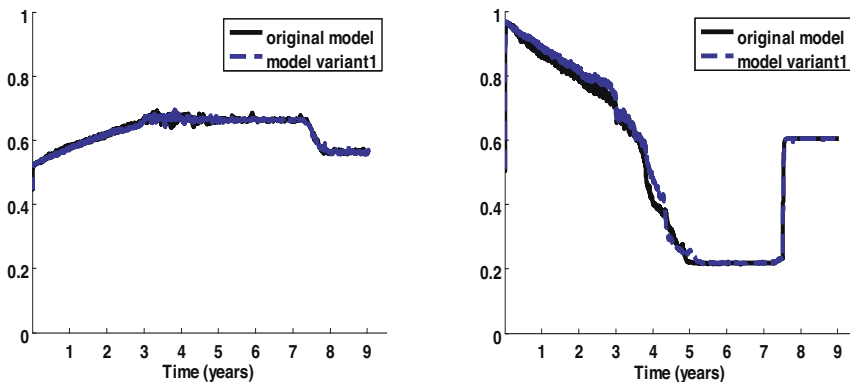


Figure 13. Performance efforts (left) and safety efforts (right) in the three phases averaged over all agents in 10 simulation runs for the original model and model variant 3. Standard deviation at each point is less than 0.05

The paired t-test showed that there were no significant differences between the models w.r.t. the performance effort. However, there were significant differences w.r.t. the safety effort in the first and the second phases. The safety effort was on average higher in model variant 3, meaning that shift rotation might have a positive effect on safety. However the magnitude of this effect in the simulation is not very high, because the shifts did not differ much from the beginning. The more differences the shifts have, the higher will be the effect. In the future more variations between the shifts will be explored.

4.6 CONCLUSIONS AND DISCUSSION

This study presents an innovative approach that can be used to address current questions regarding safety culture that attempt to get beyond linear, static approaches and that take a complex, political view on culture more seriously. Our paper showcased an example from the aircraft maintenance domain addressing the research question how the commitment to safety of maintenance technicians emerges and develops under social and organisational influences. Commitment to safety is a key aspect of organisational safety culture, but current survey-based methods offer limited insight in underlying mechanisms of development of such cultural properties. We propose an interdisciplinary approach, combining organisational ethnography with formal agent modelling and simulation experiments. As a demonstration of this approach, we developed a formal model from the ethnographic case study by Atak and Kingma (2010). We used this model to simulate, bottom-up, with a generic set of mechanisms operating throughout the simulation, the observed emergent global pattern of commitment to safety of aircraft maintenance technicians, developing over a period of 9 years. Theories of social power and influence were used to derive a formal model and supplementary data were gathered through interviews and other studies on aviation maintenance operations.

4.6.1. Value and applicability of the approach

The merit of the approach is in offering insight in relations between social and organisational power mechanisms and emergent characteristics of safety culture, not in deriving precise numerical values. Formal modelling adds to ethnographic research that it forces researchers to make theoretical connections explicit between social relations and cultural dynamics. Ethnographic accounts will tend to remain more contextualised. The ethnographer often starts from a participatory insiders' perspective. The agent-based modeler, on the contrary, builds a model of a sociotechnical system from a complex systems perspective by identifying agents, their various local properties and interactions, taking diverse feedback mechanisms into account. By taking such a systemic approach to model development, the agent-based modeler is able to provide a feedback to the ethnographer to focus their data collection efforts, observations, and explorations on particular aspects of a sociotechnical system represented by parameters, processes, and mechanisms in the model. However, it is not necessary and even not desirable that

the activities of the ethnographer are fully steered by the modeler. By keeping a more open attitude to data collection, the ethnographer may discover important aspects not considered by the modeler, which however might be important to be reflected in the model. Based on an agent-based model, diverse forms of analysis could be performed, such as sensitivity analysis and bias and uncertainty analysis. Through such an analysis important parameters, assumptions, and uncertainties in the model can be identified, which would require refinement and further identification by ethnographic research. Thus, the systematic agent-based model development and ethnographic research should take place in interaction with each other, complementing each other in an integrated methodology.

In contrast to modelling social relations with network properties like homophily (Holzhauer, Krebs & Ernst, 2013), our model uses power influencing. This is suitable for safety culture studies because the bases of power that each agent experiences are anchored in rich qualitative context descriptions. With this approach to social relations, formalisation helps to explicate contextual processes that are important in shaping a 'strong safety culture'. We thus capture a more fragile and dynamic reality than standard quantitative safety culture research methods does (Guldenmund, 2000; 2007).

The context-sensitive modelling approach may also provide managerial insights. One example is our demonstration of how lowering and harmonising performance and safety demands can lead to a significant increase in AMTs' safety efforts, with only a small reduction of performance efforts.

4.6.2. Limitations

Although the tendency may exist to view multi-agent models of safety cultural phenomena as predictive, we do not claim this: the current model is explanatory. Since cultural phenomena are context-specific, the transferability of any model depends on the extent to which the dynamics it captures are recognisable elsewhere. This requires attention to any specific context of application and likely many adaptations of the model. We draw attention to transferability as a limitation, but it may also be seen as a strength. Formal modelling is a powerful tool to make assumptions explicit and theorise back and forth between what is happening in a particular setting and what we know more generally about safety culture.

That said, the current model remains relatively high level, does not include many possible feed-back interactions, and hard-codes some influences that are in reality dynamic effects. One interesting possibility is the impact of critical incidents. When commitment to safety decreases overall, safety incidents may occur and this may give voice to maintenance personnel and safety department officials to prioritise safety. The current secondary data source was not detailed enough to find empirical evidence for such feedback loops, showing where the current model could benefit from further research.

4.6.3. Further research

The model presented here invites improvement and extension while also inspiring further theoretical development and ethnographic research. In order to agree with the contextualising tendency of ethnographic research, more detailed data may be gathered

on the precise ways in which safety and production demands are weighed. These data can lead to more adequate models and yield interesting theoretical insights. The translation from conceptual to formal models may also be automated as described by Fuentes-Fernández, Hassan, Pavón, Galán and López-Paradez (2012).

The rewards of this approach are promising. There is a persistent—but often inappropriate—assumption in both theory and practice that safety behaviour can be regulated by mainly enforcing compliance with safety regulations (Dekker, 2014). Fundamental insights of how safety is created through culture are however still spread thin (Antonsen, 2009; Edwards et al., 2013; Woods, Dekker, Cook, Johannesen & Sarter, 2010). The current approach attempts to escape this deadlock and move towards more refined thinking about the human contribution to safety (Reason, 2008).

APPENDIX 4A. MODEL DOCKING

To assess the model's expressiveness, suitability, and innovativeness, we relate it to another important modelling approach to power. Power relations between artificial agents have also been investigated in the area of multi-agent systems. Castelfranchi, Micelli and Cesta (1992) introduce different types of social dependence relations between agents, based on which social influence and power are defined. Power relations are viewed in terms of resource dependence: an agent gains power when it controls resources that another agent needs.

In Burton (2003) different types of model relations are discussed, also called model docking. Such a docking may be done at the *distributional* and *relational* levels. At the distributional level the models require to produce the same (numerical) outcomes, whereas at the relational level internal components and dynamics of the models are related. In the following it is described how the models can be related at both these levels. Note that although the social dependence relations introduced in Castelfranchi, Micelli and Cesta (1992) are qualitative, it is indicated in the same paper that the specification language may be extended by incorporating quantitative degrees of dependence between agents. To enable comparison of the models at the distributional level, a three-valued scale for measuring the degree of social dependence and power of influence is introduced: 'h' corresponding to a high degree, 'm' – medium and 'l' – low.

First we demonstrate how the models can be related at the relational level.

We start by introducing acts and goals w.r.t. which social dependencies are defined. In Table A1 notations for the agents from the case study are provided which will be used for specifying social dependence relations. The goals of AMTs provided in Table A2 were identified in accordance with the self-determination theory (Deci & Ryan, 2002), which is generally accepted as a sound empirical theory of human motivation. According to this theory, humans have several types of needs, among which *competence need* is related to seeking to control the outcome and experience mastery, *relatedness* is the need to interact, be connected to, and experience caring for others, and *autonomy* is the need to

be causal agent of one's own life. In addition to the goals derived from self-determination theory, g_1 through g_3 , we also listed goals g_4 through g_8 , which are derived from empirical data, i.e. the case study. Based on the case study description, in relation to the goals a set of acts is identified listed in Table A3.

Table A1. Notations for the agents from the case study

x_1	new AMTs
x_2	old guard
x_3	MM
x_4	SD

Table A2. The goals of the agents from the case study w.r.t. which dependence relations are defined

g_1	competence-related goals
g_2	relatedness-related goals
g_3	autonomy-related goals
g_4	Personal/psychological safety & security-related goals
g_5	achieve high performance
g_6	achieve high compliance to safety regulations
g_7	achieve high performance without compromising safety
g_8	avoid compromising safety

Table A3. The acts of the agents from the case study w.r.t. which dependence relations are defined

a_1	promote an AMT
a_2	hire an AMT with a short term contract
a_3	refrain from providing reprimands
a_4	ensure safety regulations are being observed by an AMT
a_5	approval of behaviour of an AMT
a_6	allow for AMT professional discretion

In Table A4 social dependence relations are provided, which were identified for the first phase of the organisational development in the case study; c.f. the influence relations in Fig.4. Each social dependence relation (*S-DEP* $x y a g d$) reads as: x depends on y to degree d with respect to act a useful for realising x 's goal g . Note that the original S-DEP relation from Castelfranchi, Micelli and Cesta (1992) was extended with the fifth argument – the degree of dependence, as was discussed previously.

To define social dependence relations, the influence relations from the model introduced in this paper (Fig.4) were taken as the basis. For each influence relation the power bases explained in Section 4.2 were related to particular goals and acts of agents. For example, the influence relation of MM on new AMT in the first phase has a strong legitimate basis to control promotions of AMTs, to re-hire AMTs with a short term contract and to provide reprimands. Both promotions and re-hiring of AMTs contribute positively to the satisfaction of their competence-related goals, i.e., they can be seen

a form of professional recognition. Also refraining from providing reprimands by MM serves as a positive feedback contributing to the satisfaction of the AMTs' competence-related goals. Furthermore, re-hiring of AMTs, as well as refraining from providing of reprimands contribute positively to the AMTs' personal safety & security-related goals. Since MM has a strong legitimate power basis on new AMTs, all these social dependence relations have a high degree (*h*) (Table A4, first column). Other social dependence relations in Tables A4 and A5 are defined in a similar manner.

Table A4. Social dependence relations of new AMTs in the first phase

on MM	on SD	on old guard	on new AMTs
(<i>S-DEP</i> $x_1 x_3 a_1 g_1 h$)	(<i>S-DEP</i> $x_1 x_4 a_4 g_1 l$)	(<i>S-DEP</i> $x_1 x_2 a_4 g_2 h$)	(<i>S-DEP</i> $x_1 x_1 a_5 g_2 l$)
(<i>S-DEP</i> $x_1 x_3 a_2 g_1 h$)	(<i>S-DEP</i> $x_1 x_4 a_4 g_4 l$)	(<i>S-DEP</i> $x_1 x_2 a_5 g_2 h$)	
(<i>S-DEP</i> $x_1 x_3 a_2 g_4 h$)		(<i>S-DEP</i> $x_1 x_2 a_5 g_1 h$)	
(<i>S-DEP</i> $x_1 x_3 a_3 g_1 h$)			
(<i>S-DEP</i> $x_1 x_3 a_3 g_4 h$)			

Table A5. Social dependence relations of old guard in the first phase

on MM	on SD	on old guard	on new AMTs
(<i>S-DEP</i> $x_2 x_3 a_3 g_4 l$)	(<i>S-DEP</i> $x_2 x_4 a_4 g_4 l$)	(<i>S-DEP</i> $x_2 x_2 a_4 g_2 h$)	(<i>S-DEP</i> $x_2 x_1 a_5 g_2 l$)
		(<i>S-DEP</i> $x_2 x_2 a_4 g_3 h$)	
		(<i>S-DEP</i> $x_2 x_2 a_4 g_4 h$)	

As stated in Castelfranchi, Micelli and Cesta (1992: 10), the power of influencing is derivable from dependence relations: "If *x* is dependent on *y*'s performing a certain act in view of *p*, *y* is quite likely to have the power of influencing *x* relative to some other goal of *x*'s.". The new AMTs have a high dependence on MM and old guard (Table A4). In the case study MM uses this dependence to influence new AMTs to adopt the goal of achieving a high performance:

$$H_{i=1,2,3} (INFL-POWER_{x_3 x_1 a_i g_5 h})$$

(*INFL-POWER* $x y a g v$) relation is read as *x* has the power of influencing *y* of degree *v* if *x* can do such an act *a* that makes *y* have *g* as a goal of her own. To express power of influencing relation over multiple acts *H*-relation is used in Castelfranchi, Micelli and Cesta (1992).

In the case study old guard use the new AMTs' high dependence on them to influence the new AMTs to adopt the goal of achieving high compliance to safety regulations (i.e., opposing high performance demands):

$$H_{i=4,5} (INFL-POWER_{x_2 x_1 a_i g_6 h})$$

Since the social dependence relations of the new AMTs on SD and other new AMTs are of a low degree, they do not form a sufficient basis for power influencing.

As was discussed in Section 4.4.1 and illustrated in Fig. 11 goals g_5 and g_6 may be in conflict with each other, especially when demands are high. Since both identified power of influencing relations have a high degree, new AMTs are pulled strongly by MM and old guard in the opposite directions. This results in a fragmented culture, which is in line with the outcomes of the model proposed in this paper.

The old guard has high mutual social dependencies, which unite this group even stronger in a self-reinforcing manner:

$$G_{i=2,3,4} (INFL-POWER_{x_2 x_2 a_4 g_i h})$$

The distinct behaviour of old guard – high compliance to safety and opposition to high performance demand – can be also clearly seen in the results of the model proposed in this paper (Fig. 13).

The social dependence relations for the second phase are provided in Table A6. As management gains referent power over new AMTs in this phase, a new relation is added ($S-DEP_{x_1 x_3 a_5 g_2 h}$). Furthermore, the dependence of the new AMTs on the old guard diminishes in this phase, which is reflected in the degrees of the relations in the third column. Also the mutual dependencies between the members of old guard become weaker, which is reflected in the third column of Table A7.

Table A6. Social dependence relations of new AMTs in the second phase

on MM	on SD	on old guard	on new AMTs
$(S-DEP_{x_1 x_3 a_1 g_1 h})$	$(S-DEP_{x_1 x_4 a_4 g_1 l})$	$(S-DEP_{x_1 x_2 a_4 g_2 l/m})$	$(S-DEP_{x_1 x_1 a_5 g_2 l})$
$(S-DEP_{x_1 x_3 a_2 g_1 h})$	$(S-DEP_{x_1 x_4 a_4 g_4 l})$	$(S-DEP_{x_1 x_2 a_5 g_2 l/m})$	
$(S-DEP_{x_1 x_3 a_2 g_4 h})$		$(S-DEP_{x_1 x_2 a_5 g_1 l/m})$	
$(S-DEP_{x_1 x_3 a_3 g_1 h})$			
$(S-DEP_{x_1 x_3 a_3 g_4 h})$			
$(S-DEP_{x_1 x_4 a_5 g_2 h})$			

Table A7. Social dependence relations of old guard in the second phase

on MM	on SD	on old guard	on new AMTs
$(S-DEP_{x_2 x_3 a_3 g_4 l})$	$(S-DEP_{x_2 x_4 a_4 g_4 l})$	$(S-DEP_{x_2 x_2 a_4 g_2 l/m})$	$(S-DEP_{x_2 x_1 a_5 g_2 l})$
		$(S-DEP_{x_2 x_2 a_4 g_3 l/m})$	
		$(S-DEP_{x_2 x_2 a_4 g_4 l/m})$	

Thus, the following power influencing relations can be inferred in phase 2:

$$H_{i=1,3,5} (INFL-POWER_{x_3 x_1 a_1 g_5 h})$$

$$(INFL-POWER_{x_2 x_3 a_4 g_6 l/m})$$

$$G_{i=2,3,4} (INFL-POWER_{x_2 x_2 a_4 g_i l/m})$$

MM clearly has the highest influencing power over new AMTs in this phase, and thus makes them to adopt goal g_5 . This is also in accordance with the results of the model proposed in this paper.

In the third phase the basis of legitimate power of MM becomes weaker and management pressure on production goals is not dominant anymore. This is reflected in the decreased degrees of dependencies in the first column of Table A8. Furthermore, SD becomes more proactive and gains a basis for coercive and punishment power. Thus, relation $(S-DEP_{x_1x_4a_3g_4} m-h)$ is added in the second column of Table A8. Both MM and SD gain power by allowing AMTs to make more professional judgment calls. This contributes to satisfaction of their autonomy goals g_3 and heightens their motivation to take responsibility for the work, the demands for which are now within reasonable limits. For example, MM gives AMTs more influence in creating work packages and the SD acknowledges that not all procedure violations are unsafe, if there is sound and knowledgeable professional judgment. The strength is low-medium because this power derives only from legitimacy and persuasion power bases. Thus, the relations $(S-DEP_{x_1x_3a_6g_3} l-m)$ and $(S-DEP_{x_1x_4a_6g_3} l-m)$ are added.

Table A8. Social dependence relations of new AMTs in the third phase

on MM	on SD	on new AMTs
$(S-DEP_{x_1x_3a_1g_1} m-h)$	$(S-DEP_{x_1x_4a_4g_1} m-h)$	$(S-DEP_{x_1x_1a_5g_2} l)$
$(S-DEP_{x_1x_3a_2g_1} m-h)$	$(S-DEP_{x_1x_4a_4g_4} m-h)$	
$(S-DEP_{x_1x_3a_2g_4} m-h)$	$(S-DEP_{x_1x_4a_3g_4} m-h)$	
$(S-DEP_{x_1x_3a_3g_1} m)$	$(S-DEP_{x_1x_4a_6g_3} l-m)$	
$(S-DEP_{x_1x_3a_3g_4} m)$		
$(S-DEP_{x_1x_3a_6g_3} l-m)$		

Based on the social dependence relations from Table A8 the following power of influencing relations can be inferred:

$$H_{i=1,3,6} (INFL-POWER_{x_3x_1a_1g_7} m-h)$$

$$H_{i=3,4,6} (INFL-POWER_{x_4x_1a_1g_8} m-h)$$

New g_7 and g_8 goals reflect harmonisation of the performance and safety demands in the organisation in the third phase. Note that both power of influencing relations have $m-h$ degree, which gives AMTs some freedom to perform operations in their own way.

The compared models can thus be formally related to each other, providing a test of our model's expressiveness and appropriateness for the topic of study. In the other model, social dependence relations are defined at a more detailed level than the power relations in our model. Such a level of detail is not deemed to be necessary for the application considered in this paper, given the nature of the secondary data that we referred to. Furthermore, social dependence relations are formalised in the other model using a qualitative predicate logic-based language, which is more suited to specify agent states and is less applicable for describing dynamics of processes. In contrast, our model

is quantitative and continuous; it takes a dynamic view on the evolution of power relations in an organisation. To address the current limitations of safety cultural analyses and theorising, our approach appears more appropriate.

APPENDIX 4B. SENSITIVITY ANALYSIS FOR THE FUNCTION *MAXSFT*

In this section, the sensitivity of the patterns of commitment produced by the model to the parameters of the function $maxsft(pe)=1-1/(e^{-w_1 \times pe} + w_2)$ are discussed. For $w_1=15$ and $w_2=10$ and c_{pp} close to 0.5 the function has the shape:

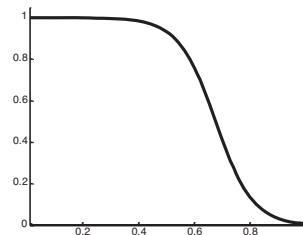


Figure B1. Change of the maximum safety effort (vertical axis) depending on the performance effort (horizontal axis) with parameters $w_1=15$ and $w_2=10$

The corresponding patterns of performance and safety efforts of the AMTs for the three phases of organisational development are provided below. The agents that left the organisation are indicated by dark blue.

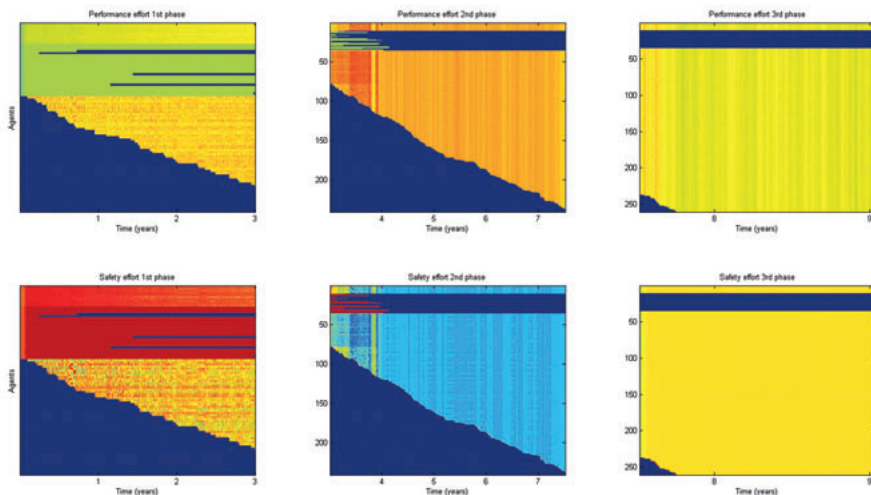


Figure B2. Visualisation of performance and safety efforts of the AMTs during the three phases with parameters $w_1=15$ and $w_2=10$

The essential validation findings discussed in Section 4.5 are also reflected in Figure B2. In the first phase commitment to safety is superficial, when safety efforts are the result of resistance of the old guard to high performance demands. Notice the difference between the high, almost uniform old guard AMTs' safety efforts (hues of red) and the new AMTs' safety efforts fluctuating under the competing influences of the management and the old guard. In the second phase, when the source of resistance is removed, safety efforts plummet across the entire workforce. In the third case, commitment becomes a stable, professional trait and is hardly impacted by the day-to-day pressures.

For $w1=35$ and $w2=30$ and c_{pp} close to 0.8 the function has the shape:

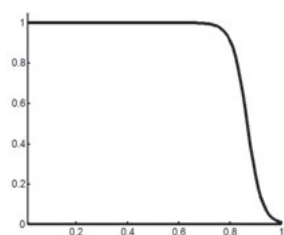


Figure B3. Change of the maximum safety effort (vertical axis) depending on the performance effort (horizontal axis) with parameters $w1=35$ and $w2=30$

The corresponding patterns of performance and safety efforts of the AMTs for the three phases of organisational development are provided below.

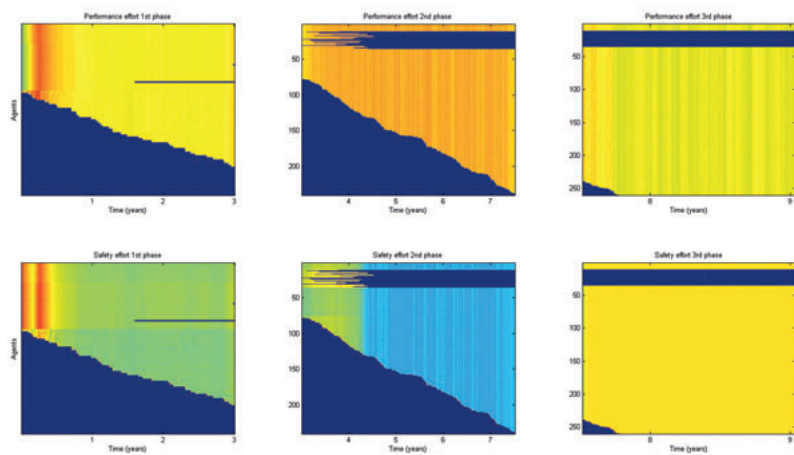


Figure B4. Visualisation of performance and safety efforts of the AMTs during the three phases with parameters $w1=35$ and $w2=30$

Also in this case the essential validation findings discussed in Section 4.5 can be observed in the emergent dynamics (Figure B4).

APPENDIX 4C. MODEL ROBUSTNESS

The robustness of the model was evaluated by running 200 Monte Carlo simulations, in which all essential parameters of the model were drawn from the uniformly distributed intervals, representing possible variations of agent attitudes in the maintenance organisation being modelled. These intervals are defined as follows:

- the initial safety efforts of the new AMTs: [0.5, 0.8] (medium-high values);
- the initial safety efforts of the old guard: [0.7, 1] (high values);
- the initial performance efforts of the new AMTs [0.5, 0.8] (medium-high values);
- the initial performance efforts of the old guard [0.4, 0.7] (medium values);
- the standard deviation of parameter α is 0.1 in all phases of the social contagion model described in Section 4.4.3;
- the intervals of the influence relations between the agents were specified as in Figure 8.

The patterns of commitment to safety of the AMTs identified in Section 5 can be seen in every Monte Carlo simulation run (Figure C1). The standard deviation is the highest in the transition period from phase 1 to phase 2, which involves many organisational changes: orientation towards production goals, increase of the MM's influence on the AMTs and marginalisation of the old guard. Thus, in general the patterns produced by the model are robust w.r.t. different parameter settings.

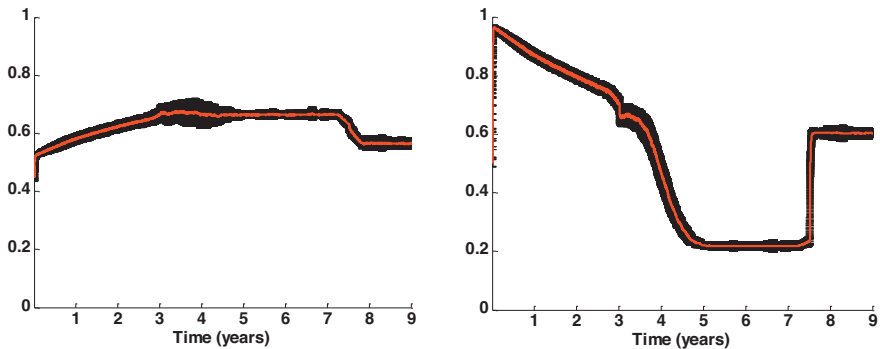


Figure C1. Mean (in red) and standard deviation (in black) of performance effort (left) and safety effort (right) calculated over all agents and 200 simulation runs

Chapter image: Never the high loader! For a commercial safety culture assignment in SE Asia.

CHAPTER 5

WHEN TO STAMP? A CASE STUDY IN AIRCRAFT GROUND HANDLING SERVICES



ABSTRACT

In this paper we show that safety analysis using the STAMP causation model is limited in the extent to which it appreciates complex dynamics of safety. When the STAMP is applied as management tool, controls may be introduced too soon in the analysis since it is necessary to understand emergent behaviour first. Emergent behaviour can be studied through organisational ethnography in parallel development with an agent-based model, as illustrated in a case study of airport ground handling services. Based on ethnographic research and theories from psychology and social sciences, we developed an agent model that showed why repeated attempts at managerial control to improve employees' safety compliance were not durable. The insights obtained through the case study shift management ideas about what control means towards creating smarter design and communication processes that involve the work force.

5.1 INTRODUCTION

Nancy Leveson's (2011) STAMP (Systems Theoretic Accident Model and Process) promises to offer an alternative view on safety from traditional rule-based behavioural approaches. It is framed as a 'New View' (Dekker, 2004), a 'model 2' (Hale & Borys, 2013), or even a whole 'new paradigm' to safety (Leveson, 2011). STAMP explicates a model of the organisation where safety is a control problem. Complex and emergent patterns in working processes are controlled by hierarchies of controlling units, e.g. management levels. These function by developing an adequate model of the process and algorithms to control the process. STAMP is 'new' or 'model 2' in the sense that it explains why safety should be a matter of continuous adjustment with thorough understanding of the complex interactions between various aspects of the work processes and technologies.

'Old' models such as the Swiss Cheese Model (SCM) simplify accidents as the outcome of chains of events that must be stopped by series of barriers (Reason, 1990). The barriers are like slices of Swiss cheese, containing holes through which some unsafe actions may inadvertently pass through. Therefore, this theory implies that organisations should find out what kind of failure modes and accident paths exist and install multiple barriers in its way, such as physical redundancy or behavioural barriers (e.g., Standard Operating Procedures). Methods that use this way of thinking can be subsumed under the label reliability engineering.

A growing number of researchers believes that at higher levels of safety and in more technologically complex contexts, safety is better represented in terms of complex dynamics, rather than SCM's linear sequences of events (Amalberti, 2001; Hale & Borys, 2013). If accidents are complex emergent phenomena, then the rationale for designing safety nets in terms of preventing dangerous linear sequences of events is flawed. It is not possible to predict all failure modes and accident paths because safety nets may interact, fail to work as intended and produce new, unknown dangers (Leveson, 2011).

Because linear reliability engineering models like the SCM have become part of the 'working theories' of safety management (Schön, 1983), also in contexts where this might not work, managers' and regulators' commitment to them may become 'bureaucratic' (Dekker, 2014). Working theories are internalised ideas and experiences that professionals, such as managers, use to understand problems and act in them. In this case, as the current literature suggests, managers may sometimes be wrongly advised to think about safety management as a chain of events issue. While they do, this may lead to conflict between managers and workers because the latter then come to view safety as a senseless burden (Hale & Borys, 2013). The rules may not seem to be about safety but about covering responsibilities. The motives for introducing safety measures may be questioned and the designers of new and improved safety systems and procedures deeply distrusted.

The STAMP model embodies a fundamentally new approach to accidents and safety because it does acknowledge the complex interactions that contribute to accidents, and provides a way to analyse this complexity. STAMP could also have promising prospects

as a working theory of safety management (Leveson, 2011), as it may help deriving more sensible safety rules and procedures. Thus, STAMP may alleviate management-work floor conflicts about symbolic or bureaucratic safety rules.

In this paper, however, we argue that as a working theory for management, STAMP should not be seen as a whole new approach to safety. While STAMP is in many respects a significant improvement from older linear accident models, it has limitations as an organisational management theory. In some ways STAMP continues to encourage top-down thinking about management, because it is not intended to represent the behaviour of people. It simply places control on behaviour without understanding its driving forces, and does not count for the complexities that workers face and the contributions that they (could) make to safety. Therefore, STAMP to some extent fails to capture the 'new' view where safety is approached positively, in the sense that workers' input to safety are fully appreciated (Hollnagel, 2014).

We substantiate this point of view with a case study in an airline ground safety department that was struggling with poor management-work floor relations as it attempted to implement safety procedures and systems. STAMP was used to identify the weak spots in management control and communication, with the aim to formulate actionable changes in management and improve the situation. We found that STAMP created some insights but did not help providing an actionable analysis of the situation, because it did not help to understand how the sour relations had arisen. In the same organisation we also conducted research using organisational ethnography and agent modelling, both providing some promising insights and courses of action.

Therefore, in order to achieve a truly 'new' view, we recommend the use of complementary approaches to STAMP that attempt to capture the social dynamics and ingenuity that emerges bottom-up. We propose a process by which knowledge from relevant disciplines can be accessed and used in an empirical analysis of a particular organisation. There is a large, untapped body of work from socio-technical systems modelling, social psychology, sociology, anthropology and organisational sciences that could refine working theories of safety managers, as well as the field of safety science. This could help analysts and managers understand the emergent behaviour of systems, before they introduce control. In this paper we show how those two methodologies can be applied in tandem to overcome the limitations of the STAMP approach.

First, we introduce organisational ethnography as a way to derive an in-depth, and more power-sensitive account describing the origin and sustainment of certain patterns and behaviours. This is an open-ended process that begins with immersing oneself in various sub-cultures of the organisation, conducting in-depth observations, interviews and document analyses, before theorising what might be going on. In the final phases, from a holistic frame of mind, the researcher may develop interventions and discuss those with members of the different sub-cultures.

Second, we introduce agent based modelling and simulation as a method to zoom in on specific parameters that might be usefully controlled in terms of a control loop suggested by STAMP. This method integrates theories of behaviour early in the analysis

to create a model. This model is then instantiated in simulations, predicting emergent patterns that may be validated using alternative datasets of the same situations that were observed. The predictions can also be used to design interventions, and further validation or adaptation of the model may occur by monitoring the path and outcome of interventions.

Thus, the safety analysis and management methodology can explain how new ideas and frustrations emerge that are seeking to be heard, and how these inputs are diffused, integrated, or locked out of management decision making.

5.2 STAMP, ORGANISATIONAL ETHNOGRAPHY AND AGENT MODELLING

STAMP is an accident causation model that reduces safety to a control problem (Leveson, 2011). The system consists of the processes that need to be controlled, controllers who have models representing the process and a control algorithm, sensors that provide data on states of processes, and actuators that exert control on the processes. One may stack controllers upon one another; the agent controlled by a higher hierarchy is essentially seen as a process that can be controlled by the same principles. The controlling unit determines the set-point at which level the controlled process should run. Leveson (2011) claims that in this way STAMP can be used to analyse accidents, design socio-technical systems, and manage safety in organisations.

When applied to organisational management, Leveson introduced the Systems Theoretic Process Analysis (STPA) to design good organisational controls or manage their functioning real-time. The STPA cycle contains 1) identifying the possible system states out of intended control constraints; 2) finding out how the control architecture could fail to control the system in these instances. In both these steps STAMP is used as tool to depict how system elements interact and what hazards could emerge. This may lead to a redesign of the controls, such as updating the control algorithm or closing a control loop by ensuring that the process provides information.

Organisational ethnography is the anthropological method applied to organisations, viewing any organisation as a group that develops a culture (Bate, 1997; Hatch, 1993). The main insight imported in organisational sciences from anthropology is that culture is highly complex (Martin, 2001) and that prediction is almost impossible, in part because culture management systems are not neutral devices since they aimed at controlling people. Management systems are political because they are built on assumptions that work out to grant some more power and privileges than others (Hardy & Clegg, 1996). Systems can also be politicising when people learn how the system works and use them to their advantage. In social science discourse this is referred as agency (Giddens, 1984), meaning people have the ability to reflect on what is happening to them, form goals, and make decisions to achieve those goals. They have various tools at their disposal, such as humour and ridicule, to distance themselves from management control while

also endorsing it (Kunda, 1992). This may render managerial control ambiguous. The solution generally proposed by organisational ethnographers is to immerse oneself in the organisation with as little preconception as possible, or at least making them as explicit as possible, and thoroughly observe what is really going on (Van Maanen, 2006). The ethnographer remains sensitive to the fact that various groups may have an interests to be represented in certain ways. All social skills of the ethnographer are used to establish rapport and engage with people, while keeping some intellectual distance (Ybema, Yanow, Wels & Kamsteeg, 2009).

Given this interest in understanding how agency works in safety management, it makes sense to apply Agent Modelling (AM). While Organisational Ethnography (OE) allows one to gather large amounts of qualitative data and inductively work towards the most appropriate framework for the dynamics observed in the given setting, AM can focus on a specific work process and make more quantitative predictions. In particular, in this research we modelled multi-agent systems. These systems consist of human and/or technological (in this case, only human) agents that have the capacity to form goals and make decisions, that influence one another, and that may participate in certain processes. Modelling complex agent systems is interesting because it allows one to understand how nonlinear patterns emerge from many local interactions. The method uses empirical data and relevant theories to create an agent model, which can be programmed in several different platforms (e.g., Matlab). Patterns of interest, such as varying level of compliance with safety procedures over time, are not hard-coded but emerge from the simulations. By matching the simulation data to empirical data, the model can be validated. Sensitivity analysis can be performed to explain why the patterns occur and make predictions.

The two methodologies are also complementary, as Passenier et al. (2016) showed. While ethnography allows for an open gaze and holistic understanding of dynamics in an organisation, formal modelling forces much more precise descriptions and explanatory frameworks that make the overall interpretation more sound. Both methodologies support a social constructionist view of organisations and social order, meaning that attention is paid to the messiness and intractability that people experience by resisting oversimplification of those experienced realities.

5.3 METHODOLOGY

We applied STAMP to a safety management problem where occupational safety emerged as the main issue of concern, a domain that Leveson (2011) also suggests could be usefully managed with STAMP. The case study was an airline ground service provider experiencing difficulties to improve safety compliance of its work force. Ground service work—concerned with (un)docking, (dis)embarking and (un)loading of aircraft—is traditionally dangerous work, and serious injuries and deaths have not been uncommon (Balk, Stroeve & Bossenbroek, 2011). In recent years, both damage to aircraft on the ground as well as harm to ground personnel have escalated, and safety

programs were setup to improve safety. In the organisation where we conducted our research, Line Oriented Safety Audits (LOSA) were introduced along with stricter rules and procedures, and attempts to change the safety culture. LOSA observations on the platform checked actual practices against written procedures and communicated what systematic deviations occurred, so that managers could enforce better compliance with these points (De Boer, Koncak, Habekotté & van Hilten, 2011).

This method of working with LOSA seemed perfectly in tune with viewing the employees as the controlled process, and the extensive hierarchy of managers as the control architecture consisting of many control loops. The process was complex, because when managers would start enforcing compliance on one point, compliance would relax on another. The organisation consists of several departments working on different locations and there are many interacting processes and coordination issues. Therefore, STAMP seemed suitable for analysing the problem. STAMP application in other cases in the same domain were proved successful (de Boer & de Jong, 2014).

STAMP research was initiated by a multidisciplinary team consisting of three students (Romy Heimerling, Rob Haest, and Jisvy van Zoelen), each supervised by one of the three authors as experts in organizational ethnography (Passenier), agent modelling (Sharpanskykh), and STAMP (de Boer) (see Table 10). Since STAMP was envisioned as the best candidate for analysing the problem, this process was leading the entire team. The ethnographer and the agent modeller assisted with interviews and platform observations to gain a deeper understanding of the problems identified by LOSA, to describe the control process, and to identify why it failed.

In this case, however, STAMP did not provide an adequate framework to analyse how and where management control was failing. There were many control loops that could be seen as failing and therefore explain how this situation had come about. The managers themselves reported many employees worked at the company for over 20 years, forming tight friendship ties and making it impossible for someone to interfere and change their behaviour. The conditions of the company, however, also did not allow refreshing the work force or shifting team composition more. Memos were ineffective: people did not read them and felt managers did not know what they were talking about. Safety reporting was low; it seemed that people were not appreciating its importance.

The solution, from the STAMP analysis, appeared to be that managers should be more present at the work floor. Yet, it was not clear what managers should do besides telling people to stick to rules, the latter being disregarded since the rules were devised by managers whose expertise was doubt. Through her interactions with personnel, the ethnography student found that employees described their managers attitude as distant and lacking interest in their concerns, including safety concerns. The data for LOSA however suggested no difference between managers whose commitment to improving safety was expressed through more visibility at the platform, and those whose commitment was less visible. An adequate understanding of the work processes and a full consideration of the motivations and skills by which ground service employees performed their work were missing. After this initial year of fieldwork, we had an

elaborate description of the control structure, but still insufficient understanding of how unwanted behaviours—of both managers and employees—arose. Lacking satisfying results, we continued for a second year with only ethnography and agent modelling.

Table 10. Interdisciplinary research team and activities

	STAMP	Organisational Ethnography	Agent Modelling
Year 1 team:	■ De Boer (supervisor) ■ Van Zoelen (student, Ba thesis)	■ Passenier (supervisor) ■ Heimerling (student, Ma thesis)	■ Sharpanskykh (supervisor) ■ Haest (student, Ma thesis)
Student activities year 1:	Student performs STPA by analysing LOSA reports and organisational charts, constructing a control architecture, and identifying control failures at Ground Services.	Student assists STAMP by analysing documents, and conducting interviews with personnel and platform observations.	Student assists STAMP mainly with the construction of the organisational control architecture and identify control failures.
Year 2 team:	■ De Boer (supervisor)	■ Passenier (supervisor) ■ Bakker (student, Ma thesis)	■ Sharpanskykh (supervisor) ■ Haest (student, Ma thesis)
Student activities year 2:		Student formulates the research question: How do managers and staff members of Ground Services make sense of safety? Results of ethnography are qualitative descriptions informed by sensemaking theory.	Student performs additional interviews, selects simulation case scenario, creates agent model, and runs and analyses simulations to find out how and why deviations emerge and what can be done to improve compliance.

To gain a better perspective on how hazards are controlled in real world ground service work settings, we changed the configuration of the project in the second year (Table 10). The student dedicated to a STAMP analysis (van Zoelen) left without replacement, and we reformulated research questions for a new organisational ethnography student (Joyce Bakker) and the same agent modelling student as in the year before (Rob Haest). This relaxed the need for the team to focus on control and find reasons why control failed. Instead, while we could still use the control architecture and the identification of hazards of the first year, we could investigate the problem with a more open mind; that is, as not necessarily a control problem. The ethnographer addressed the broader question why people in different layers of the company made different sense of safety and safety rules. The agent modeller focused on how and why in certain cases deviations emerged from routine work processes, and finally what could be done to improve compliance. As

mentioned above, organisational ethnography allows for a more up-close look at what is happening. With agent modelling, one may create a model that explicitly incorporates complexity of the work processes and the way team members influence each other. In the new configuration, we thus conducted organisational ethnography and agent modelling simultaneously for another year.

The agent modelling sub-team (Sharpanskykh and Haest) selected a newly designed procedure for the aircraft turnaround process to instantiate the model, allowing precise predictions that could be validated by LOSA data. The newly appointed organisational ethnographer (Bakker) meanwhile observed management meetings in-depth as well as work performance at multiple platforms. The aim was to understand how the joint team's insights could be translated to useful advice in view of the differentiation between work force and management. The results and suggestions presented at the end of the second year triggered discussions and were endorsed by members of management, suggesting that we had arrived at a proper analysis and actionable suggestions.

The resulting, iterative investigation process can be described in three consecutive steps. First, the agent modelling (AM) and organisational ethnography (OE) teams jointly discussed the situation of the organisation in question as presented by them by the management. They used the STAMP framework developed by the STAMP team to create an impression of the hazardous processes that exist and that are problematic, and the control architecture that allows the hazards to occur. In this stage, both teams tapped into their respective disciplinary knowledge and formulate ideas about what may be going on in the organisation that might fall out of the STAMP framework and for which management may have a blind spot. This led to a set of qualitative, open-ended questions for fieldwork.

Second, members of the AM and OE teams conducted observations and interviews at the work field, and analysed organisational schematics, charts, safety data, written communications, and procedures. The team members observed how safety-critical work was done and how members interacted with each other. They talked with members of the work force, management, and administration, and collected war stories or anecdotes that were told to express difficult dilemmas and ways of resolving them. These data were recorded as field notes, interview recordings and transcripts. The fieldworkers communicated amongst them as means to develop an idea of what were the significant agents and processes, and revisited relevant literature to dig up interesting concepts and theories.

The OE used the data to develop a qualitative framework to characterise the dynamics of the overall culture, while the AM created a conceptual model of agents, their relations and influences, and local processes they were engaged in. Connecting to developments in the organisation, the AM selected a significant process or practice to create the precise, formal model. The process, such as the implementation of the new turnaround procedure, allowed for longitudinal data gathering. The data were qualitative and/or quantitative, taken from existing databases and/or by continuing to monitor developments. The AM and OE teams regularly met to discuss their respective

conceptual model and framework, so that they were able to integrate their knowledge and confirm they understood at some level what the other team was doing.

When the teams felt they had a sense of what is going on, they moved to step three, separated into two parallel tasks. The OE characterised the dilemmas experienced by members of the organisation by writing a thick description. This involved picking out telling anecdotes or physical details, interpreting what they signified for members of the organisation, and showing how those contributed to specific behavioural dynamics as well as a more global texture of the culture. The way in which what it means to work safely may differ in different sub-cultures of an organisation, is an example of a more global texture; a detailed example of this can be found in Atak and Kingma (2010). Focusing on more a detailed work process, the AM finished the formal model and instantiated it to run simulations that should reveal patterns matching the longitudinal data. By performing sensitivity analysis, tweaking specific parameters and running statistical analyses over the results, the AM team developed predictions about how emergent patterns came about. This method is described in more detail by Sharpanskykh and Haest (2015).

With the interpretations of the simulations and the qualitative description and framework, the team reverted to step 1. They got together with members of the organisation to revisit their ideas about how dangers came about and how they may be effectively controlled. This resulted in suggestions for interventions and design recommendations as well as leading to new questions for field work. Multiple iterations of this process may be necessary to arrive at a satisfying result.

5.4 RESULTS AND DISCUSSION

The research applying OE and AM showed that control had to be re-thought as a matter of creating smarter and more bottom-up processes for procedure design and employee involvement, also suggesting some practical courses of action. This replaced the idea inspired by the initial STAMP analysis that a control loop had to be closed, interpreted as that management should be more visible and enforce top-down designed procedures and rules. While it is vital for members of the organisation to have a certain degree of control over their process, our research team effectively redefined the overarching organisational problem as one of management learning, rather than management control.

The OE results showed that employees who distrusted the design process of new procedures and the commitment of management to safety, had a point, even though managers were very active with safety. The problem was not that anyone was lazy or did not do their job properly, but rather that managers had a tendency to stick to their office and domain too much. Different units were given much leeway in how they wanted to carry out safety policies, and this together with their activity shifting emphasis from one domain to the other actually frustrated personnel and made management appear inconsistent. There was little communication between units, which could cause coordination problems. It turned out that employees did not file safety reports, because

when the issue they reported was not urgent, there was no response from the safety department. This made them believe that their reports were not being used, which was actually untrue; all reports were gathered, analysed, and discussed in regular Risk Assessment Meetings.

The result was that safety managers thought that employees did not care about the work and about safety, and that employees thought that managers did not really care. Employees felt that managers held double standards with respect to their work and safety: if they complied with procedures, they could be reprimanded for being slow, and if they worked around procedures to be on time, they could be reprimanded for violating procedures. Most worryingly, some new procedures actually carried more danger than the old ways of working that were now seen as deviant and dangerous by management. It had been forbidden, for example, to use the baggage high loader as a way to move personnel up to the aircraft baggage compartments; instead, a ladder should be used. The narrow, high ladder however was much more dangerous than the high loader—if properly used.

It was then possible to understand why personnel disqualified management as a whole and distrusted and ignored procedural instructions. Given these issues, heightened by the limited interaction between managers and work floor, it seemed plausible that polarisation could easily occur as a consequence of common group dynamics such as those described by social identity theory (Tajfel & Turner, 1979). The out-group—management—is reified and simplified and generally less trusted, while the reverse is true for the in-group. Similarly, management members appeared to have reified their image of the work force. There were some good attempts at promoting safety that could have mitigated these problems somewhat, but these were not used to their full potential. Safety delegates were appointed to promote safety, but they were not used to communicate across units. The development of new procedures often involved members of the work force to ensure the procedure incorporated their knowledge and experience, yet this was usually done with a particular group whose representativeness was questioned.

The AM research gave further insight into how and why control as exerted by using the LOSA data to enforce compliance on specific points, was ineffective, as well as how compliance could be improved. The analysis zoomed in on an adapted procedure for docking aircraft that arrived at the gate. Before aircraft are guided to the gate, the platform is checked for debris and obstacles. After the aircraft is parked in position, blocks are placed at the landing gears and pylons around the engine areas. Before the gate attaches to the plane, someone checks if it is clear and gives a thumbs-up to the operator of the moving gate. The aircraft is connected with the ground power unit and the door seals are inspected. In this sequence, the initial Foreign Object Damage/Debris (FOD) check showed up in LOSA records as relatively frequently being skipped, probably in order to save time. Management had attempted to change this by providing information and emphasising the FOD check for some time, which improved compliance; but when information ceased, compliance declined. The new procedure included an explicit role division connected to particular tasks, determined by the team leader during a short briefing just before commencing the entire process.

The AM team developed a formal agent model that explained the old situation as well as tentatively predicted with some accuracy the changed situation. The model was created using several theories. Motivational models of human behaviour used were self-determination theory (Deci & Vansteenkiste, 2004) and Maslow's (1943) hierarchy of needs, including a distinction between intuitive, habitual reasoning and conscious, rational reasoning (Kahneman, 2011). A learning model explained how new information is processed by way of social contagion, describing how new norms arise and spread in teams. Work demand and pressure were modelled as varying over time. Management control was modelled as the likelihood that team members would be reprimanded when intending to skip the FOD check. The change from the old to the new procedure was instantiated by adjusting the values for probabilities of reprimands by managers and team members and the speed of social contagion in direct (e.g. talking) or indirect (e.g. observing someone do something) communication. In the new procedure with explicit coordination (i.e. task divisions and roles), for example, the probability of reprimand from team members was estimated to be above zero, while it was set at zero in the old, implicit coordination procedure. Further detail on the model can be found in (Sharpanskykh & Haest, 2015).

The simulations of the implicit coordination scenario reproduced the pattern described above where temporary attention by management to the FOD check led to temporary increase in compliance. The explicit coordination case predicted that team members would develop a team norm to complete the FOD check before allowing the aircraft to park, and that reduced control from management would not quickly result in reduced compliance. These results were also observed in practice (Sharpanskykh & Haest, 2015). The sensitivity analysis furthermore revealed that management control was a relatively ineffective method to establish compliance. Addressing agents' needs to understand why an action needs to be performed a certain way, came out as more influential. Responding to team member norms also became an important factor. Because members have shifted in this scenario to a more conscious, rational way of reasoning, these norms then become ingrained and compliance remains high, also after management relaxes control.

One manager, upon being presented these findings, expressed being humbled and realising that he felt he might have over-estimated his influence over the process, understanding the relatively low influence of direct management control. On the other hand, once the ethnographic findings and recommendations were presented, several managers and team leaders who had in some way been involved in the research project were also enthused by realising what influence they might have. The ethnography team members suggested that the organisation form safety teams consisting of members of every level of the organisation, especially the very lowest rank, and create a thoroughly bottom-up procedural design process. This resonated so strongly with the sentiments of those present at the presentation meeting that they instantly began brainstorming about ways to make it happen. They identified some potential obstacles—how does one select people outside the circle of 'usual suspects' of people involved in safety initiatives—and

came up with solutions—asking leaders close to the work floor to select them. They expressed commitment to essentially turn around the design process of new procedures in such a way that management would primarily take expertise from the work floor for the details of the procedure, and then check against regulation, instead of deriving procedures from new regulations.

5.5 CONCLUSIONS AND SUGGESTIONS

Replacing former working theories such as the Swiss Cheese Model, STAMP is meant to capture and control better the complex dynamics of safety. Despite the potential of the overall systems theoretic approach, where safety is taken as an emergent phenomenon of complex socio-technical systems, there are some problematic simplifications in the STAMP methodology. We argue that when STAMP is applied as a management tool, control is introduced too soon in the analysis cycle, and that it is necessary to understand emergent behaviour first. Thus, to arrive at a more bottom-up idea of safety rules, which is propagated by safety 2 thinking (Hale & Borys, 2013), safety compliance issues are approached as an overarching management learning problem rather than management control.

To complement STAMP, emergent behaviour can be studied through organisational ethnography in parallel with the development of an agent-based model. Organisational ethnography is a processual (i.e. describing patterns over time), qualitative analysis of work practices and social relations at multiple levels of an organisation. Agent models represent people and technology, as required, that perform actions, make decisions with some degree of autonomy, and exert influence on each other. By properly integrating relevant theories of human behaviour as well as data on local practices and relations, the model simulations should reproduce the emergent patterns described by the processual qualitative analysis. The model can be further validated with separate datasets of the old situation, or of new developments unfolding as interventions take place. Sensitivity analysis of key parameters allows analysts and managers to pin-point and test the most efficient measures of control.

In deriving an agent model from an ethnographic account, information and nuance is lost and one should not see the agent system as a definitive description; yet it offers courses of action when STAMP is applied at this point. Sensitivity analysis of key parameters in the agent model that specify relevant agent interactions and influences, allow analysts and managers to pin-point the most efficient measures of control. Control loops are thus more contingently and smartly situated in emergent behaviours of the system.

The application of OE and AM provided a trigger for managers to learn and shift perspective, get unstuck from their soured labour relations, and engage with the safety motivations of their personnel. Thus, we suggest that STAMP is complemented with OE and AM in order to achieve a complete 'new view' in safety analysis and management. The particular findings in this case, such as the need for explaining the reasons behind instructions, expressing worker autonomy in the way procedures are designed, and

involving workers in the design process, are likely to be more generally applicable factors in establishing a 'new view' towards safety analysis and management. In this view, (safety) management is a two-way process where analysts and managers are curious enough to understand the human contribution made on the work floor, before they introduce control. Exercising control then becomes a matter of establishing a communicative rationality and aligning organisational interests such that work gets done in a way that is acceptable to all those involved.

Challenges that our approach throw up include the access to organisations and the resources and time needed to complete the analysis. Ethnographic research requires access to sites where activities of interest occur. Since at the outset it is often not yet clear what will turn out to be interesting, this requires a strong vote of confidence and flexibility from organisational officials, especially given the sensitive nature of safety-related questions. Ethnography can be very time-intensive, which may press the resources available to an investigative team. Ethnographers need time to become part of a group and get passed the sometimes subtle facades that organisational members tend to put up in any context (Goffman, 1959), and especially in relation to safety (Atak & Kingma, 2010). The creation of a detailed agent model, integrating several types of data and theory, can also be a lengthy process. Further potential challenges exist in forming an interdisciplinary research team and establishing a collaboration that bridges the different knowledge and scientific norms of the two disciplines.

The suggestion in this paper is to form teams consisting of at least one expert trained in agent modelling and one expert trained in organisational ethnography, if both are also proficient in safety analysis and management theories such as STAMP. If not, an additional member can be added with expertise on this domain; the agent modelling expert is likely to be from an engineering or computer science domain, and the ethnographer from social sciences. In our project we worked with fieldworkers and supervisors of each domain. We have addressed the challenges of interdisciplinary research, but a complementary approach such as advocated here requires a genuine interest and some knowledge overlap across fields. The project may usefully adopt the systems theoretic ideas about viewing safety as a control problem, as STAMP does, yet not be naïve about how the actual control architecture functions, given the complexity of human interaction.

APPENDIX 5A. ABBREVIATIONS

AM	Agent Modelling
FOD	Foreign Object Damage/Debris
LOSA	Line Oriented Safety Audits
OE	Organisational Ethnography
SCM	Swiss Cheese Model
STAMP	Systems Theoretic Accident Model and Process
STPA	Systems Theoretic Process Analysis

CHAPTER 6

DISCUSSION



In this dissertation I problematise the theoretical black-boxing of safety cultures. As a result of a well-established line of technical and human factors studies of accidents and incidents, industries know much about the 'input' of safety cultures. That is, the regulatory processes, often based on lessons from accidents and thinking in terms of prevention (Reason, 1990; Leveson, 2011), that guide and constrain the practices and processes in safety-critical industries (Rasmussen, 1997). However, it is much harder to grasp the mechanisms by which these regulations are transformed into outputs, which include commonly seen errors and violations as well as an overall very safe and rule compliant performance (Oliver, Calvard & Potočník, 2019). I argue that we lack insight in what happens inside the black box of the safety culture – the throughput so to speak. Earlier studies of expert practices have been characterised as methodically prepared and executed improvisations (Bigley & Roberts, 2001; Orr, 1996), which is difficult to reconcile with their strict conformity with 'safe standards' like rules and instructions or standard operating procedures (Hudson, 2001; Parker, Laurie & Hudson, 2006). As a result, seemingly contradicting their own ideology of transparency (Reason, 1998), what actually happens in safety cultures remains unclear. In view of these interesting paradoxes, my dissertation investigates what role deviations from standards play in committed safety cultures.

Reading this black box in the context of the Dutch commercial aviation industry, my main finding is that deviations from standards reflect widespread ingenuity and dexterity of operational experts dealing with 'unruly' (Wynne, 1988) sociotechnical systems. Despite ultra-high reliability of its many components, complex sociotechnical systems like the air transport system are nevertheless fraught with often subtle, but critical, contradictions and anomalies. These contradictions are observable in technical artefacts, such as when nominally functioning automatic systems perform incoherent actions, and can be traced to the assumptions programmed into their software. They are also observable in the interpretive flexibility of the meticulously designed standard operating procedures in aviation (Wright, Pocock & Fields, 1998). Presuming that such contradictions are to some extent inherent in complex sociotechnical systems (Hollnagel, Woods & Leveson, 2006; Perrow, 2011; Wynne, 1988), I found certain social and organisational processes responsible for dealing with contradictions when problems come to the surface. The overall response can be characterised as a complex process of *innovative deviance* (Merton, 1949) that is driven by operational experts and relies on 'accomplices' amongst the authorities tasked with management, oversight, prosecution, and governance.

I continue to first summarise my findings below. Then I discuss implications for safety science as well as risk debates in organisation and management. After noting practical implications, I conclude with a reflection on limitations and directions for further research.

6.1 OVERVIEW OF THE FINDINGS

In the introduction (**chapter 1**) I grounded the theoretical black-boxing problem in the Dutch research context where debate arose over the lessons to be learned from an actual black box – of the Turkish Airlines Boeing 737NG, which crashed near Amsterdam Schiphol airport in 2009. The Dutch Safety Board (2010) claims that the crash resulted from a particular combination of factors, including fatal deviations from standard operating procedures on the part of Schiphol's air traffic controller as well as the deceased flight crew. I argued that the Board construed an authoritative narrative (Brown, 2004) by implicating the authoritative concepts of normal accidents, failed high reliability organising, and compromised safety barriers in the reconstruction narrative. I found however that the Dutch Safety Board's (2010) reconstruction was partially contradicted by Dekker's (2009) advisory report, which claims the pilots could not have prevented the crash brought about by a complex software interaction of the 737NG in an already tightly coupled aviation system. The fact that Dekker's report was not published at the time became all the more salient ten years later, when two aircraft of the 737NG's success, the 737MAX, crashed due to an even worse software problem.

My analysis of the accident narratives in the two reports served as a research agenda to study safe practices and processes, rather than accidents, because the accident narratives point to a lacuna in our understanding of how work is actually done in and around safety cultures. I found that Dekker's (2009) report on the one hand helped deconstruct the Dutch Safety Board's crash reconstruction narrative, which implicated the pilots, but on the other hand helped reify the assumption, in the case of Schiphol's air traffic controller, that deviations from standards were dangerous. In view of the air traffic control organisation's unwillingness to admit failure, this seemed to imply a problematic safety commitment. In contrast, I argued that the report provides insufficient evidence of this being the case. If one accepts that interpretive flexibility of procedures are normal, necessary and thus routine part of highly skilled, professional practice, then there is not enough data to support the view that something particularly problematic was going on in this case. Indeed, there was limited authoritative knowledge of organisational mechanisms to fall back on and distinguish deeper organisational problems. While there are theories explaining why routine deviations are problematic (Snook, 2000; Vaughan, 1997; 1999), there were no authoritative competing theories to explain when and why routine deviations might be safe. Therefore, I continued to investigate deviant safety practices and processes outside the political sensitivities of air crash investigations.

The contextualising study in **chapter 2** indicates that there is a social risk in deviating for aviation professionals. On the one hand, despite the intention to act in line with the spirit of the procedure (DeSanctis & Poole, 1994) and even with ample legal anchor and precedent, deviating from the letter of the procedure can be construed as deviance by authorities within or outside the organisation. On the other hand, authorities who act as 'accomplices' appear to negotiate contrasting risk perceptions from their own legal perspective, the public, and the professional safety culture where innovative deviance

sometimes surfaces. Although policies can change as public and political moods change, at the time of my research in the Netherlands the judicial authorities were inspired and supported to act in this manner by the European policy of just culture (Kortleven et al., 2017). Ideally, just cultures resist criminalisation and enable organisations to follow their own investigative process in case of an irregularity (Dekker & Breakey, 2016). However, even though authorities were embracing the policy, there were still significant tensions throughout the industry. According to the public prosecutor, the air traffic control organisation appeared particularly traumatised by earlier experiences of 'unjust' criminalisation. If there is any truth in this observation, such trauma could perhaps help explain why they strongly defended their traffic controller's actions in the Turkish Airlines case as well as why they closed the doors to me after my initial contact, where I mentioned this crash.

I was also able to observe how the social tensions, implied when innovative deviance modifies or stretches such a negotiated order, surface in flight crews' work in the cockpit. According to the vignettes in chapter 2, these tensions become visible in conflict, political sensitivities, deviations from SOPs, and frustrations about glitches in planning and communication. In contrast with functional observation methods like LOSA, which focus only on hazards in such observations, I argue that my observations reveal glimpses of how work normally gets done in aviation HROs. As such I argue that my social perspective and approach contributes to aviation safety field with richer observations and deeper understanding. Rather than reducing the observations to hazards that need to be controlled, I suggest that they show important, even necessary forms of learning, negotiation, and reflective practice. At the same time, I acknowledge that HROs are not immune to Normal Accidents. HROs operate inherently vulnerable and hazardous systems that continually evolve and produce hazards in new and unexpected ways, which need to be further studied.

The study of airline pilots' reflective cockpit work practices in **chapter 3** follows the research agenda set by my reading of the Turkish Airlines crash reconstructions by uncovering expert-drivers of the emergence and normalisation of organisational deviance. I note that while Vaughan (1997) in her seminal study of NASA applied Merton's (1949) theory of deviance to focus on the negative consequences, where deviance expresses a lack of safety commitment, I focus on the positive consequences, where deviance expresses safety commitment. I find that in procedural grey areas, routine deviations from procedures arise within a normal process of developing expertise through action and transmitting expertise by collectively reflecting on the grey areas. My findings suggest that expertise development means developing intuition (Dreyfus & Dreyfus, 2005) and using deviations from standards to communicate about different intuitions within a setting that incorporates varying operational expertise. The two-person cockpit crew of large airline jets after all includes a captain, who can be characterised as a professional or even an expert, and a co-pilot, who is sometimes only a novice, and at a later stage usually becomes a competent learner on her or his way to captaincy.

In this well-contained, but rich research context, I find that new deviations may emerge as quick reflexive responses to anomalies as well as deliberate, reflective actions. A process model derived from fieldwork observations and interviews suggests that deviations may trigger reflection-*in*-action, which reflects an ability to think even under the acute time pressure of a risky operational situation (Yanow & Tsoukas, 2009), as well as reflection-*on*-action, which takes place afterwards. Overall, reflective practices therefore shape the bottom-up process of innovative deviance where certain procedure deviations become routine while others do not. The model suggests that through reflection-*on*-action pilots may engage in a wider, often spontaneous and informal processes of problematising observed deviance through which risks of deviant practices are reassessed. Finally, the process may lead to some forms of innovative deviance becoming normalised through formal codification in official procedures. Often this is not possible for individual organisations and innovative deviance remains a way by which professional pilots' communities of practice (Orr, 1996) deal with contradictions and weaknesses in aircraft design.

There is an argument that 'opening' a theoretical black box, such as safety cultures, and describing the social and organisational mechanisms by which such cultures reproduce themselves, can turn into an empty exercise if one ignores the moral problems implied in these mechanisms (Winner, 1993). I use the less absolute metaphor of 'reading' black boxes, which also allows me to participate in the more normative or ideological aspects of aviation safety cultures. In **chapters 4 and 5** I engaged with the engineering disciplines, who are responsible for designing safety-critical technologies and organisations, to translate insights on innovative deviance in aviation safety cultures.

The multi-agent model in **chapter 4** translates the idea that safety commitment in organisational cultures, where deviance is found, is not static and does not always follow predictable paths. Thus, the safety commitment espoused by higher management, and promoted by a company's safety department, may contrast with actual practices owing to the particular dilemmas that an organisation experiences. We found a set of typical safety cultural dilemmas in Atak and Kingma's (2010) case study of an aircraft maintenance company. That is, how to uphold safe standards under the commercial pressures arising from a quick growth phase while coping with strained internal relations under new management and changing priorities.

Focusing on these dilemmas, and reflecting the limitations of using a secondary data source, we made many simplifications in the modelling process. The model features aircraft maintenance technician agents, which stands for a more diverse group of specialisations that exist in reality. These interact with the super-agents of maintenance management and the safety department, which represent a complex management structure as two agents with opposing interests: management demands productivity while the safety department demands safety. A function coded in the technician agents determines how these agents respond to varying demands from these agents and other functions determine how they influence each other as they participate in a rudimentary representation of work processes. We distinguish junior technicians from the old guard, who are the majority in the first phase of the company's life and who regularly protest

against the new maintenance's demand for productivity by committing to a 'working to rule' safety-maximising strategy. Junior technicians in contrast are phased in during the second phase and do not resist management unless they are influenced by others. We hard-coded how over the timespan of nine years, management's and the safety department's demands vary in three distinct phases, each responding to the particular dilemmas described by the original narrative, also including how old guard technicians are gradually replaced fully with new technicians.

Even with such a simple model of power relations and work process, which nevertheless demanded a great deal of the expertise and collaboration skills within our research team, we found that the emergent patterns in the simulations matched Atak and Kingma's (2010) ethnographic narrative on key points. The graphs visualising productivity and safety performance for example show how during the growth phase, productivity soars while safety performance plummets, which coincides with Atak and Kingma's assertion that the company experienced several close calls. In the third phase the simulation graph shows that the technician agents reach a more mature safety culture where productivity and safety are in harmony. The methodology also allows for virtual experiments, by which alternative developments of the agent system could be explored, allowing us to get a sense of how the agent system works.

In **chapter 5** this work, applied to a Ground Services safety culture development project, contributes to the debate about "old" or "safety 1" versus "new" or "safety 2" approaches (Dekker, 2004; Hollnagel, 2014). To analyse why personnel routine deviations from safety procedures continued to plague the organisation, STAMP was introduced. STAMP was promoted as a "safety 2" accident model that encourages a fuller analysis of complex human, technical, and organisational factors than the conventional, linear 'safety 1' methods like bowtie methods (De Ruijter & Guldenmund, 2016) and the SCM. According to Leveson (2011), STAMP can also be used pro-actively for safety management by undertaking a Systems Theoretic Process Analysis (STPA). The team consisting of supervisors and students with expertise in the complementary fields of organisational ethnography, STAMP, and agent modelling, decided to use STPA to guide the project.

Our experience in the first year of this project suggests that STAMP/STPA still embodies top-down control thinking and inspires conventional safety 1 wisdom. Guided by the STPA process, the research team was turning up results, but this did not trigger an integration of emerging insights of what was really going on in the organisation. Because STAMP frames safety as a control problem, but offers no concept or theory for how people engage in work processes or form social relations, the team could not establish why personnel deviance emerged in the first place. Safety culture development was approached as a matter of managers having the culture and bringing it to the work floor, enabled by a sort of dashboard with controls provided by the STPA process. In reality, the problem resided within the entire organisation, including management.

The subsequent research year our team applied ethnography and agent modelling in a similar manner as described in chapter 2, using the hazards identified by STAMP but relaxing the need to explain them as a control problem. Thus we provide some

pointers for how to analyse bottom-up processes that safety 2 approaches talk about. The students asked open questions such as how different organisational members make sense of safety, enabling the team to eschew deep-seated assumptions about organisational deviance. First, the results showed that routine deviations were in many cases examples of innovative deviance, triggered by practical constraints not taken into account by existing procedures. Indeed personnel made sense of safety from the context of their operational reality, which often did not match with managers' assumptions, and which presumably caused distrust between both groups. These results challenged managers' dominant assumptions about deviance and invited them to learn, rather than to gain more means of control. Second, the agent model and simulation analysis helped relocate control in a way that was humbling to some managers. The simulations demonstrated logically that management's influence to force compliance was very limited as compared to how they imagined it. Taken together, the results led managers to conclude that procedure redesign processes, triggered by frequent aviation safety regulation updates, should be done with representation from the work floor. Although we were not around to observe the subsequent process, as reorganisations limited further access, we considered the results as usable, insightful, and promising for further development and applications to practice.

6.2 THEORETICAL IMPLICATIONS

The studies described in chapters 2 through 5, aimed at reading the theoretical black boxes of safety cultures in the context of the Dutch commercial aviation industry, find a social and organisational response that can be characterised as innovative deviance. Innovative deviance was conceived by sociologist Robert Merton (1949) to represent social and organisational responses that act in line with certain values of a culture, but deviate from the norms, such as laws, rules, and procedures, in order to achieve their goals. This enables analyses of how in societies certain practices that transgress the law are criminalised by the society, but at the same time represent innovations that sometimes endure and can also become decriminalised. In my studies, the application is more subtle, in that there are no clear transgressions of the law, but rather professionals exercising discretion in 'grey areas'. These actions can get criminalised, as the just culture literature notes (Dekker, 2011b; Dekker & Brakey, 2016), but may also represent useful practical innovations such as workarounds and shortcuts needed to keep an operational process going. Innovative deviance acknowledges that social norms, which are codified in safe standards, are in part upheld by those who take the risk of deviating from these standards in the interest of a particular constellation of shared values, of which safety is only one. This perspective also highlights how different the process might be in different contexts, as decision makers in some societies are known to respond more authoritatively, while others respond more consensually, such as in the Netherlands (Hofstede, 1993; Merritt, 2000).

My point of departure, the black boxing of safety culture, resonates with Oliver et al.'s (2017; 2019) recently published analysis of the Air France AF447 loss of control crash, which happened in the same year as the Turkish Airlines crash. When I read Oliver et al.'s insightful accident study in the course of analysing my findings of innovative deviance, I found that there are clear parallels between the crashes as well as the lessons that can be drawn. In case of AF447, flying at night over a pitch-black ocean at high altitude, incorrect sensor signals caused an Airbus 330's 'alpha protection' system to get switched off, while causing confusion about the state of the aircraft. This led to rapid loss of control as the aircraft stalled without the crew being able to understand that this was the case. Oliver et al. (2017) suggest that AF447's loss of control demonstrates how designing more predictability in systems, which demand less cognitive engagement and consequently erode users' skills, may weaken organisations' abilities to recognise and deal with unforeseen events.

Oliver et al.'s analysis resonates with my critical reading of the Turkish Airlines crash investigation reports, which suggests that the language of control and commitment used in aviation safety cultures often black-boxes the very processes and practices that deal with ambiguities and complexities in the high-tech operation. This adds to existing explanations why gathering large amounts of safety data, and promoting transparency about the contents of these databases, does not necessarily lead to safety improvements (Amalberti, 2001). Furthermore, in relation to the high reliability organisations literature, which has come to propagate a normative ideal-type of culture (Rijpma, 2003), my studies thus provide necessary nuance. That is, the theoretical frameworks by which diverse, large sets of data are interpreted in high reliability organisations, may in important respects lack the sensitivity to operations usually attributed to high reliability organisations (Weick & Sutcliffe, 2007).

The black box debate connects to a wider debate on the limitations of industrial automation (Barley & Kunda, 1992; Dreyfus & Hubert, 1992; Farjoun & Starbuck, 2007). Industries are globally grappling with the promises as well as pitfalls of increasingly intelligent software (Faraj et al., 2018). Oliver et al.'s (2017) theorising points out that there is a serious danger in the design thinking that relies on compliance with standardised processes designed for maximum predictability. My studies complement this view as they reveal a rich and socially complex organisational 'underlife' that is often ignored or rejected by management control systems because these routine deviations from standards can be interpreted within the regulatory context as organisational deviance and as such a lack of safety commitment. In reality, my studies suggest, organisational deviance often represents ingenious practical innovations that are widely shared and enhance dexterity in various forms of technical and operational work. By design, therefore, managers are bound to ignore these efforts on the work floor, even when that floor is suspended at 40,000 feet and subjected to extensive monitoring and control.

My studies revealing ingenuity and dexterity of innovative deviance place the Turkish Airlines accident in a risk management context that is lost with the black boxing of safety culture. Innovative deviance suggests that operational practices deviate from the ideal,

formally prescribed process, which is usually seen as a loss of control in the literature, described for example by the metaphor of practical 'drift' (Dekker, 2011a; Snook, 2000). In contrast, I draw attention to the observation that organisations rely on innovative deviance to keep operations under control. My studies suggest that uncovering the underlying social relations can help identify whether deviance represents a normal, bottom-up control process, or an erosion of control. The modelling study suggest that under too much strain, such as seen when production pressures are high, costs are cut, and work relations sour, the actual safety margins, which are upheld by innovative deviance, erode in more complex ways than imagined.

The positive lesson that can be drawn from my studies owes to the move away from accident models to provide alternative theories for how control and commitment is expressed in often implicit, intuitive ways. Accident models, which provide the theoretical backbone of the majority of risk and safety frameworks, help making sense of complex data in reference to limits, which in reality however are ambiguous, opaque, and difficult to observe (Oliver et al., 2017). In contrast, I focus on the role of deviations, which refers to actions that are empirically observable and represent anchor points of intuitive expertise (Dreyfus & Dreyfus, 2005) as well as reflective practice (Schön, 1983). So doing I contribute to a processual view on intuitive expertise (Akinci & Sadler-Smith, 2019; Hodgkinson & Sadler-Smith, 2018) where intuition is regarded as an important signal that deserves to be taken seriously in communication between experts of different or varying expertise.

With the learning processes of innovative deviance I also add to discussions about expertise as these processes explicate what it means to rely on experience as well as formal knowledge and thus defer to expertise (Weick & Sutcliffe, 2007). I do so by providing a competing theory of organisational deviance as learning about risks encountered in practice, which competes with the view that organisational deviance necessarily implies a dangerous lack of control over operational practices (Snook, 2000; Vaughan, 1997). Through this learning process, which is not a sufficient, but probably a necessary part of safe practices, the inherent under-specification of technical instructions, as reflected in rules and procedures (Suchman, 1987), are in a constant process of becoming resolved and reassessed. Sometimes these practical solutions are codified into formal organisational standards. Awareness of these learning processes should be helpful in pinpointing when safety cultures get disturbed, such as when organisations lack diverse practical experiences that trigger shared learning, or when authorities polarise or delegitimise professional discussions about deviant practices.

The studies in this dissertation thus contribute to a growing body of 'safety 2' research (Hollnagel, 2014). Safety 2 acknowledges that safety rules are in important ways informed by bottom-up rather than top-down processes (Hale & Borys, 2013) and therefore suggests empirically investigating 'work as done' and asks how safe conditions are created (e.g. Adriaensen et al., 2019; Jahn, 2019; Rankin, Lundberg, Woltjer, Rollenhagen, & Hollnagel, 2014; Woltjer, Pinska-Chauvin, Laursen & Josefsson, 2015). Such research reduces our reliance on the often false assumptions of functional blueprints, or 'work as

imagined' (Dekker, 2006), to understand how and why organisations stay safe. Safety 2 research is often conducted by researchers from cognitive engineering and psychology disciplines, as seen for example in the resilience engineering school (Hollnagel et al., 2006). I show that social scientific approaches to the study of high-tech, safety-critical work and organisation has relevant contributions to make to this literature. First, existing empirical studies of work as done tend to focus on cognition (e.g. Bergström, Dahlström, Henriqson & Dekker, 2010; Carim, Saurin, Havinga, Rae, Dekker & Henriqson). Less is written about the layered social and organisational processes that arise from technical work practices (Haavik, Kongsvik, Bye, Dalseth Røyrvik & Almklov, 2017). Second, I show how investigating these processes does not require the use of accident models. Safety 2 analysis frameworks that do, such as STAMP (Leveson, 2011) or FRAM (Hollnagel, 2012) have a tendency to result in the conclusion that sociotechnical systems are "complex". This, as chapter 5 showed, is not always helpful. In contrast, the practice approaches detailed in chapters 2 and 3 show theorising from empirically observable deviations from procedures or particular contextual solutions in procedural grey areas can further our insights. In modelling terms, as chapter 4 lays out, the research focus shifts from functional structures to agents doing work, interacting, and influencing each other. As chapter 5 shows, the novel methodology and theory developed in this dissertation complements current thinking in safety sciences by demonstrating a tendency to inadvertently perpetuate illusions of control.

With regard to the normative debates on Normal Accident Theory (NAT) and High Reliability Theory (HRT), the process of innovative deviance furthermore suggests that despite their acknowledged shortcomings (Rijpma, 2003), as authoritative theories, NAT and HRT could be focus points for useful learning. Learning would require acknowledging the fragility of real-life HRO processes and practices, as well as the differentiation and fragmentation of safety culture within real HROs (e.g. Atak & Kingma, 2010). HROs I argue are therefore not immune from the pattern of accidents described by NAT. To appreciate such fragility means resisting deductive reasoning from normative accident models like Reason's (1990) human error taxonomy and the Swiss Cheese Model (Reason et al., 1989), or the more normative renderings of HRO studies (e.g. Weick & Sutcliffe, 2007). Even under societal pressure to find 'the' cause, or the person(s) to blame (Dekker, 2004), it should instead perhaps be recognised that a major role of incident and accident investigations is to note contrasting, inconclusive evidence. In light of the horror that accidents are, this could mean developing new or strengthening existing social rituals and institutional structures to restore relations between the various inflicted parties (Dekker & Brakey, 2016), while allowing for more open-ended investigation narratives, which raise questions that cannot yet be answered.

How can investigation narratives create an authoritative text without solidifying a narrative on 'the' causes, underpinned by authoritative concepts and theories? Can societies accept investigation narratives that explicate the interpretive flexibility of black box data? Solutions, however imperfect, will depend much on institutional and cultural context. Failure needs to be acknowledged without ignoring interesting evidence that

might eschew established theories about sociotechnical systems. As I illustrate here, accident investigations may serve as useful guides for a sociotechnical research and development agenda. Thus, we may learn about more complex, emergent mechanisms that can be observed in, for example, commercial airline operations.

6.3 PRACTICAL IMPLICATIONS

Safety-critical organisations need to comply with safety regulations, which create considerable constraints and encourage a preoccupation with procedures and compliance. For organisations new to risk and safety management the exercise may be enlightening as well as frustrating. The rationalisation of risky organisational processes enables learning, reflection and control. Rationalisation however can also have drawbacks, such as becoming insensitive to intuitive expertise, which comes into play in safety assessments, but which can be difficult to explain. Becoming aware of, and developing a legitimate talking point with regard to the background of varying practices can help foster sensitivity to operations. This approach provides an advantage over relying purely on formal descriptions of technical and organisational safety barriers, which have a limited basis in reality. Therefore it is all the more important, when (re) designing technical systems, operating procedures, and training methods, to include the targeted practical experts in these processes.

Airline companies for example are usually very good at designing and training standard operating procedures, which is why they are considered as high reliability organisations (Weick & Sutcliffe, 2007). The drawback of such a focus however can be that every informal instruction, such as a simple trick or rule of thumb to adapt a procedure to different contexts, ultimately becomes part of an increasingly elaborate standard operating procedure (Pélegrin, 2013). For example Rankin et al.'s (2016) study of cockpit surprise ultimately aims to find the ideal generic failure handling process sequence, which can then be turned into a procedure. In contrast, my studies suggest that there is a large variety within work practices that cannot be proceduralised. Knowing how to deviate therefore qualifies as an important aspect of the overall resilience potential that organisations have and use.

To learn how to deviate sensibly, pilots not only employ their formal training in communicative and team coordination and broader awareness of various (socio-) psychological and physiological processes as taught by Crew Resource Management. Pilots also informally experiment with techniques and experience feedback of their actions in the operation. If such experiential learning is crucial for expertise development, it deserves a broad platform as well as expert guidance. Furthermore, companies train and certify pilots in flight simulators for certain procedures and scenarios. In addition, pilots could also benefit from simulator training with more complex scenarios, which are not (or ambiguously) covered by procedures:

- Asking training candidates to reflect on their recent experiences and think about what situations or techniques they want to train and discuss, besides subjecting them to formally required training and checks;
- Developing simulation training and reflective evaluation of unexpected, complex operational situations, ranging from mundane to extraordinary, such as situations with contradicting warning signals or failures that due to time pressure cannot be resolved through the standard QRH process;
- If necessary, train the trainers to help candidates 'author' their own training session, verbalise judgments based on experience, and reflect on their performance afterwards.

Leading a company in such a direction takes trust, relational work, and courage from the offices responsible. There are three key points to take into account in this process. First, key officials need to open up to innovative deviance. While innovative deviance is probably globally present, the Dutch response is consensus-driven and the interaction with authorities may more easily turn into a kind of negotiation. Fostering a just culture by opening up to a sort of negotiation with authorities, often conducted under the radar, makes sense in the Dutch society and culture but may very well fall short in other cultural and institutional contexts. This is not necessarily a bad thing. Therefore it may well be necessary to develop a context-sensitive language to address innovative deviance, taking stock of the advantages and social rituals available there. The most essential part may be to avoid falling into cultural comparisons, especially to imply any cultural superiority, because there is no such thing and because it is very unhelpful to get stuck in us-versus-them comparisons.

Second, assuming that innovative deviance is in fact a global phenomenon, with context-specific expressions that invite various organisational responses, the challenge for safety management is to foster an open attitude and genuine curiosity for deviant practices. The use of auditing tools like LOSA may be helpful as a starting point for more in-depth research into safe practices, rather than to draw conclusions about safety. A difficulty with safety auditing observed in the Netherlands is that checking or auditing compliance is seen as a judgment, which creates distance between management and work floor that distorts the relations and inhibits mutual learning. Thus, safety management risks promoting an ideology that has little to do with what people actually do. Including researchers with a professional training in qualitative social scientific methods, such as organisational ethnography, is helpful to foster an open mind, study actual practices from the point of view of the person who performs them, and recognise more complex social and organisational processes. Not everyone is equally suited to be an ethnographer: it is important to look for a combination of social skills and an analytical mindset besides formal methodological and theoretical training.

Third, the translation of qualitative observations to a systematic organisational assessment demands a well thought-out interdisciplinary approach. It is not surprising that to reap the benefits of more intelligent software capabilities, organisations also

need to learn how these systems actually work in practice. Technologies invariably interact with people who are also confronted with various technical limitations, despite the promising potential. It is possible to draw on resilience engineering methods, such as STAMP (Leveson, 2011) or FRAM (Hollnagel, 2012), which are dedicated to address this development, and select candidates who are trained in these methods. However, because they rely on functionalist models based on accident thinking, these methods also have their shortcomings. It is hard to make the analytical step from the functional modelling of resilience potential (see Adriaensen et al., 2019, for an example of a DC-9 cockpit routine) to the often informal and ambivalent social and organisational relations between people from which safe – and in some cases deviating – practices emerge. Therefore it can be hard to translate the results into practice. An alternative is to start out with (ethnographic) interviews and observations of operational experts, who will often already have an advanced understanding of the technical problems that functional modelling can identify. Involving operational experts in functional modelling can also help bring these problems to the surface. Subsequently, researchers in the field of multi-agent systems modelling can help to corroborate ideas generated by ethnography and thus generate deeper insights. It is important that modelling specialists have the ability and willingness to level with and listen to members of the other disciplines involved. Only then can they develop insights on how to influence processes as carried out by larger more complexly interrelated populations of human and technical agents.

6.4 LIMITATIONS AND FURTHER RESEARCH

6.4.1 Innovative deviance beyond the Dutch airline context

It seems likely that innovative deviance is a global phenomenon, because the paradox between compliance with standards, which dominates the view of high-tech safety critical work, and improvisations actually required to operate complex technology, is globally present. However innovative deviance may well be expressed differently and evoke different responses in other contexts than the Dutch commercial aviation industry studied here. Even in other sectors within the same national context, as a Dutch study comparing healthcare revealed (Kortleven et al., 2017), accomplices amongst the authorities may be absent or very differently organised. Presumably a lack of accomplices or just culture amongst authorities also means less effective safety processes in organisations, but these effects are difficult to prove and might be based on cultural assumptions that should be studied. It is said for example that Asian cultures like the Chinese inhibit dissent (Liao, 2015), which would imply that it is difficult to talk openly about deviance, thus limiting the learning and coping with technical anomalies and complexities through deviance. On the other hand I found that dissenting also remains a tense affair in the Dutch context, requiring specific safety cultural practices to accomplish. In other types of technical operations, perhaps other dilemmas will dominate, as well as other institutional responses.

Studying deviations from standards in other safety-critical contexts, such as nuclear power plants, will likely reveal differently deviant practices and these may be black-boxed by different safety theories and ideologies. In my studies, aviation's safety ideology provided an opening to talk about deviations from standards, since pilots' discretionary space has long been formally recognised within a distributed model of authority in air transport organisations (Stoop & Kahan, 2005). Such an opening may not always be present in other professions and industries, such as chemical processing, oil and gas, and nuclear power, where operators may also be further removed from the core process by more advanced automation. In contrast, in relation to safety-critical professions that have managed to hold on to their traditional authority and autonomy, such as surgeons, debates about deviations may be more public but also more polarised. Here, I would expect that deviations from standards can effectively become part of a regulator's arsenal to discipline powerful professional groups in order to make them accept new (safety) management systems.

Furthermore, based on my studies I expect that innovative deviance is equally important as a driver of emergent safety cultural processes in aircraft maintenance as in the cockpit. While my cockpit work studies do not include quantitative datasets to corroborate these results, many airline companies will have access to these data when they conducted a LOSA project. It would be interesting to use such data to learn about the extent and depth to which innovative deviance takes place in airline cockpits around the world. Further empirical studies of work processes and practices are also necessary to see if and how innovative deviance features in aircraft maintenance and other types of work that, despite their critical nature, are performed more 'backstage' than flying. The multi-agent system simulations suggest that the simple social mechanism of mimicking or influencing other team members' behaviours, which then spread through team rotations, can explain a great deal of how safe practices emerge and erode. By including interactions with technological agents, future agent models can explain how interactions generate and spread deviant practices. If access is provided to safety databases, such as safety incidents and reporting, perhaps agent models could even test the assumptions about the effects of different forms of deviance and compliance. That is, further studies might elaborate and test conditions under which safe practices erode (Snook, 2000; Vaughan, 1997; 1999), versus conditions under which innovative deviance puts safety values into practice.

6.4.2 Resilient routines

Further studies of deviant work practices and organisational responses should enrich our knowledge of reflective practices in risk managed organisations. An important question is whether and how deviant practices foster resilience, which is about bouncing back from disturbances, or at least degrading gracefully (Weick & Sutcliffe, 2007). As HRO theorists (Weick et al., 2008) and safety scholars (Hollnagel et al. 2006) suggest, resilience is crucial to deal with unforeseen events where organisations transgress beyond design limits. If innovative deviance enables an organisation to deal with such transgressions, large and small, then innovative deviance is an important source of an organisation's resilience

potential. Perhaps this potential can get weakened over time as regulatory processes black-box and constrain the space for reflection that drives innovative deviance. In other areas than aviation, such as nuclear power, where catastrophic failures have a potentially worse, long term impact, it seems especially urgent and interesting to investigate whether and how resilience is maintained through deviance. Could it be, for example, that by learning how and when to deviate or strike a balance in routinely encountered procedural grey areas, professional experts learn a more generic, experiential skill that they can also resort to in highly unusual, out-of-limits situations? Or is extensive training with more generic risk and failure heuristics (e.g. Rankin, Woltjer & Field, 2016) in combination with more specific crisis scenarios or emergency procedures the only way to prepare for these situations? Similar questions might be asked for sociotechnical systems with other types of risk than safety, such as security of critical infrastructures.

Studies into extreme contexts like cockpits might provide useful insights in resilient routines beyond the safety-critical domain for organisations operating in other risk contexts, such as finance or accounting (Hällgren, Rouleau & De Rond, 2018). The cockpit is an interesting extreme context because of the tight safety margins and the extensive automation and standardisation. Thus, the cockpit could also serve as an extreme case for the question if standardisation and automation leads to deskilling and thus eliminates resilience potential in organisations.

A superficial reading of this context would suggest that almost all the work done conforms to organisational routines, because pre-existing designs and key assumptions underpinning the trained routines almost always hold (Suarez & Montes, 2019). This would imply only very modest, perhaps negligible engagements in improvisational activity, such as ‘interpretations’ or ‘embellishments’ (Weick, 1998) of the operational routines as they are designed. It would also imply that organisations’ resilience potential remains invisible in the vast majority of cockpit work situations, because there are so few significant disturbances to the routine to bounce back from. Drawing lessons from superficial readings of the cockpit context to other organisations then logically emphasise conformity with formalised routines rather than raising the question how to improvise wisely in more ambiguous situations.

According to this point of view, operating airlines appears to be a more dreary affair than how I portrayed their processes here. Indeed, various aspects of the flight operation, which I have mostly omitted in my current studies, might be relatively uneventful compared to the action I described. There could be a certain selection bias as for reasons of practicability I focused on short-haul flights, where I expected that I could observe deviations from standards in a more condensed way than if I had chosen for long haul flights.

Based on what I have observed, however, I suspect that a detailed study zooming in on longer trajectories of team action (Christianson, 2019) will reveal plenty of resilience in the form of improvising within the grey areas of design assumptions. Loukopoulos, Dismukes and Barshi’s (2003) study for example highlighted that while there are many intersecting tasks or subroutines, which pilots are expected to perform simultaneously,

such multitasking is arguably a myth. In practice, routines have to be cut in parts, put on hold, cut short, picked up again, adapted, stretched, shortened, etc. That is, in order to perform many intersecting tasks, pilots probably improvise to match events with the time and sequencing presumed by the procedures (Crossan, Cunha, Vera & Cunha, 2005) and rely on quick heuristics to take shortcuts (Tuccio, 2011) rather than performing routines precisely as designed.

6.4.3 Groovy organising

My studies were predicated on the assumption, based on the insights of the HRO literature (e.g. Weick & Roberts, 1993) and Orr's (1996) influential study of field technicians, that the operation of safety-critical processes can be characterised as a continuous, methodical improvisation. This lens was useful in determining the research focus on deviations from standards, which are implied by improvisational processes, and the results suggest that improvisation does indeed play an important role in the operation of complex jets. However to date there are no studies that take this perspective on high-tech, safety-critical operations to their full potential and describe in detail how, when, to what extent, and to what effect professionals like airline pilots, air traffic controllers, and maintenance technicians actually improvise. Perhaps it is difficult to do so because it is hard to obtain the rich data necessary for answering these questions and because theorising from these data also implies an investment in *disciplined imagination* (Cornelissen, 2006; Weick, 1989). Presumably, as was the other premise of my dissertation, it is hard to 'unsee' the design blueprints of organisational routines, when organisations invest so heavily in routinising.

Building on the organisational improvisation literature, the metaphor of jazz improvisation (Barett, 1998; Weick, 1998) might inspire further studies. One of the returning themes in the organisational improvisation literature is that there are many ways to define organisational improvisation (Hadida, Tarvainen & Rose, 2015). In HRO contexts like airline cockpits it may seem more obvious to define improvisation as an episodic type of phenomenon by which teams respond to crisis situations (Bigley & Roberts, 2001; Rerup, 2001; Trotter, Salmon & Lenne, 2014; 2015). It is, however, also possible to identify more continuous, and more mundane, improvisational phenomena. Hadida et al. (2015) define team-level, low-degree organisational improvising as 'synchronising', analogously to how a jazz orchestra's rhythm section creates a groovy performance. Such synchronising phenomena are more likely to be continuous aspect of human teamwork as well as for individuals working with technical systems, which with today's digital capabilities could also easily be defined as actively synchronising agents.

To apply this analogy to a flight crew, imagine for example as a baseline a classical orchestra performance, analogously to how teams in other organisations perform a very strict ritual, such as a military parade, in an almost completely determined environment. This might be the image of perfect, ritualistic compliance (Merton, 1949), which conforms to what the safety scholars call 'work as imagined' (Dekker, 2006) because it leaves out most of the variation seen in real-life operations. Then, by contrast, imagine a jazz

performance, analogously to how a team performs a standardised process in a more hectic and indeterminate environment, such as a crew performing a flight to Amsterdam Schiphol airport.

This analogy then might highlight how teams of highly skilled technical and operational experts are connecting and interacting with each other and with external audiences through their instruments. They rely on an array of well-rehearsed standards, sometimes creating new moves on the spot but more often resorting almost automatically to their personal repertoires of 'licks' and 'crips' (Barett, 1998, p. 606). Improvising teams may also be seen to joke and talk during the performance, communicate nonverbally to cue an alternation of roles or leads, express emotions and surprise, and coordinate their performance in ways that, despite the application of shared vocabulary and standards, is largely tacitly understood.

By elaborating these processes, future research could develop insights in the perceived contradiction between improvisation and compliance with standards, on which I cited the Dutch Safety Board in the introduction of this thesis. This perception appears to be based in deep-seated cultural beliefs about the risks and fragility of improvisation versus the safety of standards. In contrast, the improvisational lens could help elaborate empirically as well as theoretically how improvisations and standards go together. As American musician Wynton Marsalis points out, despite the improvisational nature of the jazz genre, its 'harmonic progression [...] is standardised. [...] The standardised grid underlines everything from our voting ballad to the sky scrapers to the distance between lines in our roads. [...] Our understanding of that grid determines how successful we will be at what we want; so, too, with the chord progressions of a song' (Wynton at Harvard, 2017, 0:07-2:26 minutes).

Gauging from my own observations, the musical analogy could lead to interesting insights in reflective practices and resilience. The idea that flight crews synchronise as though they are seeking a groovy rhythm might for example allow researchers to discover how flight crews manage to slow down and speed up their decision making process under time pressure. My study in chapter 3 presented a model of alternating and overlapping fast reflexive and slow reflective action. Synchronising, by way of slowing down and speeding up teamwork processes in a dynamic flight routine, could elaborate this process. It may be necessary to slow down the teamwork process in order to engage in the slower reasoning process (Hodgkinson & Sadler-Smith, 2018). Experimental cockpit cognition research has indeed shown for example that reframing, or adjusting one's understanding of a situation in response to a surprise, takes time to complete (Rankin et al., 2016). There are CRM tools to slow down and reflect on risks for a moment, such as Threat and Error Management (TEM) (Helmreich et al., 2017, May), but this appears to presume a more linear and predictable flight process than what I observed in practice (cf. Dekker & Lundstrom, 2006). In reality, while crews rethink the situation, the music keeps playing. Therefore it could be worthwhile to study whether and how TEM or other management tools actually feature in improvisations by which teams slow down, reassess, and reorganise in-flight.

More fundamentally, this research may go on to discover ‘a tacit, taken-for-granted quality in all organising that we fail to see because we are distracted by more conspicuous artefacts such as structure, control, authority, planning, charters, and standard operating procedures’ (Weick, 1999, p. 533). Consider for example how flight crews’ commitment to land seems to emerge in an evolving situation, rather than through a strictly analytical process such as checking the stable approach criteria, as Dekker’s (2009) Turkish Airlines crash analysis pointed out. My own observations of a formally unstable approach in the simulator in chapter 3, as well as a real-life decision to commit to the destination airport in chapter 2, also describe such emerging commitment. Perhaps studying how teams and organisations commit to certain courses of action is more effectively done by looking through an improvisational lens (Weick, 1998), than the traditionally used lenses of decision making (e.g. Kahneman & Klein, 2009; Klein, 2015).

6.4.4 Foresight and future technologies

Ongoing technological advances may also be changing reflective practices in ways that will need to be covered by future research. Current airline jet automation for example represents semi-autonomous rather than fully autonomous technology and is a far cry from the ‘intelligent’ technology of the currently developing Artificial Intelligence (AI) paradigm. Current AI however may represent a new paradigm of automation which according to some scholars will have a massive impact on organisations and professionals (Faraj et al., 2018). By way of machine learning, AI software systems can potentially reach better judgments over certain areas of expertise that were traditionally the exclusive jurisdiction of professionals, such as interpreting scans in radiology (Hosny, Parmar, Quackenbush, Schwartz & Aerts, 2018). Research then is needed on social and organisational responses to these technical innovations, which may put greater demands on the human learning, intelligence, and creativity implied by innovative deviance. As technology operators are resituated in the further automated control process, they will likely need to develop new intuitions and heuristics to interact with new systems (cf. Hutchins, 1995a), which will include software that behaves in ways that cannot be understood with traditional means (Faraj et al., 2018).

A relevant line of future research is to study how organisations undergoing AI automation manage to retain or transform critical skills and knowledge. There are widespread fears that AI will lead to massive job losses and deskilling (Faraj et al., 2018). Indeed, the aviation case suggests that when organisations aim to eliminate violations and limit operational variability in search of protection by automatic systems, they may actually drive dangerous deskilling (Oliver et al., 2017). Researchers therefore suggest designing flexible routines, which only partially constrain teams while deliberately leaving other aspects of the performative routine open to professional discretion (Grote, Weichbrodt, Günter, Zala-Mezö & Künzle, 2009). My findings on innovative deviance on the other hand suggest that design constraints, anchored in ‘safe standards’, also trigger, feed, and incorporate reflection, creativity, and expertise development. Further studies on how and why formal standards develop in response to AI systems might thus

reveal how organisations and professions retain or perhaps transform skills, while under industry pressures to further standardise and automate processes.

Further research in the fields of regulation, routines, and artificial intelligence would benefit from radical interdisciplinarity, such as the close collaboration between textually oriented qualitative ethnographers and mathematically oriented agent modellers in my studies attempted. The value is not necessarily in developing predictive models, which may be impossible and even unwanted in view of human agency and the complexity of culture. In my experience, the value in modelling might be primarily the exercise of formal modelling itself and the way this forces participants in the process to explicate assumptions, test the internal logic of their theoretical arguments, and spread the insights gained as they continue work within their discipline. If all participants are open to learning, this could generate insightful readings in major sociotechnical questions of our time. The processes described here could for example inform debates about how to trust AI to make critical legal, surgical, and military decisions; how to reorganise semi- or fully autonomous traffic; and whether to rely on nuclear power and the safety cultures that would need to keep nuclear processes and waste safe, while we already begin to experience the impact of fossil fuel use on the climate, possibly to the detriment of societal and political stability.

Without necessarily providing any clear-cut predictions, by understanding the depth to which technical systems rely on deviant organising, I argued earlier that we can still make critical technological choices with some foresight. To illustrate the limitations to prediction, I write these concluding remarks at a time when the world, and with it the global aviation industry, is severely impacted by the corona virus crisis. This may have deeply changed the context and thus the object of my research. Does the economic hardship that presumably follows, as well as sudden changes and restrictions to operational aviation routines, trigger the creation of various shortcuts, workarounds, and other deviations from safe standards? If so, will these help create safe practices or signify an erosion of aviation's safety institutions, or worse, dangerous leaks in the global efforts to contain the virus?

Beyond this immediate crisis as experienced in aviation, however, perhaps a more general lesson is to continue to recognise the contradictions in technical and organisational designs, and expect these to surface in the experience of human operators. With increasing reliance on digital systems, capable of autonomous decision making, there is growing need to distinguish the human contribution that is needed to keep these systems aloft. My studies suggest that the human contribution can be formulated around reflective practices, which regularly deviate from standards and signify a diverse basis of socially constructed expertise, ingrained in, but not limited to, typical human traits such as habit and intuition. It seems likely that with more powerful decision making automation, the human role will centre even more on managing exceptions to rules, which are beyond the decision making abilities of robots and semi-autonomous systems like autopilots. If this is true, and societal conditions allow it, then capitalising on innovative deviance could become a vital aspect of managing and regulating even the most control-oriented organisations in the future.

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SUMMARY

This dissertation encompasses a set of studies that address persistent yet problematic assumptions about the way complex and hazardous technologies are operated by the members of aviation safety cultures. Aviation safety culture is often described as humble in terms of its acceptance of human errors and technical failures, underscored by the many redundancies, meticulous planning, and adherence to standard operating procedures. However, because of the extensive standardisation and conformity presumed necessary to stay in control, it is hard to grasp how deviations from standards belong to such a culture. Deviations from standards however are implied in the more varied, fragile, and messy processes by which operational experts like pilots, flight attendants, air traffic controllers, maintenance technicians, and ground personnel are known to apply procedures and planning in practice. As I demonstrate in the introduction, essential knowledge about these deviating processes is easily 'black-boxed' in formal-legal narratives and theoretical debates. The central research question of my dissertation therefore is: *What role do deviations from standards play in committed safety cultures?*

Reading this theoretical black box in the context of the Dutch commercial aviation industry, my main finding is that deviations from standards reflect widespread ingenuity and dexterity of operational experts dealing with contradictions in complex sociotechnical systems. My studies find certain social and organisational processes responsible for dealing with contradictions when problems come to the surface. The overall response can be characterised as *innovative deviance*, driven by operational experts and relying on 'accomplices' amongst the authorities tasked with management, oversight, prosecution, and governance.

The contextualising study in chapter 2 indicates that there is a social risk in deviating for aviation professionals, which creates some tensions. On the one hand, despite the intention to act in line with the spirit of the procedure and even with ample legal anchor and precedent, deviating from the letter of the procedure can be construed as deviance by authorities within or outside the organisation. On the other hand, authorities who act as 'accomplices' appear to negotiate contrasting risk perceptions from their own legal perspective, the public, and the professional safety culture where innovative deviance sometimes surfaces. I observed how the resulting tensions surface in flight crews' work in the cockpit in the form of humour, emotions, and stress normally seen during the interactions of a routine working day.

The study of airline pilots' cockpit work practices in chapter 3 uncovers expert-drivers of the emergence and normalisation of organisational deviance, or routine nonconformity with procedures. I note that while seminal accident studies of NASA focuses on the negative consequences of deviance, I focus on positive consequences. I find that in procedural grey areas, routine deviations from procedures arise within a normal process of developing and transmitting expertise. Expertise development means developing intuition and using deviations from standards as opportunities to communicate about different intuitions between professionals with varying experience.

There is an argument that ‘opening’ a theoretical black box can turn into an empty exercise if one ignores the moral and practical problems associated with them. In chapters 4 and 5 I therefore engage with the engineering disciplines, who are responsible for designing safety-critical technologies and organisations. Their safety culture models are often a-political, while qualitative studies show that safety cultures develop through power and (office-) politics. By formalising these insights in a multi-agent model, chapter 4 translates the idea that safety commitment in organisational cultures does not always follow predictable paths. Instead, by modelling a maintenance company’s power relations and work process, and conducting simulations with this model, we demonstrate how commitment to safety emerges in non-linear ways from (mostly routine) work and social interactions. In chapter 5 I report how this methodology offered a useful alternative for safety management to existing theories in the case of a ground services organisation. The methodology may allow companies to achieve a fuller social understanding of safety commitment and help to apply control in more effective ways.

These findings contribute to our understanding of safety cultures and also have wider implications. Innovative deviance is a concept developed by sociologist Robert Merton to analyse how certain practices that transgress the law are criminalised by societies, but at the same time represent innovations that enable people to realise cultural values. In my studies, the application is more subtle, in that there are no clear transgressions of the law, but rather professionals exercising discretion in ‘grey areas’. These actions can get criminalised, but may also represent useful practical innovations such as workarounds and shortcuts needed to keep an operational process going. In other societal contexts and domains, innovative deviance may proceed differently than in the Netherlands. Further research should explore the social and organisational responses elsewhere, since it seems likely that innovative deviance is a phenomenon that is globally present.

Practical implications of these findings include becoming aware of varying, deviating practices in order to foster sensitivity to operations. When (re)designing technical systems, operating procedures, and training methods, organisations should recognise the practical reasons for deviating and include practical experts to foster constructive learning. Leading a company in such a direction takes trust, relational work, and courage from the offices responsible. However, these efforts may be well spent. It seems likely that in the future, with more powerful decision making automation, the human role will centre even more on managing exceptions to rules. Complex exceptions after all are beyond the decision making abilities of robots and semi-autonomous systems like autopilots. If this is true, and societal conditions allow it, then capitalising on innovative deviance could become a vital aspect of managing and regulating even the most control-oriented organisations in the future.

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ABOUT THE AUTHOR

David Passenier (1982, Amsterdam) was fortunate enough to grow up in a family that prioritises doing what you love. David obtained a Private Pilot's Licence at the age of 17 and completed the propaedeutic exam of Aerospace Engineering at the TU Delft in 2004. Serving as board member of different student organisations, he was struck by the elusive complexity of human behaviour that he observed. He switched to social sciences and received a BSc in Culture, Organization and Management in 2009, and a Social Research Master (Organisation Science track) in 2012, both at the Vrije Universiteit Amsterdam. He was a KNAW (Royal Dutch Academy of the Sciences) academy assistant in 2011 and 2012.

After completing his MSc, David went on to teach at the VU's Organization Sciences department and meanwhile developed his PhD project on aviation safety cultures. He taught and coordinated case study research for up to 120 students, co-lectured organisation science introductions for up to 500 students, taught bachelor-degree seminars, and supervised a dozen master theses. He developed his PhD research by relying on ethnographic fieldwork and interdisciplinary collaborations. He published in international, peer reviewed journals as well as conference proceedings and contributed a chapter to the Routledge Companion to Risk, Crisis, and Emergency Management.

David actively seeks collaborations across the social science discipline and develops applications for aviation. In 2012, he successfully co-applied for an interdisciplinary research grant of the KNAW and VU Network Institute to unite social science and computer science approaches. Follow-up projects to which he was invited in 2014 and 2015 also included aviation engineering researchers. Since 2018 David offers freelance organisational research and draws cartoons to help professionals communicate complex messages in simple ways. He was senior researcher for a safety culture analysis of an Asian airline and aided successful multi-million grant applications in social science and business administration.

