

Measuring and Managing Airside Operational Safety Risks
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by

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Case study's specific findings related to Fraport's safety management
department are excluded from this version

Executive Summary

Although aviation industry is considered one of the world's safest industries, the introduction of a formalised safety management in all sectors of this branch is still in its infancy. A safety management system concept is relative new to airports and lately, airports have been increasingly confronted with new airside operational safety requirements and regulations.

As the airport operator is formally responsible for overall safety at the airport and little guidance has been provided by regulators for the measurement and management of risks at airports, this work researches and identifies suitable approaches to increase the effectiveness and efficiency of the airside operational safety risk measurement and management process.

Literature provides numerous views, definitions, and concepts related to risk measurement and management. However, the process of measuring and managing airside operational safety risks is a complex issue characterised by many interdependencies and approaches are abundant. Solutions depend on the risk game being played. Therefore, there is no single approach or best solution to increase the effectiveness and efficiency of the risk measurement and management process. Several recommendations can be inferred for adjusting different "screws" of the process.

**Measuring and Managing Airside Operational Safety Risks
A Case Study of Frankfurt Airport (FRA)**

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List of Abbreviations

€	Currency Sign Euro
&	Sign for "And"
5M	Accident Causation Model encompassing Man, Machine, Medium, Mission and Management factors
ACI	Airport Council International
ADREP	Accident/Incident Data Reporting System (ICAO)
ADV	Arbeitsgemeinschaft Deutscher Verkehrsflughäfen
AG	Acronym for "Aktien Gesellschaft" comparable to Ltd. in the UK
ALARP	As Low As Reasonable Practicable
AOSR	Airside Operational Safety Risk
ARMS	Active Risk Monitoring System
ASTER	Aviation Safety Targets for Effective Regulation
ATM	Air Traffic Management
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry of Transport, Building and Urban Development)
CAA	Civil Aviation Authority (UK)
CBA	Cost Benefit Analysis
COSO	Committee of Sponsoring Organizations of the Treadway Commission
D.C.	District of Columbia
DMI	Disaster Management Institute, Bhopal
Doc	Document
DTI	Department of Trade and Industry
e.g.	Exempli gratia (for example)
EASA	European Aviation Safety Agency
EBITDA	Earnings before Interest, Taxes, Depreciation, and Amortisation
EC	European Community
ECAST	European Commercial Aviation Safety Team
Ed	Edition
EHST	Environmental Health & Safety Today (Magazine)
EMBA	Executive Master of Business Administration
ERM	Enterprise Risk Management
ETA	Event Tree Analysis
et al.	et alia (and others)
etc	et cetera (and so forth/and so on)
EU	European Union

Eurocontrol	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration (US)
ff	And the Following Pages
FIUUG	Flugunfalluntersuchungsgesetz (German Flight Accident Investigation Act)
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode and Effect/Criticality Analysis
FRA	Frankfurt Airport's 3-letter code (IATA)
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Studies
HEA	Human Error Analysis
HMWVL	Hessisches Ministerium für Wirtschaft, Verkehr und Landesentwicklung (Ministry for Industry, Transport and State Development of the Federal State of Hesse, Germany)
http	Hyper Text Transport Protocol
i.a.	Inter alia (among other things)
IAASS	International Association for the Advancement of Space Safety
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
i.e.	id est (that is)
IRMI	International Risk Management Institute
ISAGO	IATA Safety Audit for Ground Operations
ISDA	International Swaps and Derivatives Association
ISO	International Organization for Standardisation
IT	Information Technology
Jr.	Junior
KPMG	Swiss Cooperative (Acronym for Klynveld, Peat, Marwick and Goerdeler)
Ltd.	Limited
LuftVZO	Luftverkehrszulassungsordnung (German Air Traffic Licensing Regulation)
m	Million
Mr.	Mister
Ms.	Misses
NASA	National Aeronautics and Space Administration
n.d.	No date
No.	Number
NPA	Notices of Proposed Amendment

op	Operational
PEST	Acronym for Political/Legal, Economical, Social, Technological
pp.	Pages
PRA	Probabilistic Risk Assessment
PRMIA	Professional Risk Managers' International Association
PSA	Probabilistic Safety Assessment
RMMP	Risk Measurement and Management Process
RMSMS	Responsible Manager for Fraport's Safety Management System
RPK	Revenue Passenger Kilometre
SARPs	Standards and Recommended Practices (ICAO)
SHEL	Acronym for Software, Hardware, Environment, Liveware
SMM	Safety Management Manual
SMS	Safety Management System
SOP	Standard Operating Procedure
SWOT	Acronym for Strengths, Weaknesses, Opportunities, Threats
UK	United Kingdom
Unite	Unification of Accounts and Marginal Costs for Transport Efficiency
US	United States
Vol.	Volume
VOSL	Value of Statistical Life
www	World Wide Web

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1. Introduction

"Expect the best, plan for the worst and prepare to be surprised."

Denis Waitley (Waitley, 2011)

Although literature considers the aviation industry one of world's safest industries, a safety management system concept is relative new to airports. Lately, airports have been increasingly confronted with new airside operational safety requirements and regulations. Airports must respond to these exigencies and balance the related costs with productivity, stakeholders' needs, and pressures of a competitive environment.

Since absolute safety is an illusion and no system is free of risks (Adebiyi et al., 2007), the likelihood of accidents with possible disastrous impact is always given. Measuring and managing risks to reduce incidents or accidents is an essential pillar of any safety management system. Methods and procedures applied hereto are decisive for the success and effectiveness of a systematic approach to safety management.

As little guidance has been provided by regulators for risk measurement and management at airports, this work researches and assesses approaches for measuring and managing risks.

1.1. Background and Context of the Study

Ludwig et al. (2007) state that airports have a key role in transporting people, merchandise, and commerce. Hence, affordable and reliable aviation is essential to support economic growth (Roelen, 2008). Cost-effective risk control is indispensable for airports to ensure reliable and affordable aviation. This in turn, demands sound methods to measure and manage risks.

Safety in the aviation industry is not a new issue. According to Vasigh et al. (2008), there is an unprecedented amount of regulatory and operational control over the industry. However, quoting EASA¹ (2011), the introduction of a formalised safety management in all sectors of the civil aviation industry is still in its infancy.

Since 2009, the International Civil Aviation Organization (ICAO) requires the implementation of a Safety Management System (SMS) at aerodromes (ICAO, 2009). Although authorities provide a regulatory framework and define basic requirements with relation to safety at aerodromes, so far, they fail to provide details or specifications for risk analysis for airports (Roelen, 2008). There is no standardised or

¹ European Aviation Safety Agency

prescribed procedure for measuring and managing airside operational safety risks at aerodromes. Airports are, in comparison to other industry members, e.g. ATM², far less regulated with regard to operational risk management.

However, according to de Bruijne et al. (2005), the airport operator is formally responsible for overall safety at the airport. Considering traffic growth forecasts, stakeholder's expectations, and economic considerations given the disastrous effects of aircraft accidents, greater efforts and more effective countermeasures are required from airport operators to achieve a constant safety level improvement. As the safety management department compete for the company's resources, their efficient use is essential to ensure the overall safety level and company's competitiveness. This postulates a systematic and cost-effective approach to airside operational safety risk measurement and management.

1.2. Project Identification and Objectives

Since airports have been mostly neglected in risk management literature, this work focuses on the identification and analysis of eligible approaches to measure and manage risks within the context of SMS at Frankfurt Airport.

This work's objective and motivation is to contribute to Fraport's knowledge base on operational risk measurement and management approaches presented by contemporary literature. Additionally, to analyse existing methods and to identify suitable approaches to measure and manage airside operational safety risks at airports as well as to recommend approaches to transform data into valuable and reliable information in order to support the risk related decision-making process.

This work should contribute to the reduction of risks as well as to the improvement and prioritisation of risk control measures to ensure an effective allocation of safety resources.

This study primarily addresses Fraport's senior management and Fraport's employees interested in this topic.

1.3. Structure

This study is organised in seven chapters. The first chapter introduces the subject and outlines this document's objectives and structure.

² Air Traffic Management

Chapter 2 reviews the relevant literature and provides this work's theoretical foundation. It explains some fundamental concepts, examines reasons for risk measurement and management, analyses the risk measurement and management process, scrutinises data relevancy to the subject, assesses methodologies, and identifies subject related challenges.

Chapter 3 presents data sources and data analysis methodology, outlines limitations of the methodology as well as this work's limitations.

Chapter 4's introduces Frankfurt Airport, analyses the subject related organisational and strategic context, and introduces FRA's SMS.

Chapter 5 reflects and discusses the theoretical findings of the literature research and chapter 6 concludes this work with a final consideration of the research findings.

Complementary information is annexed, along with a full list of data sources.

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2. Literature Review

This chapter's objective is to research and analyse risk measurement and management approaches and methodologies provided by contemporary literature.

2.1. Fundamentals

Risk measurement and management is a broad subject. Literature outlines numerous views, definitions, and concepts related to this topic. To ensure a basic common understanding, this sub-chapter not only links operational safety and risk management, but also explores the concept of risk and examines the relevance of accident causation theories to the subject.

2.1.1. Linking Operational Safety and Risk Management

Since this work researches operational risk measurement and management within the context of airside SMS, a clarification of the connection between operational SMS and risk management is required.

According to various authors (i.a. FAA, 2000; Roelen, 2008; Loebbaka, 2008, and ISO, 2009), the primary function of safety management at airports is the prevention or reduction of (unacceptable/avoidable) risks. Consequently, safety management is about managing risks. ICAO (2009) emphasises the correlation between risks and safety by stating that hazard³ identification and risk management are core processes involved in the management of safety. Thus, hazard identification and risk management are dogmatic components that underlie the overarching concept of system safety. Huang (2009) alleges that safety is not limited to risk and accident prevention, but should be considered in a broader term as risk management. Finally, Enoma & Allen (2007) even argue that safety is all about risk management.

FAA (2007) specifies safety policy and objectives, safety assurance, and safety promotion as further SMS elements. Each company has to define its own safety concept, the emphasis put on each element, and the desirable safety level in due consideration of its environmental framework. However, despite many definitions and connotations, literature agrees that risk measurement and management is an indispensable and significant part of any safety management system.

³ Hazard is not the same as risk. Hazards are potential vulnerabilities inherent in socio-technical production systems. Hazard is defined as a condition or an object with the potential to cause consequences e.g. damage to equipment or structures. Hazards in and by themselves are not bad things e.g. wind is a hazard (ICAO, 2009).

2.1.2. The Risk Concept

Within risk management literature, terminology is not consistent and precise. The term 'risk' is used in many different connotations (Kaplan & Garrik, 1981). Usually, it is applied broadly and vaguely or is defined by at least equally unspecific words. Such fosters misunderstandings and miscommunication, especially as literature disagrees about the positive or negative connotation of risk, whether it should include both aspects in one definition, and if both could be handled by a common risk management process (Hulett et al., 2002). Additionally, risk is something clearly subjective. How stakeholders perceive and respond to risk is decisive for the risk definition (Slovic, 1999). According to Power (2004), the whole concept remains elusive, contested and 'inherently controversial' as definitions also reflect and depend on specific application areas as well as on institutional interests and contexts. Different institutions, even different departments within a company, often use terms and approach risks differently as they focus on different risks aspects.

Consequently, there is no universal valid set of characteristics for describing risk (Slovic, 1999). However, the analysis of definitions from many authors has resulted in the following common aspects: First, risk addresses the uncertainty of future outcomes. Second, risk is about consequences. Third, it embodies subjective values and ideals often depending on the perspective. Fourth, risk is a result of interdependent variables. Fifth, risk is multidimensional. Sixth, risk relates to decision-making. Finally, risk is not visible. At the end, the characterisation of risk depends on which risk game is being played (Slovic, 1999).

Besides disagreeing on the risk definition, literature also distinguishes heterogeneous risk categories. Some authors differentiate controllable or uncontrollable risks (e.g. King, 1998). Other experts distinguish initial, current, and residual risk (e.g. Canale et al., 2005). Further ones in turn discern business and financial risks (e.g. Gaese, 1999), and so on.

In order to avoid misunderstandings, the universal term risk is from now on, narrowed down onto more specific term and focused area of operational risks making useful to understand some unique characteristics of operational risks and their implications on modelling methods. According to Shah (2002), these are:

Characteristic of Operational Risks	Implication
1. Op risks are endogenous, i.e., specific to the facts and circumstances of each company. They are shaped by the technology, processes, organisation, personnel, and culture of the company.	Need to gather company-specific data. However, most companies do not have a long history of relevant data.
2. Op risks are dynamic, continuously changing with business strategy, processes, technology, competition, etc.	Even a company's own historical data may not be representative of current and future risks.
3. The most cost-effective strategies for mitigating op risks involve changes to business processes, technology, organisation, and personnel.	Need a modelling approach that can measure the impact of operational decisions. For example, "how will op risks change if a key function is outsourced?"

Figure 1: Characteristics of Operational Risks (Shah, 2002)

Slovic (1999) states that whoever controls the risk definition control the rational solution to the problem at hand. The risk definition clearly influences the problem framing, the risk management approach, and defines strategic options. Therefore, before starting any risk measurement or management exercise it is indispensable to define risk.

2.1.3. Accident Causation Theories

This chapter analyses the implication of accident causation theories for the risk measurement and management process. Details on concepts and models can be researched in literature.

Accident causation theories explain possible causation mechanism of accidents, based on rather theoretical hypotheses. First generation accident causation theories e.g. Heinrich's domino theory, have a deterministic ground idea, assume that accidents follow similar pathways, and mainly occur as result of an unsafe act by a person and/or physical or mechanical hazard. These ideas provide the basis of the accident pyramid model that correlates occurrences, incidents, and accidents. These theories and its further developments by subsequent researchers still prevail and influence risk management. Ideas such as accidents are caused by successive events, events can be prevented by eliminating unsafe acts or conditions, incidents and occurrences data can be used as indicators for risks instead of rare accident data, and

major losses can be avoided by preventing minor occurrences and incidents still provide the basis for many risk management processes.

Models such as the "Swiss Cheese Model" broadened this view. Researchers recognised that safety problems emerge from the interactions between technical, human, social and organisational aspects of a company in combination with a changing environment (Körvers, 2004). Such models have contributed to the idea that a weakness in the system's design or operation, so called latent errors, can cause accidents (Wells & Rodrigues, 2003). For managers design the system, system defects may occur due to management error.

Meanwhile it is acknowledged that humans are hardly ever, the sole cause of an accident (ICAO, 2009). Theories such as the SHEL⁴ model, offer a system perspective that considers a variety of contextual and task-related factors that interact with the human operator within the system to affect operator performance (Wiegmann & Shappell, 2003). Other models such as the "5M Model" argue similarly and advise to take into account interrelationships and integration of equipment, people, environment, management, and system procedures (Ayres Jr. et al., 2009). Recent theories such as Mitroff and Pauchant's Onion Model, give insights into the dynamic mechanisms of the different layers in an organisation (Elliott et al., 2010). These models alert to the fact that attention is often focused on easily observed and measured facets of the organisation and consequently responsible managers may fail to consider more subtle and deep-seated processes that shape these layers (Smith & Elliott, 2006).

Accident causation models' evolution shows a shift from the "sequence of events" to "representing the whole system" (Katsakiori et al., 2008). Accident causation models offer important insights into the risk measurement and management context by determining the most likely cause or effect of an accident given the evidences found (Roelen, 2008). They also contribute to understand and control risks, predict system behaviour, implement measures to prevent a recurrence of accidents, and to rectify identified weaknesses (Adebisi et al., 2007 and ACI, 2010). Diverse authors agree that understanding the interrelation of contributing factors is important to identify solutions and improve safety level.

Rasmussen (1997) partially contradicts this view by alleging that efforts to improve safety by counteracting human error sources identified by causal analysis of

⁴ An acronym for Software, Hardware, Environment, Liveware

accidents tend to be ineffective as human adaptation often compensates for attempts to improve system safety. In dealing with accident causation theories, diverse authors advise to consider first, theories and models are only approximation of reality and do not cover the uniqueness of events. Second, accident causation models describe a scenario for an accident occurrence, irrespective of the specific setting. Third, a particular model may not suit all circumstances and some theories may address a problem better than others. Finally, accident causation models are usually developed based on analysis of exceptional situations e.g. accidents instead on analysis of daily business. When applying such models a balance must be found between uniqueness and generality of events (Roelen, 2008).

Accident causation theories influence risk measurement and management models choice and can significantly influence the efficiency and impact of the risk management process (Katsakiori et al., 2008). Therefore, a holistic approach, which implies combining different models and disciplinary approaches depending on the question being addressed, is recommended. Accident causation models can contribute to a multi-perspective approach and may increase awareness of decision-makers for latent failures beyond manifested front-line errors.

2.2. Measuring and Managing Risks as Indispensable Business Element

All human and organisational activities involve risks (ISO, 2009). Because of the possible impact of risks on the company's success, risks cannot be left to chance. This chapter explains why risk management is an indispensable business element. It presents reasons for measuring and managing risks, analyses economic factors related to risks, explores the relation between stakeholders and risks, and considers ethics in risk management.

2.2.1. Reasons for Measuring and Managing Risks

The Institute for Risk Management (2002) alleges that risk management protects and adds value to the organisation and its stakeholders by improving corporate governance and the decision-making process in consequence of the comprehensive and better structured understanding of business activities. It also contributes to more efficient resources allocation and a better company's image. Moreover, it develops organisational learning and the organisation's knowledge base as well as optimises operational effectiveness and efficiency.

Risk management contributes to limiting uncertainty, seizing opportunities, conserving and enhancing assets as well as safeguarding resources or minimising

exposure to losses. These factors are decisive for a company's survival in the market and conclusive reasons for implementing an effective risk management process (Wells & Rodrigues, 2003; Head, 2009).

Based on Jones-Lee (1990) and McAleese (2004), elements such as financing, liability level, technology level, environmental factors, socio-cultural climate and orientation, government policy, and compliance with regulatory requirements are -in varying degrees depending on their influence on business- also reasons for the implementation of a systematic risk management. These elements simultaneously define the risk management process' framework.

Based on diverse authors such as ISO (2009), Loebbaka (2008), Maragakis et al. (2009), and Ludwig et al. (2007), further arguments supporting the measurement and management of risks are:

- Encourage a proactive rather than reactive management;
- Improve stakeholders' confidence and trust as well as shareholder value;
- Improve control;
- Enhance health and safety;
- Improve incident management and prevention;
- Improve organisational resilience;
- Improve management ability to diagnose the firm's future challenges;
- Reduce opportunity and insurance costs as well as costs related to legal actions;
- Develop the ability to implement early warning signals;
- Improve employee morale and productivity;
- Establish marketable records, and
- Avoid investigation costs and operational disruptions.

Summarising, Robertson (2004) provides three overarching reasons for risk management and accident prevention: the law insists on it, it makes good business sense, and it is morally correct to do so. The last two points will be analysed in more detail in the following sections. The next chapter analyses tangible economic arguments that could also be used for assessing trade-offs and support decision-making processes within the risk measurement and management process.

2.2.2. Economic Factors

ISO (2009) alleges that risk management creates value as the consequences of inaction generally exceed resources expended on the process. The idea that risk

imposes costs on a company is a main point of risk management discussions. If such costs can be identified then the impact of risk on the company can be measured (Diacon & Ashby, 2002). Therefore, as any other investment, the effects of risk management have to be weighted and evaluated along with other costs and benefits as well as other influencing factors in the decision-making process (Jones-Lee, 1990). While risks are seldom acceptable, they are often tolerable if benefits are seen to outweigh costs (Stewart & Mueller, 2008). However, according to Diacon and Ashby (2002), in practice defining cost related to risks is the holy grail of risk management as it is imprecise, immeasurable, and out-of-reach.

Yet, statistical records can help delivering approximate values as according to Huang (2009), airside operational safety risks are mostly connected with accidents. Therefore, the economic effects of risk mitigation and accident prevention can be defined in terms of costs avoided (Jones-Lee, 1990). The cost related to an aircraft accident is high, generally far higher than an organisation's income, and possibly higher than the capitalisation of the company concerned (Morton et al., 2006). Besides accident's cost, economic effects such as avoidance of net output losses, interruption of operations, material damage, fatalities, medical costs, compensations, etc., have also to be considered. Mitigating risks could be vital to a company's survival.

Usually, avoided fatalities and accident rates are useful metrics for assessing trade-offs in accident accounting (Hovden, 1999 and Stewart & Mueller, 2008). Eurocontrol⁵ (2005) set the average number of fatal accidents in civil aviation at 37 worldwide, with an average of 989 fatalities per year in the period 1980-2003. I.a. to support risk related cost-benefit analysis (CBA) in the aviation industry e.g. Eurocontrol has elaborated standard inputs. Eurocontrol (2009) quantifies ground delay cost per minute with € 88, the average cost of cancelling a commercial scheduled intercontinental flight with € 75,000, and the average value of an avoided statistical fatality vary from € 0.81 to € 4.3 million per fatality averted depending on source and country. For Germany, Eurocontrol indicates a UNITE VOSL⁶ of € 2.06m (Eurocontrol, 2009). The average value of avoiding injuries is set as a proportion of a VOSL, depending on the injury seriousness. Further costs e.g. third party risks, delays, cancelations, accidents knock on and network effects have also to be taken into account (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). All costs related to an accident have to be considered even being estimates (Annex 1). As an example,

⁵ European Organisation for the Safety of Air Navigation

⁶ UNification of accounts and marginal costs for Transport Efficiency – Value of statistical life (VOSL)

the closure of FRA's runways in consequence of an aircraft accident imply cancelling or diverting up to 92 flights per hour⁷, meaning a loss in airport charges of ca. € 112,250⁸ in average per hour without even considering accident costs, delay costs, retailing revenues losses, ground services revenues losses, network costs etc.

The international community judges risks differently, particularly in relation to costs (Morton et al., 2006). Costs might be partially absorbed by insurance, but stock prices, image, and stakeholders' trust are uninsurable. Moreover, it has to be considered, that insurance coverage has to be paid-off through higher insurance premium (Roelen, 2008).

Avoiding risks or providing safety is as long profitable as its marginal value to customers equals its marginal cost of provision (Jones-Lee, 1990). However, according to Smith & Elliot (2006), the relationship between expenditures on prevention and the number of accidents is still poorly understood, meaning that a marginal cost of safety function is difficult to estimate. Nevertheless, increases in safety by avoiding risks are only optimal when the benefits justify the costs; thus, minor increases in safety that impose major costs are never cost-efficient and compromise a company's survival in the market (Vasigh et al., 2008). Ultimately, dealing with risks is a matter of trade-offs and an application of the theory of resource allocation (Nwaneri, 1970).

Possible costs of a single major accident make a strong case for improving safety. However, excess allocation of resources for protection can have an impact on the organisation's financial state, on operations' effectiveness, and as a final instance lead to bankruptcy (ICAO, 2009). One of the functions of risk management is to maintain economic viability while providing acceptable, efficient, and effective service (Wells & Rodrigues, 2003). Considering that some degree of risk is a fundamental reality, risk management is a process of trade-offs and a matter of perspective (FAA, 2000). According to Reason (2004), production and protection each has its limits as shown in the figure below:

⁷ FRA's declared capacity for the winter season 11/12

⁸ Based on own data and average values from the annual report. This data must not correspond to real data due to calculation basis and seasonality.

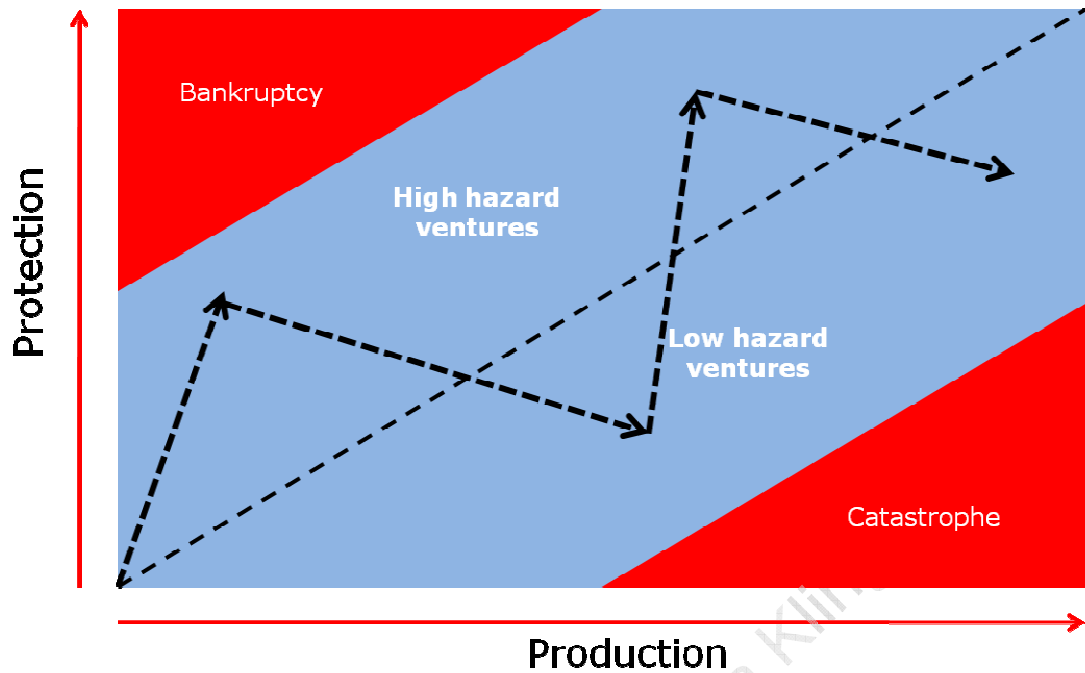


Figure 2: The Safety Space based on Reason (2004)

However, there are also intangible factors that cannot be easily included in a formal quantitative decision-making approach (Stewart & Mueller, 2008). The following sub-chapters address two of these aspects.

2.2.3. Stakeholders and the Perception of Risks

Stakeholder is a person, group or organisation that has direct or indirect stake in an organisation because it can affect or be affected by the organisation's actions, objectives and policies (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001 and Business dictionary, 2011). All stakeholders hold a different view on risks and consequently have different needs with respect to risk modelling (Roelen, 2008). For stakeholders, the willingness to take risks is subjective, often hypothetical, emotional, and irrational (Slovic, 1999). Risk acceptance is only partly connected with real risks or facts as the acceptability of risk is strongly influenced by risk perception (Hovden, 1999).

Recent studies have shown that different factors such as gender, race, political worldviews, affiliation, emotional affect, and trust are strongly correlated with risk judgements (Slovic, 1999). There are indications that risk perception and acceptance are also a question of confidence in the "system" and in the company's ability to master/control the system's complexity or a risky/dangerous situation (Morton et al.,

2006). Consequently, it is also a question of confidence in the company's risk measurement and management process.

Risk perception is also connected to perceptions of value as risk implies possible loss (Roelen, 2008). Likewise, risk appetite depends on the expected benefits associated with risk exposure. The greater the reward, the higher the risk stakeholders are willing to take (Roelen, 2008).

According to Mathis (2009), perception is volatile as perceptions can be drastically influenced by e.g. events, information flow or media coverage. The way stakeholders react to risks depends on many different features of how risk is framed, communicated, and presented (Power, 2004). Consequently, risk perception can be influenced by effective risk communication. However, Slovic (1999) alerts that mostly communication is tilted toward distrust due to a number of psychological factors.

It is essential to identify the stakeholders playing a role in determining the socio-economic feasibility of a venture (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). Stakeholders affected by risk have, directly or indirectly, a legitimate interest in the risk control level. Depending on their risk perception, influence, and risk appetite, stakeholders can hinder or promote a business venture (ISO, 2009). The way actual and possible events are perceived, classified, dramatised, visualised and mobilised determine their relevance for risk management agendas (Power, 2004). Priority is given to current problems and to those directly affecting people or businesses. According to Hovden (1999), when risk is perceived as high enough, most people will be willing to invest considerable sums in risk reduction or safety improvement and vice versa. The less people are affected and concerned by risk issues, the less the interest in such issues. Risk perception can considerably affect the availability of resources for the risk measurement and management process.

Knowledge of stakeholder's interests and a pronounced sense of stakeholders' risk appetite and perception can positively affect the risk measurement and management process.

2.2.4. Risk Management and Ethics

The classic view of businesses is that firms exist to create profits and that business managers are responsible only to their shareholders (Sloman & Hinde, 2007). This view and the resulting logic of calculating costs and benefits distributed

over time by net present value or the internal rate of return will inevitably result in a short-term decision perspective (Hovden, 1999).

Safety goals often do not coincide with real risk levels, performance, and efficiency goals and in fact, they often conflict (Aase et al., 2009). Given market forces pressure, which requires companies to produce "more with less" to remain economically viable, it is important to ensure that safety requirements will not be compromised by profit considerations (Huang, 2009).

Many issues cannot be led by economic considerations alone. Safety and risk decisions have to be made despite uncertainties and lack of knowledge. However, the choices will always include value judgements and trade-offs based on ethical assumptions (Hovden, 1999). Therefore, risk management is strongly intertwined with ethics as risk management is about making decisions about right and wrong, just or unjust, fair or unfair, and then live with the results thereafter (Childress, 2011). In dealing with risk issues, moral questions are inevitable (Hovden, 1999). Ethics define acceptable behaviours, establish a framework of professional behaviour and responsibility, and establish mechanisms for resolving ethical dilemmas. Perhaps most important, ethical behaviour and integrity are vital for maintaining company's reputation and the trust that forms the basis for successful business relationships (Hollar, 2004).

The benefits of measuring and managing risks and safety are undeniable – not only from an economic standpoint but also from a moral standpoint. Risk management creates value (ISO, 2009) and good risk management is good for business (Power, 2004). Nevertheless, decisions in favour of safety are not easily taken or enforced as they possibly contradict short-term profit maximisation and advantages of safe operations are often not seen nor easily quantified. In this case, ethics and moral values are good advisors for the company's benefit.

2.3. Measuring and Managing Risks

Measuring and managing operational safety risks is a wide and complex subject as accident causalities are mostly interdependent factors and risk consequences cannot be easily measured (Smith & Elliott, 2006). Literature provides several and varied views and descriptions of what risk management involves, how it should be conducted, and what it is for (The Institute for Risk Management, 2002). However, several authors agree that risk management encompasses all activities needed to systematically deal with risks. FAA (2000) defines risk management as the systematic

application of management and engineering principles, criteria and tools to optimise all aspects of safety within the constraints of operational effectiveness, time, and cost throughout all operational phases. Based on ISO (2009), a fundamental requirement is that risk management is dynamic, iterative, and responsive to change, implying that risk management should be a continuous and developing process. Common to several authors (i.a. Dezfuli et al., 2007; Greenfield, 2000; FAA, 2000; Kazemi, n.d.; Maragakis et al., 2009) are at least risk identification, risk analysis/assessment, risk management strategies, risk control, and risk reporting.

FAA (2000), Greenfield (2000), and Dezfuli et al. (2007) present a five-step risk management process and describe risk management as a continuous process as shown in the figure below.

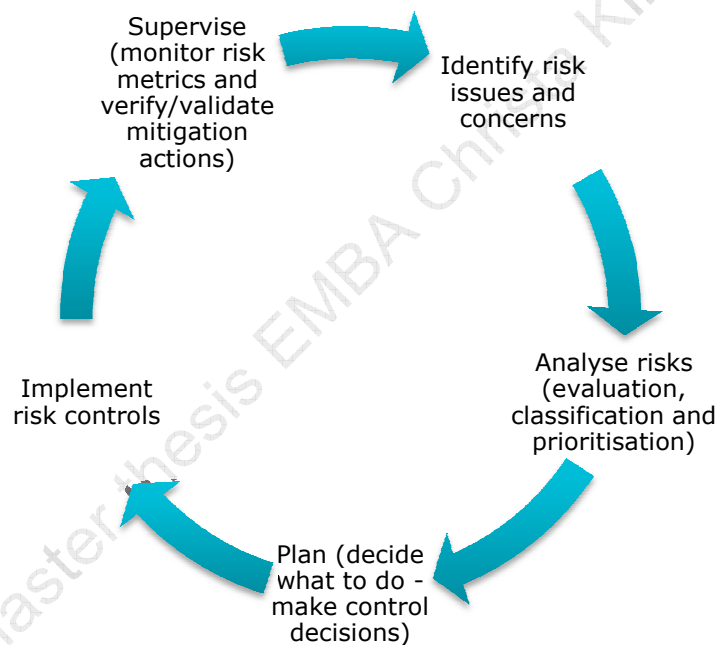


Figure 3: Risk Management Process based on FAA (2000), Greenfield (2000), and Dezfuli et al. (2007)

The approach presented by i.a. Joy & Griffiths (2007), ISO (2009), and McLeod (2006) bases on Enterprise Risk Management (ERM) and extends the model by two important tasks: "Establish the context" and "Communicate and consult", since the risk management process is embedded in a company's strategic and cultural framework, with its specific requirements, audience, perceptions, and criteria. Protocols regarding the management of risk should be consistent with the strategic, organisational and risk management context of the organisation (McLeod, 2006).

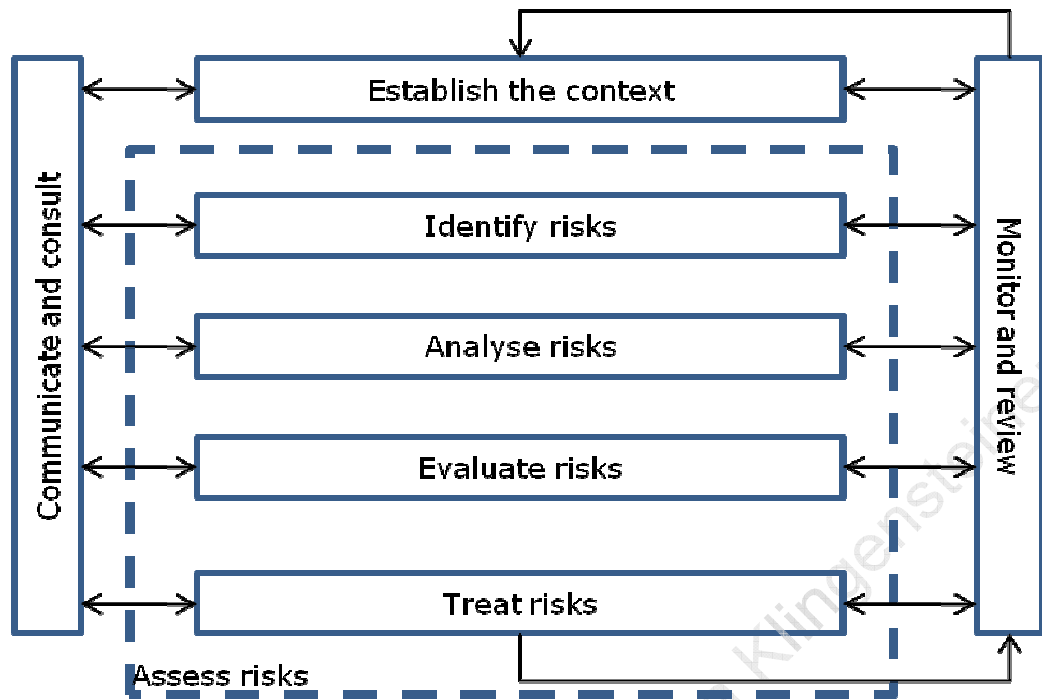


Figure 4: Risk Management Process Model based on Joy & Griffiths (2007) and ISO (2009)

In literature, many variations can be found. There are process descriptions with as many as 12 steps. However, the exact number of steps is not relevant as long as no element is missed in the process of defining different steps (Head, 2005). It is important to establish a disciplined process as the process lays the foundation for a good risk management (Samad-Khan, 2005).

According to the Institute for Risk Management (2002), the focus of good risk management is the identification and adequate treatment of risks. Risk management should methodically address all the risks surrounding the organisation's activities past, present, and future particularly. The following chapters address elements of the risk management process in more detail.

2.3.1. Establishing the Context

By establishing the context, the organisation defines the internal and external parameters to be considered when managing risks (ISO, 2009). It is an indispensable prerequisite for the risk measurement and management process as it sets risk criteria, affects the information collection and output requirements for the remaining process (Department of Urban and Transport Planning Australia, 2003). Establishing the context is also a precondition for the selection of appropriate analytical methods, as expected deliverables affect the decision of the risk assessment methods as well as the choice of tools and techniques used (Joy & Griffiths, 2007). In addition, it ensures

that information derived from these processes is adequately reported and used as a basis for decision-making and accountability at all relevant organisational levels (ISO, 2009). In order to avoid failure it has to be ensured that managing expectations as well as estimating available resources and capabilities do not differ from tactical possibilities.

For analysing a particular system, the system itself must be understood. It is essential to have substantial knowledge on all relevant aspects of the process in question, including technology, operations, regulation, and procedures for the complete lifecycle (Roelen, 2008). According to Joy & Griffiths (2007), "Establishing the context" includes five key areas that have to be analysed internally and externally. These are strategic, organisational and risk management context, risk evaluation (and acceptance) criteria, and structural decision.

This phase is a systematic and comprehensive process to identify all significant activities performed by the organisation within the identified system (Ayres Jr. et al., 2009). It is essential to define interfaces, responsibilities, and interrelations of all parties involved in the risk management process.

2.3.2. Hazards: Identification, Analysis, and Documentation

There is no consensus in the literature whether "hazard identification" is an independent process phase. However, in aviation this step should be handled independently as hazards are constantly present in operations. Hazard identification involves a critical sequence of gathering information and often causes difficulties because it calls for time, commitment to the process, and planning (Kazemi, n.d.). Hazards⁹ are not necessarily damaging or negative components of a system or a danger in itself but an event or situation that in certain conditions could potentially cause injury or damage (Ayres Jr. et al., 2009). Maragakis et al. (2009) define hazard as dormant potential for harm. It can be understood as the base of causal factors (Manuele, 2005). Hazards are not to be confused with risks. Risks are measured in terms of consequences, severity and probability (FAA, 2007). It is important to understand what hazards are and identify them in order to describe all their likely consequences and not only the most obvious and immediate ones (Wells & Rodrigues, 2003).

⁹ E.g. A 15-knot wind can be a hazard if it is blowing across the runway; however, if it is aligned with the runway, it can actually reduce the runway length needed for landing (Ayres Jr. et al., 2009).

According to Comcare (2011), the hazard identification process must also address potentially rare events and situations to ensure the full range of major accidents and their causes. For such, it is necessary to identify and challenge assumptions and existing norms of design and operation to test whether they may contain weaknesses, i.e. to think beyond the immediate experience, recognise that existing controls and procedures cannot always be guaranteed to work as expected, and learn lessons from similar organisations and businesses.

After all potential hazards are identified and documented, they have to be subjected to an assessment of possible consequences (FAA, 2007). This step comprises the definition and determination of the hazard's magnitude/amount/size, its potential consequences and the identification of any uncertainties about the hazard's nature (Joy & Griffiths, 2007). The consequences of hazards can be meaningfully expressed in economic terms in order to be used afterwards to set priorities and aid decision-making (Joy & Griffiths, 2007).

It is important to create a detailed and auditable record of the hazard identification process (Maragakis et al., 2009). Rasmussen (1997) summarises the results of this process by stating that for each particular hazard source the control structure is set, all relevant actors are identified, objectives and performance criteria are determined, the capability of control is evaluated, and the information available about the actual state of the system with respect to production objectives and safety boundaries is analysed from a feed-back control point of view.

Challenges in carrying out an effective hazard identification are: the need of substantial time to identify all hazards and potential sources for accidents, understand the complex circumstances typifying accidents as well as the need for a combination of expertise in specific techniques, knowledge of the facility and systematic tools, along with a combination of different techniques to ensure that the full range of factors is properly considered and additionally, obtain information from a range of sources and opinions and ensure objectivity (Comcare - Australian Government, 2011).

By disclosing hazards, a proactive approach can be taken toward controlling them before an incident or accident occurs (Ayres Jr. et al., 2009). However, this process step should not be a once in a lifetime exercise (Wells & Rodrigues, 2003). It has to be done repeatedly and periodically reviewed (Roelen, 2008). It also demands a

methodical approach to ensure that all areas of operation where hazards may exist have been identified (Maragakis et al., 2009).

2.3.3. Risk Assessment

Risk assessment is the process that associates "hazards" with "risks" (Canale et al., 2005). It is undertaken after having completed "hazard identification", although some interaction between the two processes may be required (Department of Urban and Transport Planning Australia, 2003). Risk assessment comprehends risk identification, risk analysis (including quantification), and risk evaluation (The Institute for Risk Management, 2002; Joy & Griffiths, 2007; Ray, 2003; ISO, 2009). According to Samad-Khan (2005) risk assessment allows a company to consider how potential events might affect the achievement of objectives. However, risk assessment has always been the most challenging part of the risk management process due to the subjectivity in the evaluation of each point and the lack of quantitative information on occurrences probability (ARMS, 2010).

Risk identification involves the association of risks to each hazard, the recognition, filtering, and ranking of potential risk or uncertain events as well their consequences, areas of impact, and their causes (Enoma & Allen, 2007). Risk identification should be approached in a methodical way to ensure that all significant activities within the organisation have been identified and all the risks flowing from these activities defined (The Institute for Risk Management, 2002). Comprehensive identification is critical, because risks that are not identified at this stage will not be included in further analysis (ISO, 2009). It is important to think outside the box and use a combination of techniques to ensure comprehensive risk identification (McLeod, 2006). This step's aim is to generate a list of risks based on those events that might enhance, prevent, degrade or delay the achievement of objectives (ISO, 2009).

Risk is the composite of the predicted consequences and likelihood/probability of the outcome (Ayres Jr. et al., 2009). Determination of consequences is independent of likelihood, and likelihood should not be considered when determining consequences (FAA, 2007). Over time, quantitative data may support or alter the determinations of consequences and probability, but the initial risk determinations will most likely be qualitative in nature, based on experience and judgement more than data (FAA, 2007). Risk analysis is about developing a risk understanding. It involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur based on e.g. accident causation models (ISO, 2009). It provides the input to risk evaluation where

decisions are made about the significance of risks to the organisation and whether each specific risk should be accepted or treated (The Institute for Risk Management, 2002). Risk evaluation involves comparing the risk level found during the analysis process with risk criteria established during the “establishing context” stage (McLeod, 2006). Decisions how to control risks will be influenced by the organisation’s risk appetite or risk attitude and the established risk criteria (ISO, 2009).

Risk quantification and measurement are an indispensable element in this phase. A basic management axiom proposed by diverse authors is “if you cannot measure it, you cannot manage it” (inter alia Adebisi et al., 2007; Wendt, 2002; Roelen, 2008; Ciavarelli, 2007; Ryan, 2009). Putting a measure on something is tantamount to getting it done as it focuses management’s attention in that area (Adebisi et al., 2007). Measuring risks and its consequences provides the organisation with a principal basis for decisions and the subsequent allocation of organisational resources to treat risks (ICAO, 2009). Measuring risks allows for risks to be ranked by priority or importance (Embarek & Hadjadj, 2010).

However, Slovic (1999) alerts to the fact that risk is inherently subjective, as it does not exist “out there,” independent from set values and cultures, waiting to be measured and that there is no such thing as “objective risk” which can be scientifically measured. Choosing risk measures is complex and judgemental, so also the choice of theoretical models, whose structure is subjective and assumption-laden, and whose inputs are dependent on judgement. This must be considered in the decision-making process.

At each level, the potential cost of performing more detailed risk assessment should be compared against the increased understanding of risks (Department of Urban and Transport Planning Australia, 2003). Generally, greater assessment effort results in a more quantitative, accurate, detailed, and robust risk understanding, allowing a more justifiable and rational basis for decision-making. However, it should be questioned whether a higher detail level justify employing further resources.

2.3.4. A Company’s Risk Appetite and Tolerance

To be able to set priorities, target values, and adequately control risks, the organisation’s risk appetite and tolerance must be determined. This can be done within the “Establishing the context” phase or for each risk independently. Definitions and explanations vary considerably in literature. According to Liebesman (2008), risk appetite is the amount of risk an entity is willing to accept. It is the measure of the

risk-reward trade-off in the business. With this specification, the company sets target values for measuring risks. Risk tolerance relates to the entity's specific objectives and is the amount of variation a company is willing to accept relative to these objectives.

Risk acceptance depends on many factors from individual risk perception (see chapter 2.2.3.) to the company's risk profile, risk appetite, and risk tolerance (Roelen, 2008). Risk is considered tolerable if the benefits gained are worth it or if the risk cannot be reduced or the cost of risk reduction is disproportionate to the improvement gained (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). However, risk tolerance is not only a matter of rewards related to risks, but also a question of risk perception and confidence in the "system" (FAA, 2000). This poses great demands on the SMS with respect to competent efficiency, personal and professional integrity in difficult decision dilemmas etc. (Hovden, 1999).

The acceptance of recommended risk control measures may depend on credible cost benefit analysis (CBA). Risk/Cost Benefit Analysis is often used to help to address the question of risk acceptability (Joy & Griffiths, 2007). Sometimes, CBA may suggest that accepting the consequences of the risk is preferable to the time, effort, and resources necessary to implement corrective action (ICAO, 2009).

The result of a risk management process should be at least a prioritisation of risks according to the greatest loss potential and greatest probability of occurring considering a company's risk appetite.

2.3.5. Risk Control Strategies

A risk control or mitigation strategy is an organisation's action plan for addressing risks in order to achieve a desired state (Maragakis et al., 2009). The strategy should capture the output of the risk management process and translate into safe operating conditions or procedures (Ayres Jr. et al., 2009). Creating and implementing risk control strategies is one of the most effective ways to protect an organisation's assets, and is nearly always more cost effective than repairing the damage after an incident (Nery, 2010). Identifying the various options for risk controlling involves balancing the cost of implementing the most appropriate option or combination of options, against the benefits of risk mitigation. Besides balancing risk mitigation plans against costs, ISO (2009) also recommends to balance against benefits, time, feasibility, and the difficulty of taking measures to reduce or eliminate the risks. Priority deserves the most appropriate and workable option that result in large

reductions in risk and generates the greatest benefit to the organisation by using the lowest possible amount of resources (The Institute for Risk Management, 2002). Organisations should design controls and mitigation plans that produce a residual risk consistent with the company's risk appetite, and monitor this entire process, making feedback adjustments as necessary. Risk control strategies include a cyclical process of assessing a risk treatment, deciding whether residual risk levels are tolerable or not, and if not tolerable generating a new risk treatment, and assessing the effect of that treatment until the residual risk reached complies with the organisation's risk criteria (ISO, 2009). The model is one of a thermostat which adjusts to changes in environment subject to given target temperature (Power, 2009).

The identification of appropriate risk mitigation measures requires a good understanding of why the hazard is likely to manifest and the factors contributing to the probability and/or the severity of its consequences (Ayres Jr. et al., 2009). Risk treatment options are not necessarily mutually exclusive, single options may not be appropriate in all circumstances, and risk mitigation may require the implementation of more than one measure. According to diverse authors i.e. ICAO (2009), The Institute for Risk Management (2002), and Ayres Jr. et al. (2009), risk control options could be:

- Risk avoidance by e.g. eliminating the activity that gives rise to the risk;
- Seeking an opportunity by starting or continuing with an activity likely to create or enhance the risk;
- Changing the nature and magnitude of likelihood;
- Changing the consequences;
- Reduction in the frequency of the hazard (barriers);
- Risk control by taking options and alternative actions that lower risk to an acceptable level;
- Risk transfer by e.g. shifting to or sharing the risk with another party or parties;
- Risk assumption by accepting the likelihood and consequences associated with the risk by choice, and
- Risk financing.

When discussing risk control strategies, it should not be forgotten that risks belong in the present. Usually, they are part of the operational context and therefore omnipresent in the workplace and operations. However, mitigation strategies should not only focus on present risks, wait until consequences of hazards materialise and then reactively address such consequences. They should also aim at proactively

containing the damaging potential of hazards in order to avoid future losses and ensure high reliable operations (ICAO, 2009).

2.3.6. Sensitivity Analysis

A company must be aware of the uncertainties involved in any risk assessment (Department of Urban and Transport Planning Australia, 2003). During the assessment process a number of assumptions have to be made, for instance with respect to the efficiency of certain measures, expected growth, future technological developments, displacement effects, hardware costs, etc. (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). The degree of uncertainty in such assumptions can be substantial. Therefore, it is important to perform a sensitivity analysis, as it defines boundaries within which the model is considered valid for use (Roelen, 2008). Sensitivity analysis is a method used to assess the uncertainty in the output of a model by measuring the variation in its outputs resulting from variation of individual parameters in order to identify the most critical issues and the degree of their impact (Saltelli et al., 2002).

The results of sensitivity analyses may indicate that more detailed investigation is required to reduce the level of uncertainty associated with assumptions made (Department of Urban and Transport Planning Australia, 2003).

2.4. Data

Data is an indispensable factor for reducing uncertainty and essential for measuring and managing risks (FAA, 2007). Apart from the methodology and structure chosen, risk analysis credibility depends on the quantity and quality of available data (Roelen, 2008).

2.4.1. Types of Data and Data Sources

Safety usually relies on lagging indicators (Mathis, 2009). Generally, it can be differentiated between numerical or statistical data and descriptive or qualitative data (Roelen, 2008). Embarek & Hadjadj (2010) divide input data in six classes: Plans and technical specifications, operations and process, substances and products used, frequencies and probabilities, policy and management, as well as history and environmental regulations.

Data can be obtained from a variety of internal or external sources. Investigation and reports of past occurrences or accidents provide material and information (Maragakis et al., 2009). Accident data has, however, one major drawback: the

relative infrequency of accidents reduces the statistical validity of accident determinants (Rose, 1990). This makes gathering data difficult as there are statistical problems associated with significant fluctuations in measured risk due to the random occurrence of small numbers of discrete events (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). Accident causation theories suggest that incidents and occurrences data are suitable alternative data sources (Roelen, 2008). Therefore, companies usually measure recordable rates e.g. number of occurrences, incidents and accidents, costs of safety-related expenses, etc. Based on ISO (2009) and ARMS (2010) further data sources are i.a. staff surveys, hazard reports, incident investigation reports, safety reporting, questionnaires, recording, safety and quality auditing, employees, external information, experience, feedback, observation, forecasts, and expert judgement, that besides numerical data also provide qualitative data.

Different data sources should be combined to ensure a comprehensive gathering of relevant information and form a coherent view of the situation. In this case, it is essential to use the same units of measurement and comparable data (Roelen, 2008). Whatever data sources used, the process for obtaining and processing data must be transparent and results must be traceable for third parties (Roelen, 2008).

2.4.2. Quantification

The purpose of quantification is to extract aggregated and useful information from collected data (Gosling et al., 2003). Data quantification is also required to use information in mathematical equations or models (Roelen, 2008). However, data quantification is challenging first, due to problems with the availability of historic accident and incident data and hereto-related implications. Second, the different categories of events recorded in databases makes it difficult mixing and comparing numbers to meaningful results or to develop meaningful risk metrics (Morton et al., 2006). Third, many elements e.g. human factors observations are often non-quantitative and expressed in plain text. In this case, the use of most data processing and analysis techniques may not be valid (Gosling et al., 2003). Fourth, perceptions are difficult to quantify. Perceptions alone are ungrounded metrics without a proper frame of reference from which appropriate actions can be determined. Besides, perceptions can be inaccurate and highly volatile (Mathis, 2009). Finally, it is difficult to develop clear anchor points for a qualitative scale or finding relevant proxy variables (Roelen, 2008).

Risk measurement and management is not an exact science. It involves several aspects of difficult quantification that are decisive for risk analysis e.g. impact of organisation and management on safety performance and dependencies between risks. Experts' knowledge can be used for assessing variables for which other adequate data are lacking (Roelen, 2008). Yet, this may increase the risk of introducing additional variability and uncertainty in results of the evaluation process.

In order to simplify or generalise complex conditions, risk related indicators are often consolidated to tallies, ratios, or other manipulations of numbers. However, consolidation of numbers may induce errors, e.g. taking the average of two data sets might make the result more statistically correct, but in some cases two dubious numbers are taken to produce a third dubious number without significance (Morton et al., 2006).

Quantification of the occurrence rate of certain events requires not only a counting of the number of event occurrences, but also one associated number of attempts (Roelen, 2008). Accident counts by themselves cannot be reliably used to measure relative safety among organisations or departments. All conditions being equal, a larger organisation could be expected to have a large number of accidents than a smaller organisation (Wells & Rodrigues, 2003). When the objective is quantification, non-event data is as important as event data (Roelen, 2008).

Although quantifiable data is essential for the measurement of risks, qualitative data is at least equally important and has to be considered by analysts.

2.4.3. Resulting Data or Output

Information has to be collected, managed, and analysed. Data has to be classified, consolidated to results and analysts have to discover patterns and extract lessons learned to identify emerging issues and support decision-making processes (Gosling et al., 2003). Prerequisite hereto is a consistent data quality and a structured database (Ayres Jr. et al., 2009; ARMS, 2010).

According to ICAO (2009), data evaluation can be supported by diverse methodologies e.g. statistical or trend analysis, normative comparisons, simulation and testing, and expert panels. However, pure data analysis is not enough. Experts' judgement is indispensable to decide whether an occurrence or situation poses a potential threat and to relativise results (Morton et al., 2006).

Roelen (2008) cautions that results of data analysis are only approximations of reality and probabilities are used to express the resulting uncertainty. Approximations introduce an error term and error propagates when used further. The outcome will be increasingly uncertain when more cause-effect relations are called upon, classically when predictions are made further into the future.

Before presenting results to e.g. decision-makers, it is essential identifying the audience and the type of analysis or presentation adequate to it. Depending on the availability of input data, requirements, and on user's expectation appropriate methods to the situation should be selected (Embarek & Hadjadj, 2010). In order to increase the reliability of outputs, decision makers should be made aware of any limitations of the data modelling used or the possibility of divergence among experts (ISO, 2009).

2.4.4. Problems and Sources of Failure

Data collection is a critical activity. It requires significant efforts and resources (Roelen, 2008). Companies face manifold challenges with regard to data collection and analysis. I.a. data collection may not be complete and comprehensive enough due to e.g. possible underreporting or information hoarding within business units (Gosling et al., 2003). This can hinder timely exploitation and prevent companies from forming a coherent view of the situation (Brown et al., 2011). This can be exacerbated by inadequate attention to maintaining the data (ICAO, 2009). Moreover, not all recorded data might be reliable as humans are subject to bias in judgement, especially, as most data is usually not specifically collected for risk or safety evaluation (Morton et al., 2006). Unambiguous reporting always requires careful definition and a common understanding of words and terms (Morton et al., 2006). Shortcomings in data availability, consistency, and organisation can be avoided by establishing a consistent terminology, written procedures that define who will collect the data, the means for collection, specific procedures, and who will receive the information (Ayres Jr. et al., 2009).

The use of accidents and incident statistics is limited because they focus mainly on mistakes made and they fall short on measuring important soft factors such as employee satisfaction and management trust (Ryan, 2009). Moreover, accidents or incidents statistics are scarce, nonexistent or transient because of the randomness in the data resulting in uncertainties in quantifying risk (Stewart & Mueller, 2008). Accident/incident reports information is also often provided in form of free and not always unambiguous text (Roelen, 2008). It has to be considered, that not all

exogenous parameters influencing trends may be found in a database. However, determining the cause of a trend is the critical element for defining effective corrective actions (Ayres Jr. et al., 2009). Therefore, the use of historical analysis alone can be particularly misleading, especially as it only allows limited inferences on the future (Roelen, 2008).

Although quantification and simplification facilitate the analysis of complex issues, risk analysis should not rely exclusively on manipulated numbers. Quantification does not in itself reduce risks. Risk analysis does not without the assessment of each event for lessons (Morton et al., 2006). However, finding proper experts to assess and evaluate databases is not always easy and expert elicitation can be a time consuming activity (Roelen, 2008).

Statistics are sometimes beyond the evolution of the practitioners, with certain terminology meaning little to the people actually using or inputting the data (Morton et al., 2006). Sometimes, there is lack of talent and analytical skills of people handling big or complex data (Brown et al., 2011) and the lack of transparent and easily comparable data further affects the identification of problems and potential causes (de Bruijne et al., 2005).

It has to be considered, that safety is a dynamic concept and data has a strong temporal and contextual sense (Huang, 2009). A system change may alter the systems' characteristics to such point that the original ratios of accidents and incidents may no longer apply (Morton et al., 2006). The lack of information, uncertainty or knowledge of the causal and temporal interconnection of events or data cannot be compensated by mathematics or methodologies (Roelen, 2008). Although data may provide a clear basis for decisions and argumentation, according to ICAO (2009), data users and analysts should understand its limitations, know the purpose for which the data is gathered as well as the credibility of the information entered by the organisation that created and maintains it to make meaningful use of data analysis results and avoid unsupportable conclusions and decisions.

2.5. Choice of Methodologies

In an attempt to reduce risk and support the complex subject of measuring and managing risks, diverse methods and scientific techniques have been developed to assess potential risks, predict the possibility of occurrence of failures, reduce personal bias, and attempt to minimise the consequences of risks (Embarek & Hadjadj, 2010). However, facing this manifold choice, it is often difficult to find the most appropriate

methodology for a specific situation that allows the management to obtain the most complete and beneficial result. This chapter evaluates methodological approaches presented by contemporary literature to assess and manage risks.

The risk management approach is highly dependent on data quality, applied methods, and experience levels of handling persons (Embarek & Hadjadj, 2010). The need to manage and analyse ever-larger amounts of data require the use of increasingly sophisticated methodologies and tools. These should help analysts to discover patterns, estimate realistic consequences of risk, associate these estimates with probability, and extract lessons learned in order to identify emerging safety issues and support decision-making (Gosling et al., 2003).

According to diverse authors, inter alia Rasche (2001), Kazemi (n.d.), ISO (2009), Embarek & Hadjadj (2010), and Adebisi et al. (2007), methodologies and techniques may be either qualitative, semi-quantitative, quantitative or a combination of these depending on the circumstances.

Quantitative methodologies

Quantitative methodologies or methods based on statistical analysis base on evaluating the frequency, severity, and economic loss related to risks. They involve the calculation of probability, and sometimes consequences, using numerical data where the numbers are not rank but rather "real numbers" (Joy & Griffiths, 2007). Fully quantitative methodologies tend to be quite complex, since they take into account of a large number of variables (Department of Urban and Transport Planning Australia, 2003). The use of quantitative techniques requires a disciplined approach to recording and interpreting incident, accident, and maintenance information to provide accurate and auditable inputs (Rasche, 2001). Quantitative methodologies base on systematic processes, which allows for traceability and further analysis (Maragakis et al., 2009). As such, they offer the opportunity to be more objective and analytical than the qualitative or semi-qualitative approaches (Joy & Griffiths, 2007). According to Joy & Griffiths (2007), quantitative methodologies, although exhaustive and detailed, are clearly not foolproof. They have two primary shortcomings: one is the misleading output when the selection of failure statistics is not well considered and the other is the fact that much of the decision-making in the risk assessment is inevitably done by an expensive and not always available consultant due to the required expertise. Furthermore, quantitative techniques have been disappointing in application to management and cognitive complex human control activities (Adebisi et al., 2007).

Qualitative methodologies

Qualitative methods are often used first to obtain a general indication of the risk level and to reveal the major risks (ISO, 2009). They base on evaluation of the potential system of risks and increasing of hazard severity (Adebiyi et al., 2007). Qualitative methodologies are heuristic processes based mostly on expert judgement (Maragakis et al., 2009). They are often used where risks do not lend themselves to quantification or when sufficient credible data required for quantitative assessments are either not practicably available or obtaining or analysing data might not be cost-effective (Samad-Khan, 2005). Qualitative methodologies often allow identifying and assessing hazards and risks that other approaches cannot register and is often the only way to measure and manage risks in advance of accidents or to indicate behaviour related issues (Krause & Hidley, 1989). Quantitative techniques are comparatively cheap and readily applied but are unable to provide numerical estimates and therefore relative ranking of identified risks (Rasche, 2001). They usually are less accurate and transparent due to the crudity of the measures used (Joy & Griffiths, 2007).

Semi-quantitative methodologies

Semi-quantitative methodologies based on a combination of data and expert input allow some relative ranking, but these techniques are still unable to provide detailed assessments of systems safety, effects of common cause failures and redundancy features (Rasche, 2001). Semi-quantitative methodologies, in addition to containing all the elements of qualitative methodologies, include sufficient quantification of risk contributors to demonstrate that all relevant risk criteria will be met (Department of Urban and Transport Planning Australia, 2003). They attempt to match the thoroughness of qualitative methodologies in identifying all of the failure modes but then ask a series of "bite sized" questions of a representative site/engineering team to establish the risk value (Joy & Griffiths, 2007).

There is a continuum of risk modelling methods that vary in their relative reliance on historical data versus expert input (Shah, 2002). Each method has advantages and disadvantages over the others and requires varying skill levels.

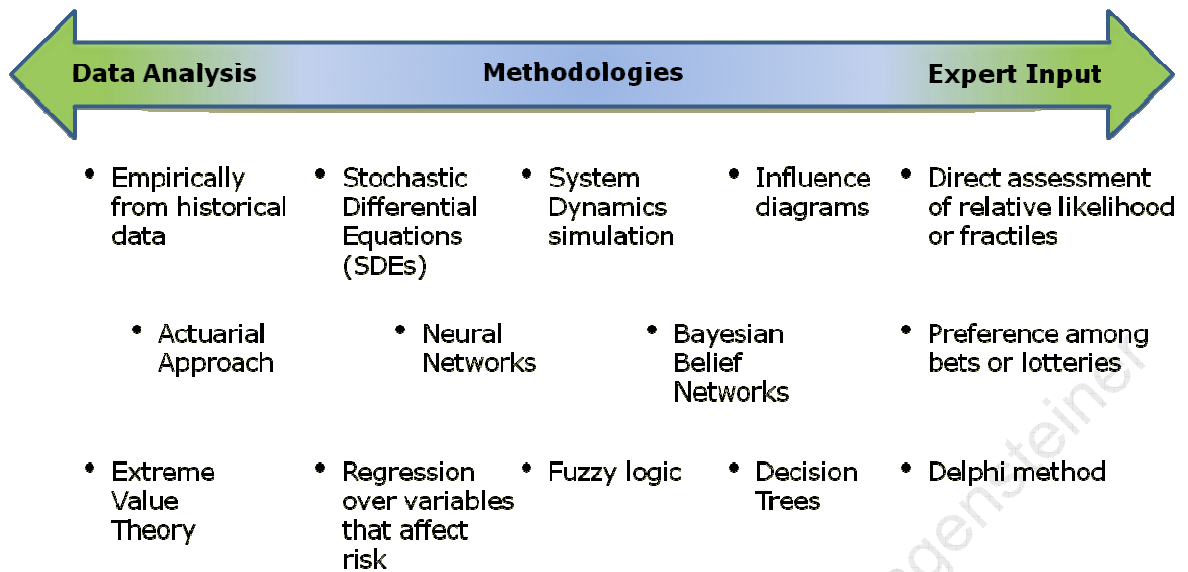


Figure 5: Examples of Different Methodologies according to their Classification based on Shah (2002)

When possible and appropriate, quantitative methodologies should be applied as they bring more precision and are used in more complex activities (ISO, 2009). Petersen (2005) even alleges that qualitative judgements alone are apt to be grossly incorrect. Nevertheless, it is essential that guidance and reasons for applying certain methodologies are given in a traceable and understandable way in order to ensure an effective use and appreciation of the risk assessment (Joy & Griffiths, 2007).

Modelling techniques need to be flexible enough to consolidate knowledge fragmented across many experts (Shah, 2002). A composition or combination of different methodologies enables the company to achieve more complete and profitable results (FAA, 2000). However, based on Slovic (1999), the choice or combination of choices can make results look either more or less risky. The choice of the most appropriate methodology depends on the scale, complexity, and scope of the system to be analysed as well as on the availability of basic input data and type of results needed or expected (FAA, 2000). Furthermore, it depends on the operation type, user's involvement level, domain knowledge, and point of view (Roelen, 2008). The choice of methodologies should reflect the need for precision and the culture of the business unit (Samad-Khan, 2005).

One single methodology cannot be used to answer all questions. Results from a single methodology always provide room for interpretation. It is just one way of looking at reality; there may be others that are different without being necessarily

wrong (Roelen, 2008). According to diverse authors, when choosing or applying a methodology, it should be considered that:

- Methodologies involve numerous assumptions;
- Most methodologies can only be used by specialists or skilled people;
- Methodologies might not be suitable to day-to-day operations and different methodologies require different amounts of resources;
- Methodologies assemble information from different disciplines;
- The application of methodologies assembles current knowledge;
- Meanings of terms used should be equally understood by those using the methodologies and by decision makers;
- No methodology can systematically anticipate typical human frailties/failures.

Methodologies offer the possibility for a systematic approach that can assist with key decision-making (Joy & Griffiths, 2007). Nevertheless, the chosen method must be appropriate to the situation as well as be objective and transparent, so that different persons analysing the same data on different occasions should obtain the same results (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). Results have to be reproducible, and should be expressed as far as possible in objectively quantifiable units.

The effective use of methodologies and tools is not a simple or inexpensive matter. Staff will need to be trained in the use of the tools, and given enough opportunity to use them regularly to retain proficiency in their use, which may well require an increase in staff numbers (Gosling et al., 2003). Methodologies and tools have to suit or be adapted to user's needs, capabilities, and operational context as well as be able to interface with the company's data management systems (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001). Finally, it may be necessary to adapt the data reporting system and the company's reporting culture. Ultimately, the decision of how many resources to invest into enhanced data analysis involves a judgement that balances the increase in cost of the risk management process against the reduction in the risk of an accident (Gosling et al., 2003).

Literature suggests that methodologies can also be classified according to the phases of the risk management process or according to the expected deliverables or objectives or be divided in empirical, statistical, and empirical and statistical simultaneously. However, many methodologies, tools, and techniques are not exclusively created for a specific phase of the risk management process or for a certain objective and can be used in more than one phase or to reach one or more

objectives. Reporting and discussing the details of methodologies, tools, and techniques available would exceed this work's frame. A choice of methodologies, tools, and techniques with a short description as well as strengths and weaknesses are presented in annex 2.

2.6. Challenges of Risk Management

In theory, risk management has developed over many years into a mature discipline with defined processes and diverse methodologies. Nevertheless, businesses are often deprived of the expected and needed benefits, despite the theoretical principle that risk management contribute to business success (Hillson, 2006). This chapter addresses common challenges and pitfalls of risk management.

Usually, risk management deals only with uncertainties with potentially adverse affect, i.e. threats, neglecting the existence of opportunities related to risks. Comprehensive risk management should not only focus on the negative connotation of risks and on general minimisation of risks, but rather critical question of the risks taken in comparison to the corresponding chances or opportunities (Barodte & Fischer, 2009). Risks should be taken intelligently, with full awareness of the degree of uncertainty and its potential effects on objectives in order to achieve the increased rewards associated with safe risk-taking (Hillson, 2006). However, it is usually difficult to escape the threat-focused mentality associated with traditional approaches to risk management (Hillson, 2002). Process modifications e.g. introducing SWOT analysis, constraints or force field analysis might be appropriate to encourage opportunity identification alongside threats; yet, different response strategies are required for opportunities (Hillson, 2006).

The risk management discipline has sought to formalise risk assessment in an attempt to reduce the effects of personal bias (Smith & Elliott, 2006). Yet, it has been argued that any attempt to objectivise or quantify risk will fail because no matter the degree of sophistication of the mathematics all risk assessment is inherently value laden (Toft and Reynolds, 1992). Nevertheless, a structured approach to risk management may be better than none; however, a good understanding of the aims and objectives of such a process is more important than detailed statistical knowledge (Smith & Elliott, 2006).

Operational risk management is often seen as an independent and separate discipline and is seldom integral part of operational processes (Barodte & Fischer, 2009). Risk management should be an integral part of operations and be consistent

throughout all hierarchical levels. A clear relationship between the different levels of the risk management process should be ensured. Hillson (2006) states that risk should be managed proactively in all hierarchical levels in order to deliver benefits. This requires use of shared language and definitions, a common risk process framework, a supportive risk-aware culture, and ensuring that staff at all levels are committed, competent, and professional in their risk management approach (Hillson, 2006).

Risk management should not concentrate on predicting extreme events or perpetuating the illusion that future can be anticipated (Taleb et al., 2009). By focusing on few extreme scenarios, other possibilities may be neglected, other risk types may be overlooked or even new risks may be created and thus the system may become more vulnerable (Stulz, 2009). Risk management should be about lessening the impact of not understandable and predictable threats to reduce the company's vulnerability to risks.

Risk management modelling usually bases on extrapolating from the past to forecast the probability that a given risk will materialise. Doing so, concealed risks are often overlooked or not reported (Stulz, 2009). This approach reveals broad tendencies and recurring patterns, but in a dynamic environment, it cannot make reliable predictions (Bhidé, 2010). Risk managers often mistakenly use hindsight as foresight (Taleb et al., 2009). Besides analysing past data, effective risk management requires i.a. making extremely good judgement calls involving data and metrics, having a clear sense of how all the moving parts work together, and communicating them well (Stulz, 2009).

Many risk managers rely on quantitative models to measure risks. However, for all their econometric sophistication, statistical models are ultimately a simplified form of history (Bhidé, 2010). Statistical models and algorithms have value under certain circumstances, but when misused, poorly understood or overused they can be dysfunctional as they do not consider the uniqueness of events (Bhidé, 2010). Looking for a single number to represent risks is inviting disaster (Taleb et al., 2009). Moreover, what is measured is not identical with stakeholders' risk perception. The way risk is framed and presented influences people's understanding of it and their risk awareness more than just any figures (Taleb et al., 2009).

As businesses have become more complex, dynamic, and interdependencies have increased, managers have struggled to maintain control and make decisions under

uncertainty. Using enterprise data warehousing and data mining has substantially increased the amount of data available to managers. However, the amount of data has not significantly increased their understanding of the enterprise wide business dynamics (Shah, 2002). Managers have responded to this development by becoming more specialised and by developing a much deeper understanding of their domain. However, simultaneously they lose sight of how their domain interacts with others (Shah, 2002). Managers have to look at the whole picture and act in real time to face these challenges (Stulz, 2009).

Finally, to work effectively and to access the business benefits praised by literature, risk measurement and management requires commitment from the organisation's executive management, the assignment of responsibilities within the organisation, the allocation of resources for training, and the development of enhanced risk awareness by all stakeholders (The Institute for Risk Management, 2002). Communication is an important issue to involve stakeholders and gain promoters. Risk management systems provide little protection if risk managers do not communicate clearly (Taleb et al., 2009). The best, most complex and expensive risk management systems can induce a false sense of safety/security and lead to bad decisions when their output is poorly communicated to top management (Stulz, 2009).

The best methodology and the best risk management process are chanceless if these challenges are not mastered.

2.7. Summary

The literature research has shown that measuring and managing risks are a complex and comprehensive subject with many underlying theories and philosophies. Although, there is no consensus in literature with regard to the different concepts and processes, there are many arguments supporting the implementation of a systematic and comprehensive risk management process. Literature agrees that risk measurement and management are indispensable business elements and important sources of business value.

Besides the definition and implementation of a structured risk measurement and management process, risk management also involves ethical considerations, individual perspective and perceptions as well as considerations of the company's risk appetite and acceptance. The exploitation of the benefits of the risk measurement and management process depends on the implementation of a systematic, flexible,

and comprehensive process. Yet at the end, risk management remains a matter of trade-offs with regard to the risk treatment strategies.

Companies face a wide choice of quantitative and qualitative methodologies to support and facilitate the risk measurement and management process. However, despite the manifold choice of analytical methods, risk management is still subjective and value laden due to the different assumptions made during the process. Data, methodologies, and expert judgements promote the objectivity and determine the quality of the risk measurement and management process.

Nevertheless, measuring and managing risks is challenging as data issues are complex, appropriate methodologies are not easily chosen, and the risk management process is confronted with considerable pitfalls.

There is no doubt that measuring and managing risks and therefore, increasing safety is resource intensive. Still, literature agrees that the benefits outweigh the costs and provides many approaches that can contribute to improve the efficiency of an operative risk measurement and management process.

Extract of Master thesis EMBA China Klingenstein

3. Approach and Limitations

This chapter describes the process of data collection and analysis. Furthermore, this work's scope is defined, assumptions are presented, and the limitations of this work are outlined.

3.1. Data Sources and Analysis

A hallmark of research is the use of multiple data sources, a strategy that also enhances data credibility (Baxter & Jack, 2008). Using multiple sources also help avoiding tunnel vision and ensures construct validity (Stuart et al., 2002). For this study, several information sources are used: literature research, structured interviews, analysis of information material and documents, observation, and use of quantitative data. The data for the analysis is taken from various internal and external sources.

Therein, interviews provide the possibility to gain insights and access expert knowledge in measuring and managing airside operative risks at FRA. The interviews' aim is to learn how operative safety risks are presently being measured and managed at FRA as well as the reasons for adopting or adjusting these approaches. This knowledge is supplemented by document research and to a certain extent by the researcher's observation.

The interviews are face-to face and open-ended. The researcher is aware that there may be some sort of distraction by taking notes while interviewing and a personal connotation or bias may be involved when translating the interview.

Once the research material is brought forth, it has to be analysed by means of comparative analysis (Verschuren, 2003). Deviations from theoretical approaches do not automatically mean that the approach adopted is a wrong one. Nevertheless, research results may provide ideas and discover improvement or optimising potentials.

3.2. Limitations of Case Studies

Case study based research is often criticised. Stuart et al. (2002) for example state that they are only useful for explanatory research and lack rigor. Case studies offer little basis for scientific generalisation because of the inherent subjectivity and since they are based on qualitative subjective data, as usually only a single subject is examined (Zainal, 2007). Yet, measuring and managing risks is highly dependent on the respective context and environment so that findings are either way, unique and

not easily transferable. However, the transferability of findings is not within this work's discussion and is recommended for future research.

Critics claim that the process of preparing case studies takes too long and report only the researcher's conclusions. The analysis and presentation of case study data is subject to more risk of researcher bias and to bias introduced due to inter/intra-organisational political processes than other research strategies (Schell, 1992). In this work, personal bias cannot be neglected or completely avoided. However, this is the most indicated way to explore the complexities of real-life situations that may not be captured otherwise.

Interviewing only a small group of persons also bears some risks. Research has shown that personal interviews are often influenced by sympathy, antipathy, and prejudice (United Nations, 1997). Interviewers can also influence results by the way they phrase the questions (manipulation by actors) (Schell, 1992). However, structured interviews can be seen beneficial as they provide insight information and interviewees report on personal experience. Simultaneously, there are some advantages such as flexibility to discover, address, and explore issues as they arise in the progress of work.

The researcher is aware of the limitations of the results presented and conscious that further fields for analysis may be necessary to assess all aspects of measuring and managing risks. Nevertheless, this work provides an insight in measuring and managing airside operational safety risks at FRA that otherwise would not become accessible. Despite the mentioned limitations, the single case study can be considered the appropriate approach for this research, as it enables the researcher to gain insights into the case, to understand practical approaches, and to validate theoretical approaches in real-life context.

3.3. Limiting the Scope and Assumptions

Although literature covers different types of risks, this project is limited to measuring and managing airside operational safety risk at FRA in its present context and configuration. It focuses on strategic aspects of the operational airside safety risk measurement and management process not aiming on detailed description or mathematical analysis and statistics. In the context of this work, operational safety is defined as the protection of the airport operations against potential risks of operational and technical nature (Kühn, 2010). Aviation security and occupational health as well as other participants of the aircraft handling process at airports e.g.

airlines and ATM are not considered in this study. Other Fraport sites are also not subject of evaluation. Findings cannot be generalised or transferred to other companies and no comparison can be made to other airports. The potential success of the provided recommendations is also not addressed by this project.

Risks resulting from unlawful acts or military intervention are not taken into account because information on this subject is not disseminated. Only risks in Fraport's direct sphere of influence are considered, although the author is aware that Fraport is also responsible for a multitude of subsidiary processes. The interactions with the different parties on the FRA site are also not considered.

As within Fraport primarily the respective organisational unit measures and manages the respective risks, it is not within the scope of this study nor the author's responsibility to conciliate methodologies or approaches recommended here with Fraport's strategic risk management approach.

The researcher is aware that absolute safety cannot be achieved by risk measurement and management, neither that one identified methodology fits all needs. Risk analysis has explanatory and predictive power to support decisions, but users must be aware of the approach's limitations. This work can only deliver recommendations that should be further exposed to intelligent debate, criticism, and amendment by stakeholders and experts involved in the measurement and management of airside operational risks at FRA.

Extract of Master thesis MPA Christa Ringensteiner

4. Frankfurt Airport

This chapter introduces Frankfurt Airport in its actual business context and introduces Fraport's SMS in a shortened version.

4.1. Frankfurt Airport

Fraport is an airport managing company. It provides airport infrastructure and all services related to airport operations. Prior to its privatisation in 2001, Fraport was a government-owned organisation. As a privatised company¹⁰, Fraport still has many public service structures and operates in a strongly regulated and highly specialised environment that affect strategy and operations. Fraport's core business is the management of its headquarter site Frankfurt Airport (FRA), Germany's biggest airport (Fraport, 2011). In March 2011, FRA ranked third in Europe (after London-Heathrow (LHR) and Paris-Charles de Gaulle (CDG)) and ninth worldwide in the number of total passengers (Fraport, 2011).

According to Fraport's "Facts and Figures" (2011), FRA is served by 114 airlines flying to around 300 destinations in 110 countries worldwide. With more than 53 million passengers, 464,000 aircraft movements, and 2.2 million metric tons of cargo handled in an area of only about 21 square kilometres Fraport generated € 2.194 billion revenue and group profits of € 271.5 million in 2010. Frankfurt Airport is Germany's largest employment complex with more than 500 companies and 71,000 employees. Fraport alone employs nearly 12,000 people at FRA.

The demand for airport services is directly correlated to the air traffic volume. Fraport reports an almost continuous growth trend since 1950. Boeing is forecasting a market growth rate of 3.3% for the world economy and an airline traffic growth rate of 5.1% (RPK) from 2010 to 2030 (BOEING, 2011). This data suggests that traffic will continuously increase at FRA.

Challenges related to measuring and managing risks increase likewise as risk levels are expected to remain low despite prospering traffic. Frankfurt Airport's market environment is characterised by a strongly regulated market with increasing challenges in the field of the social, environmental, and technological developments (Annex 3: PEST analysis).

¹⁰ However, still mainly owned by the state of Hesse and the city of Frankfurt (51.6%) (Fraport, 2009)

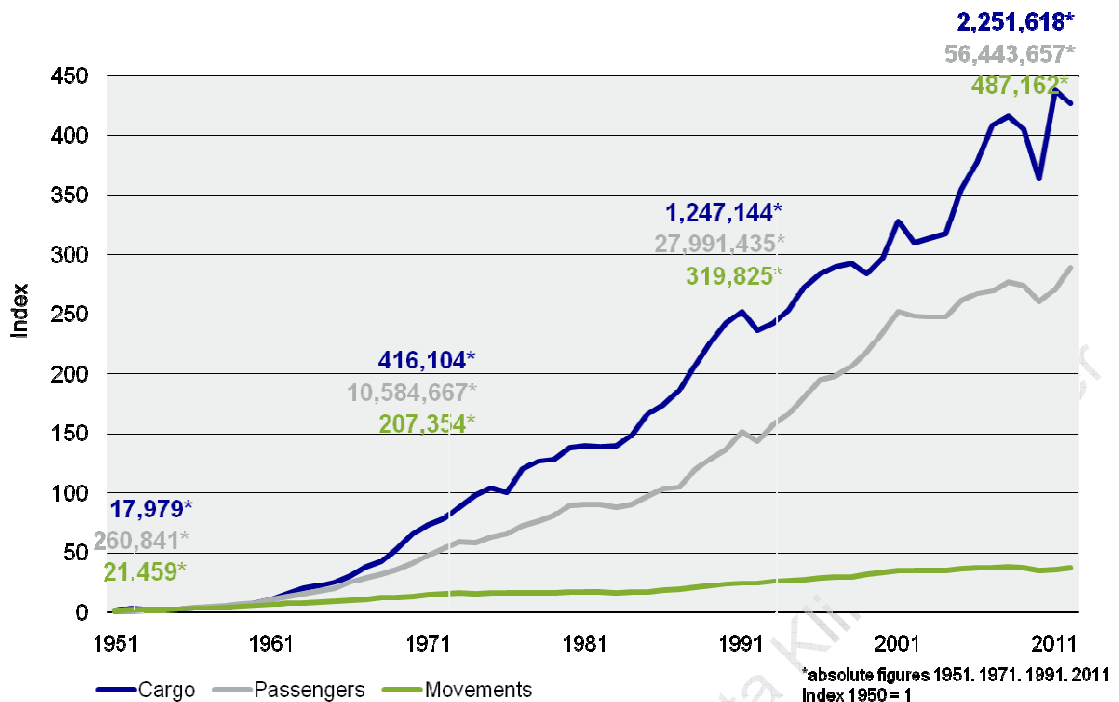


Figure 6: Fraport's Continuous Growth: Movements, Passengers, Cargo 1950 - 2011 (Fraport, 2011)

The management of Frankfurt Airport is characterised by high process complexity and process interdependencies both within and outside the company, requiring the management of numerous interfaces. Fraport's safety risk management interacts and simultaneously affects many other companies and vice-versa.

4.2. Fraport's Organisational Structure and Strategic Risk Management Approach

Fraport is divided in four main strategic business units: Aviation, Ground Handling, Retail & Properties, and External Activities as well as three service units and twelve central units (Annex 4). The service units carry the interdepartmental service and support functions for the individual business divisions. The central departments are responsible for intradepartmental central tasks within the company (Fraport, 2011).

Following Fraport's Annual Report 2010, the Aviation segment - the department mainly affected by airside operational safety risks - with its 6,074 employees produced revenue of € 693.9 million in 2010. Aviation's revenues represent 31.6% of Fraport's total turnover and 18.5% of Fraport's EBITDA.

Fraport states in its vision that safety and security are its top priority. According to Fraport's Annual Report 2010, the company sets itself clear objectives for

strategically important issues and defines measures required to achieve them. These have been summarised in a sustainability program and were adopted by the Executive Board in 2011. The strategic sustainability program assigned to the central unit "Sustainability Management & Corporate Compliance" is based on the materiality matrix shown below:

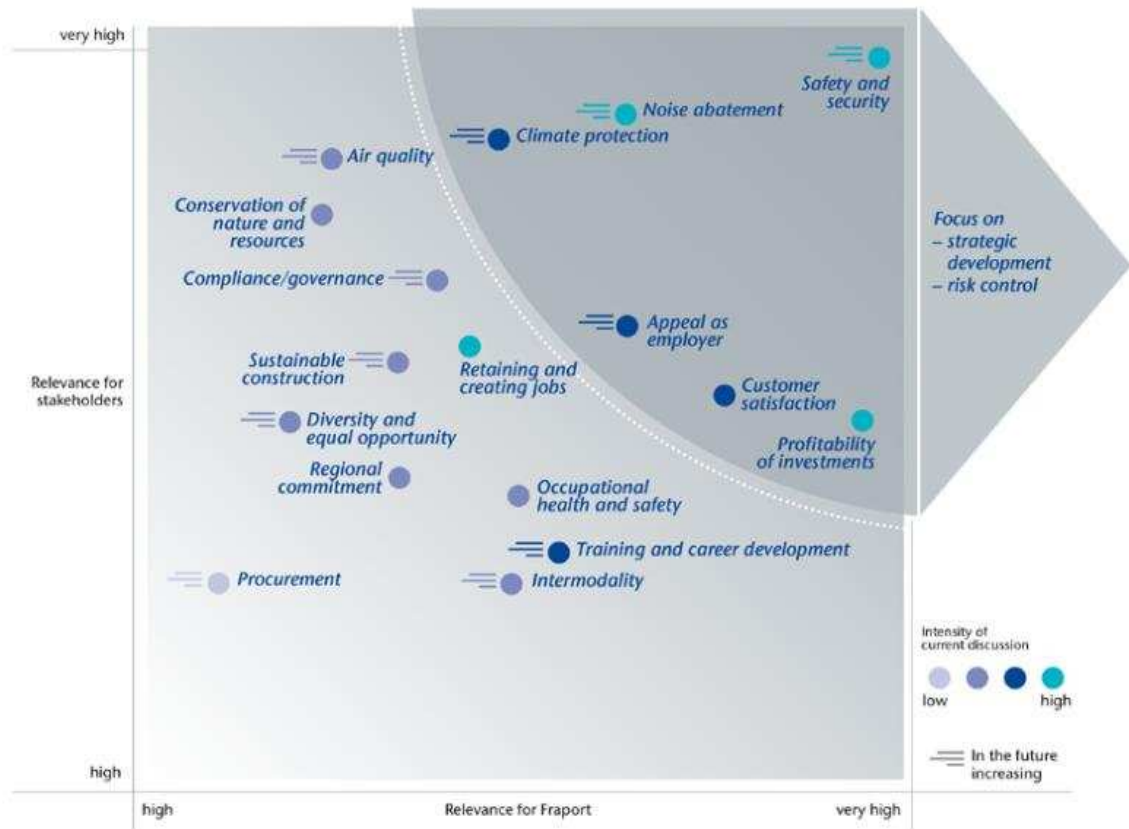


Figure 7: Fraport's Materiality Matrix (Fraport, 2011)

The materiality matrix presents relevant issues for Fraport and its stakeholders, also indicating how much importance is being presently attributed to the respective topic. Safety in airport operations is the top priority issue in the matrix.

According to Fraport's Annual Report (2010), Fraport actively seeks out opportunities and seizes them whenever the potential benefits of doing so are in an acceptable balance to the risks involved. Controlled risk exposure is the primary objective of Fraport's strategic risk management system (Fraport, 2011).

According to Fraport's Annual Report (2011), the company has adopted the following risk principles:

- The risk strategy is coordinated with the corporate strategy and is required to be consistent with it, as the strategy specifies to what extent the company's operations are exposed to risks;
- Risk management is integrated into ongoing business processes;
- Risks are managed primarily by the organisational units which operates locally;
- The aim of the risk management process is to ensure that significant risks are identified, constantly monitored, and limited to an acceptable level;
- Actively and openly communicating risk is a major success factor in the risk management system;
- All of Fraport's employees are expected to actively participate in risk management in their area of responsibility.

Risk reports are collected from the divisions and are evaluated by a Risk Management Committee that evaluates Fraport's risk situation at company level based on a "risk map". Risks that may jeopardise the company as an ongoing concern or risks that exceed defined thresholds in the potential damage they may cause and in the probability of their occurrence are considered to be material and are reported to the Executive Board (Fraport, 2011).

Airside operational safety risks are categorised as "Other Risks" and are cited by the Annual Report (2010) as follows: "Operations in Frankfurt may be affected by local events such as accidents, attacks with a terrorist intent, fires or technical malfunctions as well as events that influence the operation of the national and international air traffic (such as natural disasters, extreme weather events and epidemics). Fraport's insurance policy covers the standard risks faced by the airport companies. It includes occurrences of damages that result in the loss or damage of assets, including any consequential business interruption costs as well as claims for damages by third parties arising from Fraport's corporate liability risks."

These elements as well as diverse regulations and law prescriptions provide the framework for Fraport's SMS and for the management of airside operational safety risks at FRA.

4.3. Frankfurt Airport's Safety Management System

SMS's purpose is to ensure operational safety for airport operations and for the services associated with it under compliance with relevant regulations and laws (Kühn, 2010). The responsible manager for Fraport's Safety Management System

(RMSMS) and his team employees report that SMS is i.a. responsible for the safety risks management system, collecting and analysing safety risks related data, issuing safety recommendations when risks are detected, monitoring corrective measures and assessing their effectiveness as well as regularly reporting on the development of operational safety at FRA (Kühn, 2010).

In accordance with ICAO's recommendations, within SMS risk to operational safety is defined as a potential source of damage, which harbours risks both when used as intended and with inappropriate use or in the event of an error which can result in personal injuries/fatalities, damage to infrastructure and equipment of the airport and/or damage of aircraft (Kühn, 2010). SMS encompasses mainly all activities in the airport's manoeuvring area (Annex 5). This area enfolds a multitude of high-paced activities that involve aircraft, vehicles, and individuals working in close proximity with one another (Wells & Rodrigues, 2003).

4.3.1. Reasons for Implementing a SMS at Frankfurt Airport

The responsible manager for the SMS reports that i.a. SMS has been implemented at Frankfurt Airport in order to comply with legal and regulatory requirements. Since 1987, when airports have begun to be privatised and evolve from public utilities to private enterprises concerned with making profit, ICAO¹¹ took steps to promote safety management as a prerequisite for a sustainable aviation business. In 2000, the ICAO Air Navigation Commission commenced the process to amend Annex 14, Volume I, *Aerodrome Design and Operations*. New airport licensing and certification requirements called for the development and implementation of a SMS. In July 2004, ICAO's Annex 14 provided that "aerodromes should have in operation a safety management system". In July 2009, the text was amended and "should" became "shall".

Up to the creation of the European Aviation Safety Agency (EASA) regulation of aerodromes had been a matter of each individual EU Member State by itself but underpinned by the ICAO Standards and Recommended Practices (Airport Business, 2010). In order to fulfil all ICAO specifications, the EASA was launched in 2003. It is a legally, administratively and financially self-governed EC agency (Stockmann & Wiener, 2008). On 21 October 2009, the EC Regulation 1108/2009 was adopted to extend the competencies of EASA to address i.a. safety of aerodromes as there were no pre-existing EU-rules for designing operational safety of aerodromes (EASA,

¹¹ The ICAO sets standards and regulations necessary for aviation for the 191 UN member states.

2011). However, EASA is not yet another regulatory level in addition to ICAO, but it primarily should ensure the execution of ICAO standards and recommendations in an efficient and effective way (Stockmann & Wiener, 2008).

The ICAO regulation and the EU directive have been transcribed into German law with the implementation of the 10th amended regulation of the Air Traffic Licensing Act¹² into national legislation as per 5th January 2007 (Fraport, 2010). Consequently, the implementation of SMS is mandatory since the German regulation¹³ became effective in 2007.

Fraport has followed ICAO's recommendation and has implemented a SMS in FRA on November 24th 2005. At the beginning, the Chief Airport Operations was also the responsible manager for the SMS in personal union. As quoted by the RMSMS, "To comply with German law, as per March 1st 2007, Fraport has to clearly divide respective responsibilities and competences". Since then, the safety management department exists in its present constellation - as an own support unit for the Senior Executive Vice President Aviation and as in-house consultant for all airside operational risk and safety related issues.

ICAO's Annex 14 requires the implementation of a SMS that at least identifies safety hazards, ensures that remedial action necessary to maintain an acceptable level of safety is implemented, provides for continuous monitoring and regular assessment of the safety level achieved, and aims to make continuous improvement to the overall level of safety (ICAO, 2009). According to ICAO (2009), SMS should encompass the assessment and mitigation of safety risks and consequences of hazards that threaten the capabilities of an organisation to a level as low as reasonably practicable (ALARP). The objective of safety risk management should be providing the foundation for a balanced allocation of resources between all assessed safety risks and such safety risks the control and mitigation which are viable (ICAO, 2009). These definitions and requirements apply to FRA's SMS.

The following ICAO documents refer to airport SMS:

- Annex 14, *Aerodromes*, Volume I, Aerodrome Design and Operations, Section 1.4, Certification of Aerodromes; Section 1.5, Safety Management that became applicable in November 2005 (mandatory).

¹² LuftVZO or Luftverkehrszulassungsordnung

¹³ Notice of appointment of a responsible manager for the SMS by the airport operator of 28.02.2007 to the responsible authority, the Ministry for Industry, Transport and State Development of the Federal State of Hesse

- Document 9774, *Manual on Certification of Aerodromes*, First Edition, 2001
- *Safety Management Manual (SMM) 9859*, Second edition, 2009.

The implementation of a SMS at airports is compulsory. However, the SMM has just reference character and is non-binding. Due to striking differences in national standards, the Safety Regulation in Europe is presently characterised by a framework yet to be filled. The SMS at FRA has been implemented to comply with national and international regulation.

4.3.2. Stakeholders

In order to identify requirements that affect the choice of risk measurement and management approaches it is essential to identify stakeholders playing a role in the strategic orientation of measuring and managing airside operational safety risks at FRA. Actually, all parties working or visiting Frankfurt Airport are SMS stakeholders at different degrees.

There are stakeholders with considerable influence on the risk measurement and management process. Main stakeholders are on one hand, regulatory authorities such as ICAO, EASA, and HMWVL¹⁴ that prescribe the management of airside operational risks to an ALARP level and define the respective requirements. On the other hand, there is the service provider represented by the management and operational departments with its organisational structures, implemented responsibilities, as well as operational processes and culture.

Decisive stakeholders for the risk measuring and managing process are the senior management and all operative departments as they influence the process by providing necessary resources and supporting structural developments. Moreover, they play an important role in the risk management process itself. They both influence the overarching strategy of risk management and are influenced by the results and the way risks are measured, managed, and communicated. Their risk awareness and acceptance directly affect the way the risk measuring and management process is framed.

Employees are equally important as they have interest in the reduction of risks and are expected to actively participate in risk management. The RMSMS reports that employees are both determinants and contributors to the risk measurement and management process. The identified stakeholders affecting or being affected by risk measurement and management process are for example:

¹⁴ Ministry for Industry, Transport and State Development of the Federal State of Hesse

- Institutions and external stakeholders: trade unions, lobby groups (e.g. ADV, ACI, IATA etc.), competent airport authorities (e.g. BMVBS), insurance companies;
- Companies working within FRA's boundaries: airlines, ATM Providers, ground services companies, contractors;
- Stakeholders within the company: management, strategic risk management department, press unit, operations;
- Society and others: public, passengers, media, rail, people living or working at the airport's vicinities.

Differing interpretations and diverging opinions may arise due to stakeholder's individual interests and risk perceptions. SMS faces the challenge of balancing and reconciling stakeholder's different interests in the risk measurement and management process. The RMSMS states that SMS implementation at airports is actually a change management process and has to be managed as such. Therefore, communication is an indispensable element to combine the various interests and avoid conflicts that may hinder the process.

4.3.3. Responsibilities, Objectives, and Requirements

According to §108 LuftVZO, SMS non-implementation, meaning the non-compliance with German law, could lead to a fine and in last consequence to the loss of Fraport's operating licence.

There are no mandatory guidelines, requirements or specifications with regard to the organisation and configuration of measurement and management of airside operational risks yet. ICAO provides the above mentioned framework and the already mentioned definitions as well as prescribes to reduce risks to ALARP level, but there are no prescribed processes neither a definition of "reasonably practicable". However, ICAO works on basis of Standards and Recommended Practices (SARPs) with a strong recommendation character. SARPs set the standards in the civil aviation industry.

According to Kühn (2010), the RMSMS has the safety program oversight. He bears no operational responsibility. SMS has to be impartial and independent. German law defines the safety management department as an in-house consultant for safety and risk related issues. Based on ICAO, the RMSMS provides for SMS operation and evolution and advises the company's management as well as the process owners in all risks and safety aspects. With regard to risks, he is officially responsible for collecting and analysing data on operational risks, issuing recommendations when

risks are detected, monitoring corrective measures and assessing their effectiveness. The operative management, in turn, is responsible for the daily report management, investigations performed, and implementation of corrective action. The primary responsibility for operational safety is with the process owners. In case of concerns, process owners are called upon to develop, implement, and document measures to remedy them. Thus, diverse committees e.g. Safety Review Board or Ramp Safety Committee have been implemented in which the RMSMS takes part as advisor to ensure information exchange and stakeholders integration as information that enters the risk analysis and management process may and should be contested by different groups to consider different perspectives, raise awareness for risk issues, and ensure communication. The company's executive management has the responsibility to create the organisational, objective, and personnel conditions for the airport safe operating condition and its proper operation. The executive management is also officially responsible for setting targets and objectives as well as reviewing their attainment.

SMS's goal is to ensure operational safety for airport operations and for the services associated with it while complying with relevant regulation and laws (Kühn, 2010).

Extract of Master thesis EMBA Christa Königsmüller

5. Discussing Theoretical Findings

This work reveals that different risk measurement and management approaches exist within Fraport. While i.e. strategic risk management focuses on company's interest balancing opportunities and risks, SMS's risk approach reflects authorities' protective culture and philosophy, targeting on reducing risks to ALARP-level. Clearly, both approaches focus on different risk perspectives making a common approach not recommendable, but literature alerts that inconsistent terminology and concepts may foster misunderstanding and miscommunication. According to literature, differing definitions and concepts as well as focussing solely on the negative risk connotation could misguide the mindset of analysts and managers to look solely for problems, reducing so benefits related to controlled risk exposure. Hence, it is advisable to broaden the risk definition and consequently the whole process. No objections hereto are known as long as legal compliance is ensured. This should not automatically imply increasing risk level or decreasing safety level. It should rather broaden management's focus and ensure considering all risk relevant data as according to literature, a broad approach ensures comprehensive information collection, reduces uncertainties, and provides a more reliable basis for decision-making. Decisions related hereto will depend on the "risk game" being played. Yet, literature emphasises that a broad risk definition is essential for adding value to the organisation.

Literature alerts that by solely complying with regulations' minimal requirements the process' strategic value is diminished and that such an approach fails delivering advantages praised by literature (chapter 2.2.) reducing so the company's benefit. In face of the obligation to systematic manage airside operational safety risks and Fraport's interest for reliability and cost-effective operations, FRA should seize the opportunity to establish a state of the art process that is more than a technical-analytical or a compliance exercise. Literature findings recommend establishing a comprehensive and systematic process, e.g. an ERM based process, that could increase FRA's ability to forecast the future, widen the range of outcomes with which it is prepared to deal without surprise as well as reduce uncertainties and risks positively affecting the company's results and increasing competitive advantage. Such a process should be dynamic and iterative, able to identify and challenge existing assumptions within the company. Literature also proposes to consider implementing a holistic approach. Different disciplinary approaches should be taken into account and the process should be defined permeable enough to consider relevant facts outside the defined framework and implement it as a continuous risk management cycle as suggested in chapter 2.3. The process should also be progressive in character

accounting for systemic changes and environment complexities. Literature findings emphasise the importance of risk management activities being traceable and recorded as the process should be continuously evaluated and updated and such records provide the foundation for future process improvements. Due to airport's system complexity, implementing such an approach may be challenging. Yet, according to literature, such an approach could increase operations' reliability.

Research findings alert not to focus a process solely on easily observable and measured organisation facets. Accident causation theories could provide different approaches to help addressing underlying causal factors and considering all influential system factors. Working on basis of different accident causation theories in all process' phases could help addressing different risk aspects and facilitate recognising solutions. Different models should be systematically combined throughout the process depending on the question being addressed. However, literature calls attention to accident causations theories limitations (chapter 2.1.3). Literature findings suggest to minimise remaining process uncertainties by additionally applying market approaches e.g. market research or value chain analysis.

Including more pro-active elements and increasing cost/benefit awareness throughout the process could be advantageous e.g. improving process effectiveness or finding an appropriate risk/reward ratio for the airport. A more cost/benefit oriented approach could help to underline the process' economic relevance, facilitate risk prioritisation, and ensure efficient resources allocation. However, a CBA based approach should not be used to argue that it is acceptable to reduce existing safety standards. Addressing risk issues in a way that will result in a higher payback, allowing FRA to identify and address the highest priority needs and allocate resources accordingly could maximise safety investments effects.

According to literature findings, stakeholders' risk reward ratios as well as stakeholders' risk perception, appetite, and concernment are important process determinants. Literature research outcomes suggest that stakeholders' risk perception considerably influence the risk measurement and management relevance in managers' agenda. Therefore, managing them is important for the process' success. However, in some cases considering stakeholders interests reflected in perceptions and risk appetite could contradict ethical principles as well as ICAO's requirements and protective philosophy. Communication is an important element to involve stakeholders, gain supporters, and management commitment. When designing a new process, open and active communication to address stakeholders'

risk perception without tilting it toward distrust and implementing a culture of fear should be taken into account as it could contribute to the process' success.

The airport is a complex, interdependent, and multi-dimensional system, making a comprehensive "establishing the context" a challenging and time-consuming task. Yet, a risk management process should not be implemented without considering the context and existing framework. Without it, e.g. appropriate methodologies cannot be adequately chosen. Moreover, few or even no methodologies tailored to airports specific needs exist. Consequently, managers turn to approaches borrowed from other sectors to assess airport specific risks. In case the context and requirements are not defined, this could be a costly mistake. Airport's increasing integration, automation, and complexity demand a system specific approach as well as tailored predictive and monitoring methodologies. Establishing clear objectives, parameters, and requirements is indispensable hereto as it lays out the basis for the whole process and process related decisions.

Literature findings point out that a risk measurement and management process should embed a balanced mixture of quantitative and qualitative methodologies. However, many methodologies suggested by literature are complicated and demand highly specialised skills and knowledge (chapter 2.5. and annex 2). Although risk measurement and management is a potentially powerful instrument, as with all instruments, if it is not used with care and understanding, the outcomes may be distorted and constitute a poor basis for decision-making. The use of more easily applicable and understandable qualitative methodologies usually provides an adequate basis for risk identification and prioritisation. However, the level of assumptions and personal bias tend to increase the more qualitative approaches used. The question is whether and to what extent an increased accuracy of findings and reduced uncertainty level compensate for the needed investments and related costs e.g. employment of additional experts. Nevertheless, combining different methodologies and approaches is recommended to reduce assumptions level.

Literature agrees that data and data management play a considerable role in risk measurement and management. Since operational risks are endogenous, literature findings even advise to gather company-specific data to identify and analyse hazards and risks. Although, company specific data provides indispensable knowledge about the status quo and whether the situation is getting better or worse, literature findings emphasises that focusing on analysing historic data can be particularly misleading as it may not be representative of current and future risks. Furthermore, literature adverts

to problems and pitfalls, some of them addressed in chapter 2.4.4. Inappropriate data or database undermines and threaten the risk measurement and management process. To avoid problems with data, literature findings propose to establish a standardised, transparent, and reliable data collection and management approach. However, the process should not only focus on gathering easily collectable data or easily observed and measurable facts (chapter 2.1.3.), but also take more subtle and deep seated processes into account by regularly addressing different data sources beyond operative reports e.g. surveys.

According to the literature review, quantification is important as what is being measured is also being managed. Literature findings emphasise that quantification is indispensable for risk decisions, subsequent resources allocation or decisions about risk control strategies. However, risk quantification should not be exaggerated. Reliance on quantitative data alone is dangerous and may be problematic. Some risk aspects are intangible (or indirect) or non-quantifiable making difficult to include them in a formal quantitative decision-making approach. It can be derived from literature findings, that as risk nature is value-laden any attempt to quantify risk is condemned to fail no matter the degree of mathematics sophistication. There will always be a certain assumption and uncertainty level surrounding risk calculations. Moreover, quantifying risks does not ensure risk reduction itself. Risk management is much more than assessing quantifiable figures. Research results suggest implementing approaches based on figures that also take into account qualitative elements and still allows for expert interpretation. Introducing more objective and traceable approaches may considerable improve stakeholders' understanding and cost-effectiveness of risk mitigation strategies. Yet, a structured approach to risk assessment and a good understanding of the process' aims and objectives may be more important than detailed statistical knowledge.

Literature review outcomes also recommend integrating proactive risk analysis methodologies. With today's extremely low accident rate, it is increasingly difficult to improve the safety level by relying solely on reactive approaches. Anticipative approaches base on the idea that it is bad for business to wait for an accident to happen and then figuring out how to prevent reoccurrence.

According to literature findings, a risk management process should encompass all activities needed to systematically deal with risks considering operational effectiveness, time, cost, and practicability. Assigning and openly communicating responsibilities throughout the organisation with each manager and employee

responsible for managing risks in their respective responsibility area as advised by literature and as expected by Fraport's strategic risk management (chapter 2.6. and chapter 4.2.) could contribute to the success of the process.

Generally, it should not be relied on insurance to cover accident costs as risk control strategy, as e.g. image and stakeholders' trust are never insured. Several risk control strategies are provided by literature. Literature recommends balancing the cost of implementing strategies against the benefits of risk mitigation when deciding about the most appropriate risk control strategy. It is probably safe to assume that the capabilities to do so are not omnipresent, as specific risk knowledge is needed hereto. Decision what risk control strategy to follow need considering e.g. operation and risk significance. However, risk control itself can introduce risks that need to be assessed, treated, monitored, and reviewed e.g. failure or ineffectiveness of risk control measures.

Introducing a systematic risk measurement and management process as advised by literature may be rational and functional, yet, it may incubate risks of its own e.g. creating a false sense of security/safety in consequence of e.g. or defining a process too narrowly, so that it may e.g. fail to identify hazards or consider possible outcomes. Implementing a comprehensive process may also exacerbate obsession and reliability on internal control systems as well as overwhelm other organisational functions and bound attention and rationality. Risk management theory has sought to formalise the process as an attempt to reduce complexity and the effects of personal bias. Yet, any approach chosen will canalise results and influence decision-making processes. Implementing a process/system should support decision-making processes, but never substitute common sense or expert knowledge. Analytical processes should not be overestimated especially with regard to their ability to predict the future. Values entering the risk analysis process should be regularly contested by different stakeholders to avoid a one-sided view of risks and biased attitudes.

Summarising, a holistic as well as systematic risk measurement and management approach can positively affect organisational outcome.

6. Conclusion

It has to be concluded that there is no single answer or best solution to the on how to measure and manage airside operational safety risks. Extensive literature exists on the subject. However, approaches presented by literature are not always consistent. Moreover, this work has shown that measuring and managing risks is a complex issue characterised by many interdependencies. Therefore, several recommendations can be inferred for adjusting different "screws" of the process.

Literature generally agrees, that risk management should go beyond legal compliance or technical analytical practices based on historic data to develop the advantages praised by literature. This study has revealed, that to certain degree, an effective risk measurement and management process is even essential to improve risk awareness and focus management attention on risk related issues.

While each risk might have a different source, all risks affect the organisation's performance and if unmonitored and unmanaged may negatively affect earnings and growth. An improved risk measurement and management process has the potential to access many advantages praised by literature, i.a. reducing uncertainty and developing explanatory and predictive power to support decisions. Integrating different approaches into a single process as well as strengthening risk quantification and cost/benefit analysis throughout the process might be challenging and costly, yet indispensable to a sound situation analysis, enhancing consistency and objectivity as well as improving process' efficiency and effectiveness.

Based on Diacon in Paton (2011) FRA's objective should be the implementation of a consequent and strongly focused risk measurement and management process to make the organisation more robust. It should not be about anticipating everything, it should be about building a process structure that will make the organisation robust enough to deliver the outcomes according to the company's risk appetite within the set framework.

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Annex 1: Accident Cost Factors and Estimates based on ASTER (Nationaal Lucht- en Ruimtevaartlaboratorium, 2001) - This list is not exhaustive and accident cost can vary considerably depending on the accident and involved parties.

Cost element	Estimates	Main stakeholders
Aircraft physical damage	Minor, 15% damage Moderate, 50% damage Major, 80% damage Disaster, 100 % damage Catastrophic, 100% damage Aircraft market value depends on type and age. E.g. A321 € 50.7m	Airline, airport, owner, insurance
Site contamination and clearance	Wide body 1.2m-2.8 m € Narrow body 0.7m-1.3m € Smaller aircraft 0.13m-0.2m €	Airport, airline, ground services, insurance
Cost for delay	For the airlines: Wide body: 22 € per seat per hour Narrow body: 20 € per seat per hour Ground cost of delay 22 €/min	Airlines, airports, passengers, ground services, ATM etc.
Airport closure	Airport disruption depends on severity of the accident, estimates are: Catastrophic 5 days Disaster 5 days Major 4 days Moderate 2 days Minor 2 days Only applicable if accident occurs on or close to the runway.	All stakeholders
Deaths and injuries	Value of Statistical Life (VOSL) 1-2.64 m € VOSL differs per country. Value of injury is 13% of VOSL.	Airlines, airport, insurance, society
Loss of staff investment	E.g. replacement cost per pilot 45,000 € (training, experience etc.)	Society, airline, airport, Insurance
Loss of baggage, cargo, mail	Underfloor cargo carried on passenger flights 110,000 € Personal baggage on passenger flights 45,000 €	Sender, receiver, insurance

Cost element	Estimates	Main stakeholders
S&R costs	Average SAR cost claim 0.6m €	Society, airport
Airport immediate response	Average costs per accident 0.5-3m €	Airport
Cost of accident investigation	State 0.1-100m €. Only for catastrophic and disaster events. Huge range, depends among others on effort needed for wreckage reconstruction.	State, manufacturer, airline, airport
Third party damage (physical damage, deaths, injuries, inconvenience and loss of use)	Third party death and injury: use similar VOSL as in passenger death and injury. Third party physical damage.	Airlines, insurance, third party stakeholders
Loss of investment income (to insurers on monies paid out of claims)	These costs are usually reflected in insurance premiums.	Airport
Increased cost of insurance	Approximately loss of 20% insurance discount.	Airport and other insureds
Loss of income	Part of 'loss of reputation' costs.	Airport, airlines
Loss of reputation	E.g. airline loss of turnover 0-380m € Huge range. Loss to society is far less than to airport, since major part of reduced demand will shift to other airport.	Airport, region
Loss of company value (decrease in share value and market capability)		Airport, airline, shareholders
Social costs (effects of closures, general delay etc)/ Loss to society (tax, skills, etc.)		Society, airport
Fines, punitive damages		Guilty stakeholders

Annex 2: Comparison of a Choice of Methodologies based on Rasche, 2001.

Exclusively qualitative methodologies are 'what if', FMEA and FMECA, and HAZOP. Table based on Rasche, 2001. List is not exhaustive. Further approaches can be researched in literature.

Methodology	Life Cycle phases	Skill level	Strengths	Weaknesses	Cost	No of people requested
'What if'	All phases	No special training, cursory understanding of system	Very inexpensive, few data required and user friendly, can use quickly	Inadequate for complex systems, cannot identify dependencies	\$	••
FMEA & FMECA (Failure Mode and Effect/Criticality Analysis)	After design is finalised	Moderate training, and understanding of system required	Thorough and good for identifying single point failures	Addresses failures not safety issues and usually performed late in design phase, human error not addressed, very time consuming and possibly expensive, able to reflect system interactions, redundancies and common cause failures (CCF)	\$\$ - \$\$\$	2
HAZOP - Hazard and operability studies	Throughout life part design phase	Moderate training, and very good understanding of process requirements, facilitation of HAZOP critical for success of technique	Very thorough technique, identifies ultimate consequences and evaluates existing safeguards, good for complex systems, good tool for identifying process inefficiencies	Can be expensive and time consuming, requires a committed and disciplined team and facilitation, unable to reflect redundancies and CCF's	\$\$ - \$\$\$	6

Human Error Analysis (HEA)	Design phase, accident and incident investigation, design reviews, setting up of training regimes, preparation of emergency response procedures or safety critical task preparation	Significant training & understanding of system requirements, particularly safety critical tasks and dependencies	Identifies human error and ways to mitigate mistakes, can be used to 'people proof' systems, ideal for evaluating safety critical tasks, both qualitative and quantitative approaches	Quantification can be misleading as human behaviour very difficult to model, gathering of data can be difficult and established databanks may not be representative for the particular task or application	\$\$ - \$\$\$	2
Reliability Block Diagrams	Throughout life part design phase	As for FTA, uses	As for FTA, difficult to consider other sources of failure e.g. human error	As for FTA	\$\$ - \$\$\$	2
Fault Tree Analysis (FTA)	Throughout all stages of operation - particularly design stages and modification of design	Considerable training and in depth understanding of system requirements, best done using appropriate software as modelling and quantification sometimes cumbersome	Very thorough, excellent for complex systems where combination and interaction of events and failure needs to be considered, utilises statistical data of equipment failures to evaluate probability for unwanted top event, provides visual model of the safety system, provides ranked lists and combinations of critical components, excellent tool to model redundancies and fault tolerance (vulnerability), qualitative and quantitative applications, widely used in nuclear industry to model catastrophic risk. Method been duplicated in MORT method (accident/incident investigation)	May be costly and time consuming, relies on correct capture of faults and failure mechanisms and interaction to predict system behaviour, databases may be unsuitable for specific application but failure information can be supported using FORM methods, unable to model temporal events	\$\$ - \$\$\$	2

Event Tree Analysis (ETA)	All phases including accident/incident investigation, excellent tool to model catastrophic events and escalation, ideally suited to model efficiency of emergency response and safety critical tasks	Significant training & understanding of system required, relies on identification of all event scenarios and numerical estimates of event likelihood's (from FTA), best done using appropriate software	Excellent tool to model dependencies and temporal escalation of events, provides numerical estimate of likelihood of an escalated event. Widely used in nuclear industry to model catastrophic risk	Can be costly and time consuming, relies on the correct capture of event escalation, relies on scarce data which may be supplemented by FTA or FORM	\$ - \$\$\$	4
FORM - First Order Reliability Methods - fully probabilistic	Design phase and modification, verification of design, accident investigation	Considerable - should only be done by experts in the field, best done using appropriate software	Able to use and reflect variability in input data of any engineering system, in the absence of actual failure data can use FORM to synthesise failure data for use in FTA or ETA, ability to use design calculations to predict likelihood of failure, sensitivities and likely failure regime.	Definition of safety margin equations can be challenging, cannot be used for HRA, requires numerical estimates of input parameters	\$ - \$\$\$	2
Monte Carlo Methods (MC)	All phases, but ideally during consolidated design to establish reliability of system	Relatively low, usually carried out using add-on software to spreadsheet packages	Intuitive process but relies on creation of a mathematical model which describes the risk parameter, considerable experience in several industries, MC provides range of outcomes and enables better estimation of risk. Once model built, input distributions are quickly updated to yield new results.	Creation of a mathematical model can be challenging, MC relies on computerised methods e.g. spreadsheeting, depending on complexity, considerable computing resources are used. Modelling assumes underlying distributions of variables that may be difficult to establish given data either limited or not available. Variability of result also affected by model itself.	\$ - \$\$	2

PRA & PSA - Probabilistic Risk and Safety Assessment	Design and throughout life as designs are verified, design of emergency preparedness plans and evaluation of safety critical tasks, if analysis maintained as living PSA, can measure improvements	High, requires understanding of system dependencies	Combines strengths of several other methodologies. Best methodology for catastrophic risk assessments, can forecast probabilities of accidents and likely magnitude of consequences. Results can be used in preparation of emergency response plans, safety critical tasks or submissions to government, tools such as FTA allow the review of individual contributors to risk before solution is implemented.	Costly and significant effort required, relies on thorough identification of all possible accident scenarios and assignment of statistical probabilities. However, once established model is easily updated and changes in risk level can easily be established.	\$\$\$\$ \$	6
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Annex 3: FRA's Market Environment based on a PEST Analysis (Jobber, 2007)

PEST-Factors influence SMS's risk measurement and management process, but are outside the Fraport's control:

Political/legal: Frankfurt Airport is strongly influenced by regulations on international, European, and national levels. They considerably restrict its action field. Regulative requirements significantly affect not only SMS but also all operational processes, leaving little room for deviations. FRA is subject to national and EASA's regulation that has taken over air safety-related competencies from the member states – a former sovereign responsibility of each EU Member state. Its tasks include the enforcement of the highest possible safety standard; however, the influence of European regulations on airport safety is still in an early developing phase. Yet, airports are increasingly being confronted with new systemic and regulative requirements, thus considerably restricting its design freedom.

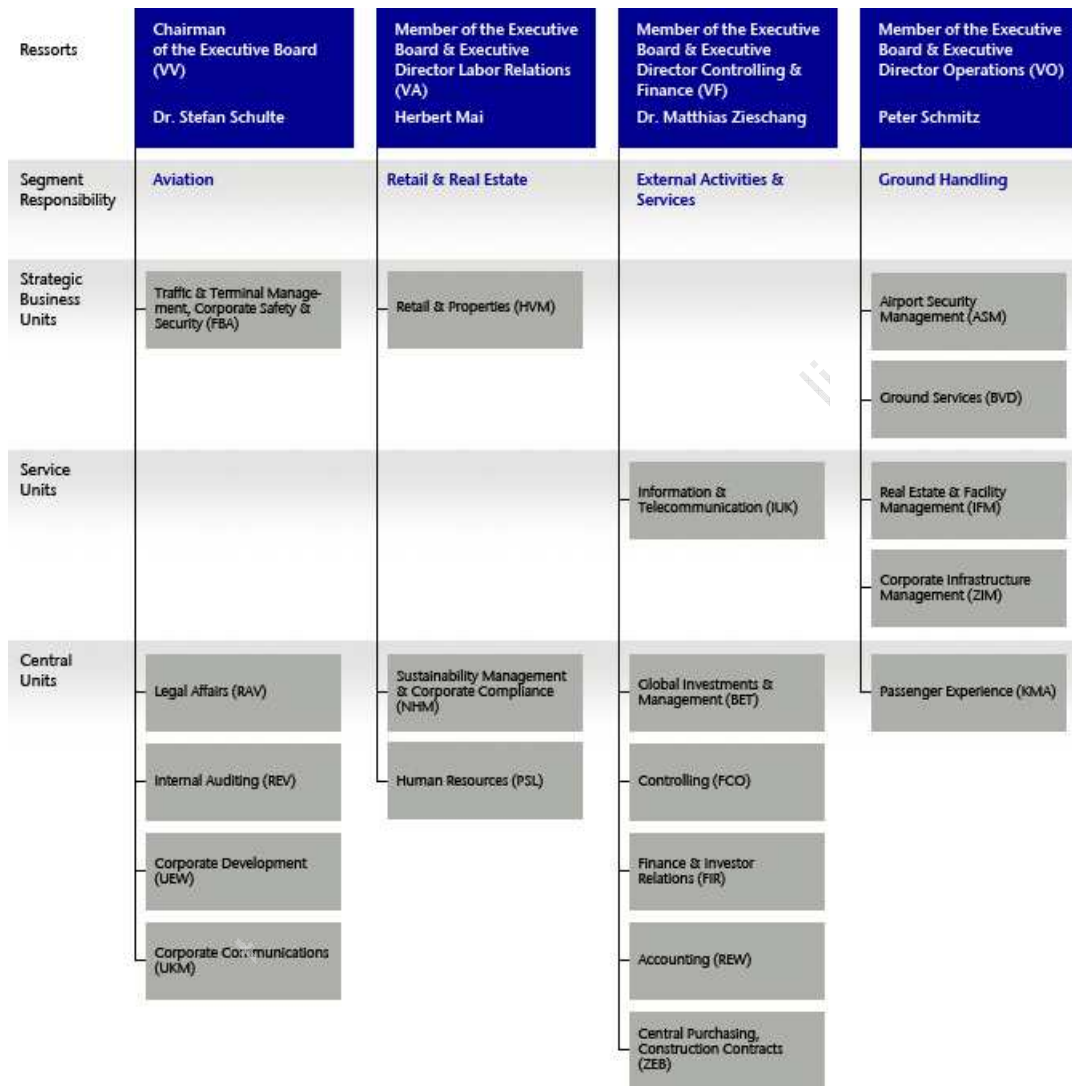
Economical: The EU market is facing an economic downturn. The financial and economic crises have resulted in a severe decrease in the European economic performance. Since banks were especially affected by the crisis, their loans are only given with high-risk premiums, resulting in decreased availability of loans at accessible prices. This in turn, raises investment prices and could affect Fraport's cash-flow.

Social: Society is increasingly aware of ecological and risk related issues regarding the start of FRA's fourth runway operations. Therefore, a sensible behaviour with regard to stakeholders is expected from the airport. Fraport has been especially confronted with increasing population's resistance due to recent traffic growth. The population is highly interested in the airport's activities and opposes further growth using safety arguments at the very least. Individual real incomes are decreasing considerably. Consequently, people spend less money on leisure and travel. Furthermore, demographic changes challenges airport's process designs.

Technological: The introduction of new technologies or new generation of large aircraft challenges Fraport's services, processes, and infrastructure. Increasing automation can significantly affect the airport and in turn affect the configuration of the system. An increasingly technological configuration can promote system errors that are not easily detectable. Constant alterations in framework may influence risk management and the risk measurement and management process in a yet unknown way.

Annex 4: Fraport's Organisational Chart as of August 2011 (Fraport, 2011)

The SMS-department is part of the Strategic Business Unit "Traffic & Terminal Management, Corporate Safety and Security (FBA)" within the Aviation segment.



*The Unit "Boards and Committees" (VV1) is related directly to the CEO.
 The Unit "Investment Management" (VF1) is related directly to the CFO.
 The Unit "Representative for Data Protection" (VA1) is related directly to the Executive Director Labour Relations.*

Annex 5: FRA's Manoeuvring Area

SMS is responsible for the measurement and management system of airside operational safety risks in FRA's manoeuvring area. These are the blue and green area shown in the figure below. Source: Fraport. The new runway (green ellipse) area is also integral part of the manoeuvring area.

