Towards improving detection of early warning signals within organizations: an approach to the identification and utilization of underlying factors from an organizational perspective

Luyk, J.

DOI:
10.6100/IR716241

Published: 01/01/2011

Document Version
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

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Link to publication

Citation for published version (APA):

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Towards Improving Detection of Early Warning Signals within Organizations

An Approach to the Identification and Utilization of Underlying Factors from an Organizational Perspective
Towards Improving Detection of Early Warning Signals within Organizations

An Approach to the Identification and Utilization of Underlying Factors from an Organizational Perspective

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus, prof.dr.ir. C.J. van Duijn, voor een commissie aangewezen door het College voor Promoties in het openbaar te verdedigen op woensdag 31 augustus 2011 om 14.00 uur

door

Joël Luyk

goingen te Eindhoven
Dit proefschrift is goedgekeurd door de promotoren:

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Luyk, J.

A catalogue record is available from the Eindhoven University of Technology Library


NUR 953

Keywords: Proactive risk management / Industrial organizations / Risk detection / Early warning signals / Cognitive detection / Influencing factors

Printed by: University Printing Office, Eindhoven
Acknowledgements

Although only one name marks the cover of this thesis, there are in fact various people to acknowledge for its existence. Without them, the milestone which this thesis represents, i.e. the end of my Ph.D. research project which started midway 2006, would have never been met. For that, a special thank you is in order, for all those who have supported me in one way or another throughout the duration of my project.

Firstly, I would like to express my gratitude to my supervisors beginning with my first promotor, prof. Dimitrios Karydas. I deeply appreciate your continued support and commitment to my research project throughout the years. You were always willing to devote time to our research meetings despite your hectic travelling schedule, in Eindhoven, Amsterdam or elsewhere, via any means of communication at any time of day. I greatly enjoyed these discussions, and am very thankful for your invaluable insights and remarks which helped me to develop myself both professionally and personally. I look forward to more inspiring meetings beyond the context of this thesis in the future! Next, I would like to thank prof. Aarnout Brombacher, my second promotor. You have been a great supervisor, mentor, and troubleshooter, and I am very grateful for your early involvement in my project. Besides your valuable comments and suggestions which helped me to improve the quality of my research, your ability to seek out and create research and business opportunities has proved to be essential at various points in my project, which I greatly appreciate and acknowledge.

As my co-promotor, dr. Jan Rouvroye has been a constant and reliable determining factor in my project from the start. Jan, without your support, varying from acting as a second researcher in some of the research activities, to reviewing my work in great detail and acting as an academic and professional guide, I can honestly say that there would not have been a thesis. I hope that your weekends and holidays will be less filled with work related activities now that you have one less Ph.D. student asking for your advice, although I doubt this will be the case.

Next, I would like to thank prof. Rob Kusters, prof. Martin Newby and prof. Hans Pasman for taking seat on my Ph.D. committee, and for their review of my thesis. Based on your comments and constructive criticism, I was able to improve the thesis in several respects, including by giving further insight into the practical implications and boundaries of my research findings and by addressing various methodological issues.

For making this Ph.D. project possible by acting as a great source of expert knowledge, validation and inspiration, I would like to thank the Nederlandse Vereniging voor Risicoanalyse en Bedrijfszekerheid (NVRB). I highly appreciate the opportunities given by the board of this professional association to contact its members. In particular, I would like to thank then chairman of the board prof. Aarnout Brombacher for his assistance, and then chairman of the program committee Cornelia Damstra for facilitating the focus group meeting. Above all, I would like to express my gratitude to those association members who either contributed to the focus group or survey for their time, interest and insights. Without them, both model development and model validation as described in chapters 4 and 5 would have been infeasible.
In the early phase of my project, part of my research was conducted at Nuon Power Buggenum, which laid the foundation for this thesis. In this respect, I would like to thank Carlo Wolters for expressing his initial interest in the Ph.D. research project, and for giving me the opportunity to cooperate with many people at the plant, of which in particular I would like to mention Jo Salden, Ruud Nadels and Michiel Houben. Also, I would like to thank Vasileios Kotzampasis, whose research performed at the plant as part of his graduation project contributed to the existence of this thesis.

At the Eindhoven University of Technology, I would like to thank Jun Hu for his technical support on the use of the web based software used for the survey discussed in chapters 5 and 6. Moreover, thank you to all of my colleagues old and new, of the then sub department of Quality and Reliability Engineering at the faculty of Technology Management, and the later sub department of Business Process Design at the faculty of Industrial Design. Besides helping out with my research in various respects, I am grateful to my fellow Ph.D. students for listening to my frustrations inherent to doing a Ph.D. research project, and giving good advice when needed. Thanks also for all the shared lunches, walks, running and badminton playing, and the enjoyable ‘vakgroepuitjes’.

Afsluitend wil ik mijn familie en vrienden bedanken voor hun begrip en ondersteuning gedurende de afgelopen jaren, en in het bijzonder gedurende de laatste maanden van mijn project. Pap en mam, bedankt voor jullie onvoorwaardelijke vertrouwen in mij; jullie gevoel van trots op mijn prestaties betekent onzettend veel voor mij. Frans en Roely, heel hartelijk bedankt voor jullie oprechte medeleven en voor alles wat jullie hebben gedaan zodat ook privé alles op rolletjes bleef lopen in de tijden dat ik me weer eens moest opsluiten om aan mijn proefschrift te werken. Anton en Raymond, geweldig dat jullie mijn paranimfen willen zijn.

Lieve Ilse en Flore, de laatse woorden van mijn dankwoord zijn uiteraard voor jullie. Wat ben ik blij dat ik jullie in mijn leven heb. Flore, bedankt voor alle keren dat je met een enkele glimlach of tekening mijn dag weer goed maakte. Ilse, hoe ik deze klus ooit geklaard zou kunnen hebben zonder jouw onvoorwaardelijke liefde, humor, relativeringsvermogen, steun en aanmoediging kan ik me onmogelijk voorstellen. Dit proefschrift draag ik dan ook op aan jullie, mijn twee power vrouwen.

Joël Luyk
Eindhoven, 2011
Summary

Towards Improving Detection of Early Warning Signals within Organizations – An Approach to the Identification and Utilization of Underlying Factors from an Organizational Perspective

In today’s society, there is a strong need for organizations to proactively manage risk given the increasing product, process and business chain complexity they are facing, and the increasingly dynamic and competitive environment in which they are operating. At the same time, these trends add to the difficulty in executing proactive risk management, amongst other things since organizational threats are consequently becoming increasingly unforeseeable nowadays. Within this context, this thesis explores how industrial organizations might potentially improve one particular aspect of their proactive management of risk, namely the detection of early warning signals of potential risks by people within the organization.

Review of literature from various risk management disciplines demonstrated that although most disciplines acknowledge the potential of people within an organization to detect early warning signals, structured approaches (tools, methods) on how to conduct or improve this kind of organizational early warning signal detection are currently not available. More insight is hence needed into this type of detection, to learn how an organization could potentially improve its detection ability.

For this purpose, a conceptual framework of organizational early warning signal detection was developed as a starting point, based on insights from communication theory, organizational systems theory, and theory on the cognitive processing of warnings by individuals. The framework is characterized by three main elements, the role of which on organizational early warning signal detection was confirmed by case study analysis. More specifically, organizational early warning signal detection requires 1) propagation of the early warning signal(s) or signal estimate(s) across the organization, at all levels (strategic, tactical, operational), 2) individual early warning signal detection in an organizational context resulting in signal-directed behavior or action, both of which are affected by 3) influencing factors that can either positively or negatively affect signal detection in four main categories:

- **Human factors**: factors active on an individual level
- **Internal environment**: factors active on an organizational level, corresponding to factors active in the organizational subsystems Technology, Structure, Culture, and Strategy
- **External environment**: factors active on the interface between an organization and its external environment
- **Exogenous**: factors originating from an organization’s external environment, which are considered outside the scope of this thesis

An overview of influencing factors of organizational early warning signal detection is currently missing from literature, though the case study analysis as well as risk management literature (in the form of specific guidelines to early warning signal detection) indicated some potential factors. This thesis aimed to obtain such an overview, as part of the effort to learn how signal detection might be improved.
To identify influencing factors, it was determined that the identification approach to be employed had to meet the following criteria, i.e. the approach should be able to capture insights non-specific for any one particular organization, should support an exploratory approach to research, and should utilize both multiple data sources and multiple research methods, the integration of which is captured in a structured framework. Based on these criteria, a general approach to factor identification was proposed consisting of two phases or steps: model development (in order to construct an initial model of influencing factors) and model validation (to further validate the initial model, in order to try to obtain a comprehensive overview of factors).

Application of the proposed approach relied on three main data sources: literature on crisis management and resilience engineering, risk management experts assembled in an expertise network transcending industries, and case studies (mainly of major industrial accidents). An initial model of 21 influencing factors in the categories Human factors, Internal environment and External environment was obtained by means of the concurrent application of an extensive literature study and focus group. On the level of individual factors, comparable results were obtained and the focus group was able to confirm the existence of factors obtained from literature. For that reason, it was decided to proceed with model validation. Model validation was performed in two iterations. Results of an internet based survey overall confirmed the relevance of influencing factors in the initial model, but also suggested some minor modifications. The consequent analysis of various case studies did not yield any new insights compared to the post-survey model of influencing factors, and it was hence decided to accept this model as a validated list of influencing factors of organizational early warning signal detection.

As such, based on its application, it was concluded that the proposed approach is effective with regard to its intended goal (i.e. factor identification). Moreover, it was found that consultation of risk management experts assembled in an expertise network is a particularly rich source of information in a field of study in which sources of evidence are not widely available. The exploratory insight gained into influencing factors can next be utilized for the purpose of potentially improving organizational early warning signal detection at various levels, ranging from a basic level to more practical means of utilization.

At a basic level, such insight can help organizations realize that signal detection largely lies within an organization’s range of control, and hence is the organization’s responsibility to some extent. Also, the overview of factors makes explicit that poor organizational early warning signal detection can not necessarily be attributed to human failure (or in other words, it can not necessarily be attributed to influencing factors in the Human factors category).

Furthermore, exploratory insight gained into influencing factors can act as input to additional research into influencing factors, both descriptive (related to factor characteristics) and analytic (related to factor dependencies) in nature. In this thesis, descriptive research into factor relevance (i.e. the degree of influence of a factor on organizational early warning signal detection) was performed, since insight into factor relevance can potentially allow prioritization of influencing factors, which is desirable from an organization’s perspective. Research into factor relevance by means of an internet based survey indicated that what was intuitively expected, namely that some factors have a higher degree of influence on signal detection than other factors. Survey findings moreover suggested that prioritization according to factor relevance would be possible on the level of individual factors, but not on the level of factor categories. Lastly, it was found that differences in factor relevance might exist between
industries and organizational levels (strategic, tactical, operational), though survey results were non-conclusive.

When trying to improve organizational early warning signal detection in practice, such potential differences between industries and organizations need to be taken into account. In this respect, it is important to realize that the obtained overview of influencing factors can only be considered valid for its intended purpose, i.e. to give an overview of the ways in which early warning signal detection is affected in industrial organizations in general. Also, since both organizations and their environment change over time, the overview of influencing factors can only be considered valid at the time at which the overview was obtained, given its dynamic nature. Consequently, prior to utilizing insight into influencing factors for the purpose of signal detection improvement in a particular industrial or organizational setting, the extent to which factors found are applicable to the organization (and/or industry) in question should be ascertained. One way of meeting the precondition of industry and/or organization specificity was suggested by an existing diagnostic tool for safety enhancement called Tripod-Delta, namely by means of the identification of indicator items for each influencing factor by a syndicate of specialists from the industry and/or organization under consideration.

Indicator items identified can next set the stage for utilizing insight into influencing factors in practice. For that purpose, this thesis proposed a diagnostic evaluation tool for organizational early warning signal detection, which allows organizations to learn where problems might be found with regard to their ability to detect early warning signals, in terms of the relative cause of concern of each influencing factor. As such, application of the tool can provide an organization with a sense of direction for improvement, and can contribute to areas such as decision analysis and support, and (organizational) assessment.

Although based on an existing diagnostic tool to enhance safety which has been validated in various organizations and industries, the proposed tool itself also needs to be tested and validated. Implementation of the proposed tool in various organizational settings across industries is therefore recommended. This type of research is suggested to be performed together with further descriptive research (direction of effect, factor quantification) and analytic research (factor dependencies) into influencing factors, as part of the effort to allow additional and more practical means of utilizing insights gained for the purpose of signal detection improvement to become feasible.
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1 Introduction

There is a strong need for proactive risk management in today’s society. Several industry wide trends are apparent, which increase the need for proactive risk management but at the same time add to the difficulty in executing proactive risk management. Amongst other trends, these include increasing product and process complexity, increasing complexity in the business chain, an increasingly dynamic and competitive environment and decreasing societal tolerance for failure. The general aim of this thesis is to gain insight into how (industrial) organizations proactively manage risk, and, more importantly, how to potentially improve an organization’s ability to proactively manage risk, in light of the earlier mentioned trends.

1.1 Industrial accidents: the need for and difficulty in managing risks

One of the most severe industrial accidents in recent years is undoubtedly the Deepwater Horizon oil spill in the Gulf of Mexico. On April 20, 2010, hydrocarbons escaped from the Macondo well, leading to several explosions and subsequent fire on Transocean’s Deepwater Horizon oil rig, killing 11 crew members and injuring many others (Graham et al., 2011). The fire lasted for several days, until eventually the oil rig sank on April 22. It is estimated that nearly five million barrels of crude oil have leaked into the Gulf of Mexico, making it one of the largest oil spills ever. The accident and the subsequent spill have had major consequences. First and foremost, there are the people directly killed and injured by the explosions and fire. Secondly, marine and wild life is severely damaged by the spill. These effects will likely be irreversible to a large extent. Thirdly, coastline areas along the Gulf of Mexico were hit, both economically and environmentally. Fourthly, economically speaking, the oil spill has had major consequences for the main parties involved, which include amongst others BP, Transocean and Halliburton. Litigation and the related financial claims, loss of the oil rig and the loss of nearly 5 million barrels of oil and reputational damage are but a few of the issues Deepwater Horizon parties are facing after the event. Fifthly, the oil and gas industry, as well as regulatory authorities, are affected. For one thing, in the aftermath of the Deepwater horizon oil spill, the U.S. administration decided to maintain a longtime ban on offshore drilling in certain parts of the Gulf of Mexico and the Atlantic coast. More importantly, the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling concluded that a comprehensive, integrated set of reforms is required to improve industry and regulator performance (Graham et al., 2011). This demonstrates how one single incident leads to repercussions for the complete oil drilling sector, next to the immediate consequences for all directly involved companies and affected stakeholders.

The latter conclusion (i.e. the need for industry and regulator reforms) was drawn, since the root cause of the oil spill was mainly attributed to systemic failure of industry (risk) management and communication, as well as ineffective regulatory oversight. Graham et al. (2011) state that “BP, Transocean, and Halliburton did not adequately identify or address risks of an accident; not in the well design, cementing, or temporary abandonment procedures”. Furthermore, according to Graham et al. (2011), their management systems were marked by poor risk communication to other parties involved, decision making processes within BP and other parties were poorly managed, and an adequate safety culture was absent.
Also, warning signs prior to the accident were ignored or not acted upon. According to Bea (2010), early warning signals such as repeated major gas kicks were present but were “not properly detected, analyzed or corrected”. These failures of industry (risk) management contributed to the immediate causes of the accident, i.e. failure to contain hydrocarbon pressures in the well, due to poor design and failure of the cement at the bottom of the well, the mud in the well and in the riser, and the blowout preventer (Graham et al., 2011). Given the main root cause of the accident, the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling concluded that the accident of April 20 was avoidable, and resulted from clear mistakes made in the first instance by BP, Halliburton, and Transocean, and by regulatory authorities (Graham et al., 2011).

To a large extent, the Deepwater Horizon accident can be attributed to failure in management and control of risk prior to the well blowout, as was discussed earlier. Hence, in order to try to prevent an accident such as the Deepwater Horizon oil spill, or at least mitigate its consequences, it is important that risks are adequately managed and controlled beforehand, and that risk management is not mainly limited to risk containment and recovery. The occurrence of the Deepwater Horizon accident at the same time demonstrates that proactive (i.e. prior to the accident) management of risk is complex and difficult to execute.

Besides the Deepwater Horizon accident, numerous other examples of industrial accidents are described in literature, which illustrate both the need for and difficulty in proactive risk management. In light of the Deepwater Horizon accident, the accident at BP Texas City in 2005 is particularly interesting given the similarities between the accidents. On March 23, 2005, BP Texas City Refinery suffered one of the worst industrial accidents in recent U.S. history with an explosion during the isomerization unit startup, caused by heavier-than-air hydrocarbon vapors combusting after coming into contact with an ignition source, killing 15 and injuring 180 (U.S. Chemical Safety and Hazard Investigation Board, 2007; Baker et al., 2007). As was the case at Deepwater Horizon, the BP Texas City accident also involved a hydrocarbon explosion, and showed an overlap in contributing causes (e.g. poor quality control, poor safety culture) and pre warning signs that were insufficiently addressed (such as frequent earlier fires and other incidents) by the same party involved (i.e. BP). Despite these similarities, BP was apparently insufficiently capable of using the lessons learnt to try to prepare for, or potentially prevent, similar types of accidents from occurring in the future.

The industrial accidents described above are but a small sample of the many major industrial accidents that occurred in recent years. Nevertheless, although different in nature and consequence, these accidents demonstrate the need for proactive risk management, in order to potentially prevent an accident or at least mitigate its consequences. Furthermore, the occurrence of these accidents at the same time demonstrates that proactive management of risk is complex and difficult to execute. Part of its complexity lies in the cluster of technical, human and organizational factors that contribute to most industrial accidents, and the uncertainty related to the potential outcome of the (combined) factors. Moreover, the mere existence of indicators prior to an accident, whether it be pre warning signs or past experience, is no guarantee that an organization will be able to successfully manage the associated risks proactively.

Given a number of industry wide trends, the need for proactive risk management is particularly strong in today’s society. These trends at the same time add to the difficulty in managing risk proactively.
Before elaborating on these trends, the concepts of risk and risk management as regarded in this thesis are further discussed, and definitions appropriate for the research context (i.e. proactive risk management in industrial organizations) are presented.

1.2 Risk and risk management defined

Risk and risk management are terms that are frequently used in various areas of application, which include economics, engineering and social sciences. According to Aven (2009), both terminology and methods for dealing with risk differ between disciplines, increasing the likelihood of misinterpretation and making communication across disciplines difficult. Also, Aven remarks that there is “a lot of confusion concerning what risk is and what should be the basic thinking concerning analysis of risk and uncertainty, within the various application areas”. Numerous other authors including Vaughan (1997) and Wharton (1992) have come to the same conclusion, which signifies the need to clarify what is meant by ‘risk’ and ‘risk management’ in this thesis.

1.2.1 Risk

Many different definitions of risk can be found in literature (for example, see ISO/IEC (2002), Kaplan & Garrick (1981), Kumamoto & Henley (1996)). More commonly, risk is considered as a two-dimensional combination of the likelihood (probability) of an event and the related consequences (ISO/IEC, 2002). Often, this combination is regarded as the product of probability and consequence, leading to an expected (quantified) value of risk. Aven (2009) adopts a slightly different definition, i.e. “the two-dimensional combination of consequences and associated uncertainties” related to some (initiating) event.

For a number of reasons, the latter definition is more appropriate given the research context of this thesis. Most importantly, the latter definition more strongly emphasizes the uncertain character inherent to risk, which is true for the event itself (e.g. occurrence and timing of the event), as well as for the potential consequences. Of course, probability is a means to express the degree of uncertainty (as is acknowledged by many authors including Bedford & Cooke (2001)) and in that sense uncertainty is taken into account in the ISO/IEC definition as well. Also, the associated uncertainties in Aven’s definition might be partly expressed using probabilities. However, some uncertainties might not be reflected by computed expected values and probabilities (Aven, 2009).

Moreover, considering probabilities instead of uncertainties inadvertently might lead to the impression that risk management is about ‘getting the number’, i.e. expected (quantified) value of risk and deciding what to do based on this quantitative insight. This thesis acknowledges the value of (quantitative) risk assessment as an integral part of risk management, but at the same time considers risk management as encompassing a wide variety of activities both qualitative and quantitative in nature. The research described in this thesis tends more towards the qualitative side of risk management, as will be explained in section 1.2.2 as well as in the next chapter, making Aven’s definition more appropriate.

1.2.2 Risk management

According to ISO/IEC (2002), risk management is the “coordinated set of activities that direct and control an organization with respect to risk”. As stated by Cameron & Raman (2005), these activities include at the least risk identification, risk assessment (analysis and evaluation), risk treatment (elimination, mitigation, transfer), risk acceptance (tolerability/acceptability criteria), risk communication (information sharing with
stakeholders) and risk monitoring (auditing, evaluation, compliance). This indicates that managing risk does not start at the moment when a potential risk has become reality and e.g. a major industrial accident has occurred, but encompasses a wide array of activities prior to the event too.

To demonstrate this, a simplified version of Mitroff’s crisis management model is presented in figure 1.1 (Mitroff, 1988). Crisis management can be regarded as management of a specific class of risks, since crises are “low probability, high consequence events that threaten the most fundamental goals of an organization” (Weick, 1988). Basically, crisis management can be split in three phases. One, the pre-crisis phase which consists of signal detection and preparation. This involves identification of potential risks and taking preparatory action, such as implementing plans or procedures to minimize impact. Two, the phase in which the crisis unravels. This phase is characterized by containing the crisis as quickly as possible. Executing evacuation plans or setting up emergency communication channels are examples of containment activities. The next phase, post-crisis, entails crisis recovery in which the aim is to return to the pre-crisis status as soon as possible.

As figure 1.1 demonstrates, effective risk management consists of activities both during and after the event (reactive) and prior to the event (proactive). The distinction between proactive risk management and reactive risk management is mainly for the purpose of delineation, though the term proactive risk management is also often used in literature, e.g. by Rasmussen & Svedung (2000). For example, through learning from past experience (see Kletz, 2001), valuable input is obtained to identify and to prepare for future events. In that sense, the reactive part of risk management acts as input for the proactive part of risk management. Another complicating factor in distinguishing between proactive and reactive is that most risk management activities such as risk treatment, risk monitoring and risk communication are both proactive and reactive in nature. Consequently, the distinction mainly serves the purpose to clarify this thesis’ focus on risk detection, identification and preparation, instead of containment and recovery.

It is important to emphasize that risk management is a broad discipline with many potential areas of application. Hence, a further delineation beyond proactive versus reactive risk management is needed, which is the topic of the next section.

1.3 Risk management in industrial organizations

In the past, the consequence dimension of risk mainly related to adversity, such as the loss of life and limb, property damage or financial loss. Nowadays, more organizations do not solely consider risk as something that should be avoided at all costs, but also realize that “informed risk taking is a means to competitive advantage” (Casualty Actuarial Society, 2003).
Subsequently, the definition of risk is often extended to include not only unfavorable consequences but favorable consequences (e.g. market opportunities) as well, as is demonstrated by the broader definition of risk given by ISO/IEC (2002). Risk management is hence more often associated with managing both threats and opportunities. For example, Enterprise Risk Management deals with “risks and opportunities affecting value creation or preservation” across the enterprise (COSO, 2004). Nevertheless, this thesis takes on the more restrictive or classical perspective on risk, and considers risk management as a means to direct and control an organization with respect to organizational threats instead of opportunities. Firstly, the restricted definition is more appropriate for most of the disciplines on which this thesis draws inspiration with respect to theory and case studies, which includes safety management. Secondly, one can consider not taking advantage of a favorable consequence (e.g. missing a market opportunity) as an unfavorable consequence or a potential threat to an organization’s survival. In that sense, the more restricted definition also takes (missed) opportunities into account.

An organization is susceptible to various kinds of threats, which allows for a classification of risk based on the nature of the threat. Both Sheffi (2005) and the Casualty Actuarial Society (2003) distinguish between four risk types or vulnerabilities:

- Hazard risks, including fire and other property damage, liability suits (e.g., operations, products, environmental), personal injury, disease, disability and natural perils
- Operational risks, including business interruptions (e.g. production, capacity, efficiency), human resources, empowerment, integrity, information technology, theft and other crime
- Financial risks, including price, liquidity, credit, inflation and hedging
- Strategic risks, including competition, societal trends, technological innovation, capital availability, regulatory and political trends

When a hazard risk related event such as a major fire occurs, other consequences whether it be operational (e.g. business interruption) or financial (e.g. financial loss) will likely accompany the event. Hence, it should be emphasized that the risk types relate to the nature or source of the threats. For instance, if a threat originates from the financial market, economy, or an organization’s own financial mismanagement, the related risk type is financial (Sheffi, 2005).

Depending on the type of organization, one particular type of risk might be more prominently present than other types. For example, financial or service organizations such as banks or pension funds will more likely face financial and strategic risks compared to hazard risks. Industrial organizations, such as companies active in the chemical, oil, nuclear, transport or manufacturing industry, will more likely face hazard and operational risks compared to financial and strategic risks. The focus of this thesis is not on financial or service organizations, but on industrial organizations. Through the exploration of risk related theory such as safety management, the analysis of industrial accidents such as Deepwater Horizon and many others, and the input of risk management experts active in industrial organizations, this research draws conclusions with respect to the (proactive) management of especially hazard and operational risks in the context of industrial organizations.
An organizational perspective on (proactive) risk management fits in the historical development of risk related research activities, of which the developments in safety thinking are exemplary. Particularly in the last fifty years, safety thinking has shifted in focus, to a large extent triggered by the occurrence of some major industrial accidents such as Bhopal and Three Mile Island and the insights gained after these events. In the field of system safety and accident causation, four major ages in safety concern can be distinguished (Reason, 1991; Wilpert, 2002). The first age, i.e. the technical age, is characterized by a focus on engineering and operational methods for risk management such as establishing (physical) safeguards to improve safety. The transition from the technical domain to the human domain marks the beginning of the human age. In the human age, more emphasis is placed on the human as an essential part of the human-system interaction and as a potential source of error, including e.g. execution failures and diagnostic errors. The third age is the socio-technical age, which bridges the gap between the first two ages. Starting around the beginning of the 1980s, following some major industrial accidents, it was realized that safety problems emerge from poorly understood interactions between the technical, social and organizational aspects of the systems (Wilpert, 2002). As stated by Reason (1997), organizations should thus manage both the “sharp end” of safety (active failures at the workforce level) and “blunt end” of safety (conditions set by the organization/management leading to active failures). Currently, safety thinking has moved into the fourth (partly overlapping) age, i.e. the inter-organizational age. Drawing from the insights gained during the first three ages, the inter-organizational age is characterized by a need to further understand structural and less structural interactions both within the organization and between the organization and its (external) stakeholders. Research into safety culture (see e.g. Guldenmund, 2000; Pidgeon, 1998), the importance of which was emphasized by Apostolakis (2010), and research into High Reliability Organizations or HROs (see e.g. Weick & Sutcliffe, 2007) mark some of the major contributions made in the inter-organizational age.

In literature, the shifting focus in safety thinking is apparent in the evolution of safety theory throughout the years, as well as the ongoing development and improvement of tools and methods to improve safety supporting this theory. In a recent paper, Saleh et al. (2010) identify and describe some of the major contributions to the literature on accident causation and system safety extending into the socio-technical age and the inter-organizational age. These contributions include but are not limited to Turner’s Man-Made Disasters (1978), normal accident theory (Perrow, 1984), probabilistic risk analysis (see Bedford & Cooke, 2001) and HRO theory (see Weick & Sutcliffe, 2007). In addition to these contributions, they discuss ideas that are “emerging as foundational in the literature on and thinking about system safety and accident causation”. These latest contributions to the field of system safety can be characterized in two ways. Firstly, a control perspective on system safety is adopted. In this perspective, safety is controlled through the establishment of technical and organizational safety barriers and the enforcement of safety constraints (Leveson, 2004). Also, safety control is a joint effort which involves many levels of decision makers, including politicians, managers, and operators (Rasmussen & Svedung, 2000). Secondly, a ‘systems theoretic’ approach is required for system safety and control, taking into account interactions of components, subsystems and stakeholders in technical and socio-technical (i.e. organizational) systems (Saleh et al., 2010).

These topical insights from the field of system safety are valuable for the field of risk management as well. As will be demonstrated in the next section, in order to manage risk effectively in today’s society, it will become more important to take into account the many interactions between an organization’s internal environment and external environment.
Also, it should be realized that risk management involves not only an organization’s management but all levels within the organization. This thesis attempts to incorporate these perspectives in the management of risk in industrial organizations and draws on some of the theoretical foundations of (organizational) systems theory as will be further discussed in chapter 3.

1.4 Trends affecting proactive risk management

As stated by Rasmussen & Svedung (2000), “the present dynamic society brings with it some dramatic changes of the conditions of industrial risk management”. Several industry wide trends are apparent, which increase the need for proactive risk management but at the same time add to the difficulty in executing proactive risk management. Based on the work by Brombacher et al. (2001), Brombacher et al. (2005), Knegtering & Pasman (2009) and Rasmussen & Svedung (2000), four major trends affecting proactive risk management in industrial organizations can be identified:

- Increasing product and process complexity
- Increasing complexity in the business chain
- Increasingly dynamic and competitive environment
- Decreasing societal tolerance for failure

Besides these four trends, a fifth trend is observed, i.e. increasing societal risk avoidance. In the following subsections, these five trends will be further discussed.

1.4.1 Increasing product and process complexity

In various industries, it is observed that product and process complexity is increasing rapidly (Brombacher et al., 2001). In the consumer electronics industry, products have become increasingly complex over the years for a number of reasons, including added functionality and increasing software content. As a result, potential customer–product interactions as well as the interactions between product components/subsystems and between products become more difficult to predict (Magniez, 2007; Petkova, 2003). This is also true for the potential risks related to these interactions, such as ‘hard’ and ‘soft’ product failure. In the process industry, Knegtering & Pasman (2009) observe that “process installations have become even more complex than before by the drive for energy saving, higher flexibility, better product quality and smaller buffers, while they are more and more pushed to their operating limits”.

A major contributor to increasing process complexity is the fast pace of change of technology (Rasmussen & Svedung, 2000). For industrial installations, the fast pace of change of technology is often accompanied by another trend, i.e. an increase in scale. As a downside of technological progress, many processes incorporating new technology are characterized by a high degree of uncertainty. This uncertainty originates from the potential interactions within the process given the new technology, and the potential outcome of these interactions. When scale of operations increases at the same time, a growing potential for large-scale accidents is created. Moreover, Rasmussen & Svedung (2000) note that management structures presently do not follow technology’s pace of change, adding to the difficulty in managing the inherent uncertainty associated with new technologies. This trend is also apparent in regulation and legislation lagging behind, resulting in increased responsibility for organizations to demonstrate their efforts in managing risk beyond simply following prescriptive regulations.
The accident at the Deepwater Horizon oil rig described at the beginning of this chapter is characterized by a high degree of technological process complexity. Offshore oil drilling at depths of up to ten kilometers, as was being performed on Deepwater Horizon, requires state-of-the-art technology, employment of which brings along a high degree of uncertainty in terms of potential interactions within the process and the potential outcomes of these interactions. Together with some of the other trends to be discussed, in a cluster of technical, human and organizational causes, this set the stage for the eventual accident at the oil rig and its associated consequences.

1.4.2 Increasing complexity in the business chain

Today’s business chains span the globe and involve a multitude of parties. For example, many suppliers, contract manufacturers, distributors, logistics providers, original equipment manufacturers, wholesalers and retailers are involved in today’s supply chains (Sheffi, 2005). As he states, this “web of participating players creates complexities, making it difficult to realize where vulnerabilities may lie. It also creates interdependencies that exacerbate these difficulties”. As a consequence, assessing potential threats to the organization and the organization’s business chain a priori is increasingly difficult. Other authors support the claim that today’s business chains are becoming increasingly complex. Harland et al. (2003) indicate that current business trends (increasing product/service complexity, outsourcing, globalization, e-business) are leading to complex and dynamic supply networks. As a consequence, risk is increasing in these networks. Rasmussen & Svedung (2000) conclude that the rapid development of e.g. transport systems and information technology “leads to a high degree of integration and coupling of systems and the effects of a single decision can have dramatic effects that propagate rapidly and widely through the global society”. This increases both the need for and difficulty in managing risk proactively in today’s society.

In industries such as the consumer electronics industry, the effects of globalization and outsourcing of activities such as product development and (component) manufacturing to partners spanning the globe create the same type of conditions (Brombacher et al., 2001). Operating in a global market means that organizations are increasingly affected by both local and global disturbances. Outsourcing can create unwanted dependencies on suppliers (Petkova, 2003), and might cause disturbances on the supplier’s side to propagate through the whole business chain. This was the case for mobile phone manufacturer Ericsson, when in March 2000 a small fire in a key component supplier’s semiconductor plant proved to have far-reaching consequences for Ericsson, allegedly losing 400 million dollars in potential revenue in the process (Latour, 2001). This example illustrates that given the increasing complexity in today’s business chains, it is becoming more important to manage potential disturbances throughout the whole business chain, in a proactive manner.

The difficulty in the proactive management of risk due to business chain complexity is also illustrated by the Deepwater Horizon accident. In drilling the exploratory well in the Macondo prospect, various parties were involved. The drilling of the well was executed by the Deepwater Horizon oil rig. This rig was owned by Transocean, but leased by BP, i.e. the operator and principal developer of the Macondo prospect. Besides BP and Transocean, the rig was operated by sub contractors. One of the key contractors was Halliburton, hired by BP to install and cement the production casing. Given the fact that all these parties were involved in the operation of the oil rig, these parties have a joint responsibility for the successful and safe operation of the rig. Such joint responsibility adds to the difficulty in the (proactive) management of risk associated with rig operation.
If not carefully managed, this can lead to a situation which is characterized by uncertainty about the particular responsibilities of each of the parties involved. This was the case at the Deepwater Horizon oil rig, and contributed to the failure in proper risk management and communication, which Graham et al. (2011) marked as one of the root causes of the accident.

1.4.3 Increasingly dynamic and competitive environment

Operating as an industrial organization in today’s society is increasingly demanding, as organizations are subject to severe environmental pressure in a dynamic, competitive environment (Rasmussen & Svedung, 2000). Figure 1.2 gives an impression of the different decision making levels involved in controlling (the risks of) hazardous processes (Rasmussen, 1997). As this figure demonstrates, there is a broad socio-technical environment involved in the management of risk which extends beyond what is being done at a company’s (management) level. This environment brings along environmental stressors putting additional pressure on risk management. One of these stressors is the pace of technological change as was discussed in section 1.4.1. Other environmental stressors include changing market conditions and financial pressures, and changing public awareness.

Fig. 1.2: Socio-technical environment of risk management (Rasmussen, 1997)
Companies today live in a highly competitive environment. Subsequently, there is continuous strong pressure on saving time and reducing costs. From a time perspective, there is strong pressure to bring products to the customer as early as possible, reducing time to market (Brombacher et al., 2005). Doing so is financially attractive for several reasons. Within the consumer electronics industry for example, being on the market faster than competitors gives a competitive advantage. In many other industries such as the oil industry, (operational) delays more directly equal missed revenues. In other words, time is money, resulting in a strong emphasis on doing things faster.

Increased pressure to save time and reduce costs inadvertently affects risk management. As stated by Knegtering & Pasman (2009), “in a world driven by competition and decreasing earning capacity, emphasis is on reducing cost and saving time enhanced by the natural incline to minimize effort. This can easily produce conditions in which risk awareness fades away”. Decreasing interest in risk management due to a strong focus on time and costs is particularly dangerous. With increasing time pressure, the window of opportunity to identify potential threats and to manage these threats effectively decreases. This adds to the difficulty in managing risk proactively.

At the same time, the dynamic environment adds to the need for proactive risk management. This is increasingly acknowledged by governments and regulators, which have historically strongly influenced the way organizations manage risk, particularly in the field of safety management. The Dutch Scientific Council for Government Policy concludes that the increasingly dynamic environment of organizations forces them to adopt a different approach to risk, which takes into account uncertainties instead of previously assumed to be known risks (Wetenschappelijke Raad voor het Regeringsbeleid, 2008). Subsequently, they suggest government and regulator policies which enforce a stronger focus on the identification of potential uncertainties and the translation of these uncertainties into risks.

Furthermore, the strong influence of environmental stressors like public awareness and public opinion can have a detrimental effect on organizations over an extended period of time, as the aftermath of some of history’s major industrial accidents including Deepwater Horizon show. Efforts to prevent such events from occurring, through a proactive approach to managing risk, are thus desirable.

1.4.4 Decreasing societal tolerance for failure

According to Brombacher et al. (2001), people in today’s society often do not fully realize the (technological) complexity of the systems they are using and that surround them, and simply expect them to work. As a result, there is a decreasing tolerance for unexpected and undesired system behavior, deemed as system failure. In the consumer electronics industry, this decreasing tolerance for failure is apparent in the increasing number of complaints relating to problems with product understanding and product expectations (Den Ouden, 2006). The growing number of online communities and action groups and their ability to rapidly spread information about poor product performance on a global scale is an additional complicating factor. In society in general, decreasing tolerance for failure is apparent in the aftermath of some of history’s major industrial accidents. Organizations involved in these accidents will be publicly scrutinized over their involvement in the accident and can experience the effect of negative public image long after the event.
Given society’s decreasing tolerance for system failure, the need to prevent system failure (which includes failure as perceived by system users and other stakeholders) and the need to identify indications of system failure as early as possible become increasingly important.

1.4.5 Increasing societal risk avoidance
A fifth trend is observed in today’s society, i.e. the trend of societal risk avoidance. Nowadays, triggered by the occurrence of events such as the September 11th terrorist attacks, both governments and businesses for various reasons want to avoid certain risks almost at all costs given the potential consequences. As an example, consider the safety measures taken in the (commercial) aviation industry post September 11, 2001, where tremendous amounts of money are spent on measures that may or may not be very effective for prevention. To avoid risk, proactive management of risk is essential. Thus, this fifth trend adds to the need for proactive risk management.

Risk avoidance does not come without its challenges however. Besides the direct consequences associated with risk avoidance (e.g. direct costs of establishing stricter safety measures), there are indirect consequences in terms of costs and damage which should be taken into account as well. This adds to the difficulty in managing risk proactively due to the uncertainty associated with avoiding risk. As an example of the indirect damage of risk avoidance, Gigerenzer (2006) estimated that approximately 1500 Americans died on the road in the year following the September 11 terrorist attacks as a consequence of choosing road transportation instead of air transportation.

1.5 Aim of the thesis
The discussion on societal trends, including increasing product and process complexity, increasing complexity in the business chain, and an increasingly dynamic and competitive environment, has shown that there is a strong need for organizations to proactively manage risk in today’s society. Whereas these trends affect the need for proactive risk management, they also at the same time add to the difficulty in executing proactive risk management. This need for and difficulty in proactive risk management is particularly apparent when considering the occurrence of major industrial accidents such as Deepwater Horizon.

The general aim of this thesis is consequently to gain insight into how organizations proactively manage risk, and, more importantly, how to potentially improve an organization’s ability to proactively manage risk, given the trends mentioned earlier. More specifically, the focus of this thesis is on proactive risk management in industrial organizations as was discussed in section 1.3.

Insight into (the potential improvement of) proactive risk management in industrial organizations is valuable in various respects. Firstly, this thesis adopts an (inter) organizational perspective on risk management, which is in line with the current age of (safety) risk thinking, as was discussed in section 1.3. Thus, it can potentially contribute to a research domain of topical interest. Secondly, such insight might practically help organizations, e.g. by identifying main areas of interest, to anticipate and ideally to prevent organizational threats. Though this is directly beneficial to the organizations in question, benefits of improved proactive risk management can extend to an organization’s broader socio-technical environment (including organizational stakeholders) as well. Thirdly, such insight might further assist governments and regulators in their efforts to establish policies that enforce a stronger focus on the proactive management of risk.
As part of obtaining this thesis’ general aim, the next chapter provides an in-depth discussion on proactive risk management, resulting in research objectives and related research questions which this thesis attempts to answer. Before that, the structure of this thesis is given in the next section.

### 1.6 Thesis structure

This thesis is organized in the following manner:

Chapter 2 firstly demonstrates the particular relevance of early warning signal detection within proactive risk management, given the societal trends discussed in chapter 1. Next, the particular scope on early warning signals and their detection adopted in this thesis is explained. It is then determined how early warning signals and their detection as regarded in this thesis are currently incorporated in various risk management disciplines. Based on these insights, research objectives and related research questions are presented. This chapter ends with a discussion of the chosen research approach.

Chapter 3 explores communication theory, organizational systems theory, and theory on the cognitive processing of warnings by individuals in order to construct a conceptual framework of organizational early warning signal detection. By means of analyzing a case study in which signal detection has played an important role, the value of this framework in providing insight into organizational early warning signal detection is illustrated.

As the discussion of the conceptual framework and case study analysis in chapter 3 will demonstrate, underlying factors exist that can both positively and negatively affect organizational early warning signal detection. Chapter 4 introduces a structured approach to the identification of these factors. Application of the first step of the approach, i.e. model development, is also discussed in this chapter.

Chapter 5 discusses application of the next step of the approach to the identification of underlying factors, i.e. model validation, which resulted in a validated list of underlying factors. Based on the overall results of the application of the proposed approach, conclusions with regard to the effectiveness of the approach are drawn at the end of chapter 5. Also, the issue of how insight gained into influencing factors might be made specific to any one particular industry or organization for the purpose of signal detection improvement is addressed here.

Chapter 6 explores how insight gained into influencing factors might be utilized for the purpose of improving organizational early warning signal detection. For one thing, exploratory insight gained by application of the proposed approach to factor identification can act as input to further research into influencing factors. Results of further research into a particular factor characteristic, i.e. factor relevance, are presented. Lastly, more practical means of utilizing insight into factors and their relevance from an organization’s perspective are explored, amongst other things in the form of a diagnostic evaluation tool.

Chapter 7 gives an overview of the research described in this thesis and the main conclusions. The scientific and industrial contributions are presented followed by a discussion on the generalization of the research results. Lastly, recommendations for future research are stated, and a final reflection is given.
2 Proactive risk management: delineation and discussion

Given the need for and difficulty in managing risk proactively in today’s society, this chapter further explores proactive risk management and illustrates the particular relevance of risk detection and more specifically, early warning signal detection, within proactive risk management. Next, the particular scope on early warning signals and their detection adopted in this thesis is explained. It is then determined how early warning signals and their detection as regarded in this thesis are currently incorporated in various risk management disciplines and what specific methods or tools might be used for detection. Based on these insights, the concept of situation awareness in relation to early warning signal detection is explored, after which the main research objectives and related research questions are presented. This chapter ends with a discussion of the research approach.

2.1 Proactive risk management

Risk management encompasses a wide array of activities, aimed at directing and controlling an organization with respect to risk (ISO/IEC, 2002). The focus of this thesis on proactive risk management as put forward in the previous chapter excludes risk management activities such as containment and recovery, but leaves a broad set of activities included.

This is demonstrated by table 2.1, which gives an overview of the major steps and activities in some of the risk management methodologies that can be found in literature. These steps, which are mainly proactive in nature, originate from various disciplines, including enterprise risk management and loss prevention in the process industry. Differences exist among the methodologies, mainly in terms of which activities are included or excluded, and the terminology used.

More importantly however, table 2.1 emphasizes the commonalities in the overall approach to managing risk across various disciplines. This is particularly true in the ‘early’ steps of risk management. Regardless of different terminology, every risk management methodology acknowledges the value and necessity of risk identification and risk evaluation as an integral part of risk management, and the need for further action based on these insights such as risk treatment and risk monitoring. This is indicated by the dotted lines in table 2.1. On how to deal with the activities put forward and the methods associated with the execution of the activities, disciplines and methodologies differ though. For example, organizations in the process industry will more likely use approaches such as checklists, what-if analysis and hazard and operability studies (HAZOPs) for risk identification (Kletz & Amyotte, 2010). On the other hand, FERMA (2003) lists brainstorming, surveys, benchmarking and scenario analysis as potential identification techniques.

Overall, it can be concluded that risk management is context specific (e.g. depending on the organization’s objectives) and that risk identification takes on a central role in risk management, which is acknowledged across various disciplines.
Table 2.1: Major steps/activities in risk management across various disciplines

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</thead>
<tbody>
<tr>
<td>Related discipline</td>
<td>Risk management in general</td>
<td>Enterprise risk management</td>
<td>Loss prevention in the process industry</td>
<td>Management of business risk in general</td>
<td>Risk management for public and business sector</td>
</tr>
<tr>
<td>Objective setting</td>
<td>Risk assessment - analysis</td>
<td>Event identification</td>
<td>Identify hazards</td>
<td>Identifying risks</td>
<td>Risk assessment - analysis</td>
</tr>
<tr>
<td>Risk assessment - evaluation</td>
<td>Risk assessment</td>
<td>Understanding hazards</td>
<td>Evaluating risks</td>
<td>Risk assessment - evaluation</td>
<td></td>
</tr>
<tr>
<td>Major steps / activities in risk management</td>
<td>Risk response</td>
<td>Avoid hazards</td>
<td>Considering alternatives and selecting the risk treatment device</td>
<td>Risk reporting</td>
<td>Decision</td>
</tr>
<tr>
<td>Risk treatment (elimination, mitigation, transfer)</td>
<td>Control Activities</td>
<td>Reduce severity</td>
<td>Implementing the decision</td>
<td>Risk treatment</td>
<td>Residual risk reporting</td>
</tr>
<tr>
<td>Information &amp; Communication</td>
<td>Reduce likelihood</td>
<td></td>
<td>Monitoring</td>
<td>Monitoring</td>
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<tr>
<td>Risk acceptance</td>
<td>Monitoring</td>
<td>Segregate</td>
<td>Evaluating and reviewing</td>
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<td>Risk information</td>
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<tr>
<td>Risk communication</td>
<td></td>
<td>Apply safeguards (active, passive, procedural)</td>
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<td>Risk monitoring</td>
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<td>Apply residual risk reduction measures</td>
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<tr>
<td>(auditing, evaluation, compliance)</td>
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Risk identification subsequently acts as the input for other risk management activities such as risk evaluation, risk treatment and response, and risk monitoring. Although there is a sequential nature in this, it should be stressed that risk management activities might not always be executed in the order mentioned above. In light of some emerging unforeseen risk for instance, which does not immediately threaten an organization’s survival but does require swift action, an organization might decide to turn to risk treatment and monitoring first instead of further assessing the risk.

In his model, Mitroff (1988) also acknowledges the importance of risk identification in proactive risk management, in particular the proactive management of crises (see figure 1.1 in chapter 1). He roughly distinguishes between two main phases, i.e. signal detection and preparation. Signal detection refers to the identification and comprehension of early warning signals, the existence of which prior to most crises is confirmed by numerous authors including Hensgen et al. (2003) and Mitroff et al. (1987).
As Perrow (1984) claimed, if these signals are detected early enough and appropriate resources are available, crises can be avoided. This can be regarded as one mode of crisis preparation (Hensgen et al., 2003). The other mode of preparation is to take effort to mitigate the effects of a crisis through various strategies, one of which might be to undertake protective measures. Preparation might take the form of safety policies, maintenance procedures, audits, emergency planning or training (Mitroff et al., 1987).

The distinction between detection on the one hand and preparation on the other hand is valid in the risk management methodologies listed in table 2.1 as well. In this perspective, risk detection corresponds to the analysis part of risk assessment, in which risk identification takes on a prominent role. Risk preparation corresponds to the activities following the analysis part of risk assessment, including risk evaluation, risk treatment and response, and risk monitoring. In making this distinction, it is important to stress two things. Firstly, by detecting risks, an organization is essentially preparing for potential threats, as risk detection is a proactive approach to the management of risk. However, it encompasses other activities than the activities considered to be part of risk preparation in this thesis. Thus, one should keep in mind that the distinction between risk detection and risk preparation does not exclude the preparatory nature of risk detection. Secondly, it should be noted that evaluation in this sense is somewhat of a grey area. As stated, risk detection encompasses both identification and comprehension of potential risk(s), of which comprehension does require some sort of evaluation of the identified risk(s). However, risk evaluation as a part of risk assessment in the methodologies provided in table 2.1 is more related to the application of structured approaches, both qualitative and quantitative in nature, such as approaches to assess the probability of occurrence, which consequently act as input to determine the most appropriate risk treatment or risk response. This thesis adopts the latter viewpoint on risk evaluation. Hence, the terms risk comprehension and risk evaluation are not considered to be interchangeable in this thesis, and risk evaluation is considered to be part of risk preparation.

In the remainder of this thesis, the distinction put forward in Mitroff’s model (1988) is adopted. Firstly, because it allows the reconciliation of various risk management methodologies with diverse terminology and varying activities under a single coordinating structure. Secondly, Mitroff’s distinction more strongly puts forward the importance of risk identification in proactive risk management, as was established earlier. Moreover, by considering detection instead of identification, the need for comprehension of risks identified is further stressed though most risk management methodologies do consider comprehension as an integral part of risk identification, albeit more implicitly.

Thus, in this thesis proactive risk management is considered to encompass two main phases: risk detection and risk preparation. This thesis explores the detection phase of proactive risk management rather than the risk preparation phase, the rationale for which is discussed in the next subsection.

### 2.1.1 Increasing uncertainty: detection versus preparation

As was discussed in section 1.2.1, risk is defined in this thesis as the “two-dimensional combination of consequences and associated uncertainties” related to some (initiating) event (adopted from Aven, 2009). Hence, risk management is essentially about the management of uncertainty. To one extent, this involves reduction of uncertainty, which can include gaining more insight into what potential threats an industrial organization will be facing, more insight into the potential consequences, or the combination of both.
To the other extent, risk management involves setting the most appropriate risk management strategy given the (reduced) uncertainty.

Bedford & Cooke (2001) define uncertainty as “that which disappears when we become certain”. Galbraith (1973) mentions the discrepancy between the amount of information available and the amount of information needed as the main source of uncertainty in organizations. Thus, a means for organizations to reduce uncertainty or to become more certain is to reduce the gap between information available and information needed. With respect to risk management, this implies targeting the information discrepancy related to potential threats.

In today’s society, given the trends discussed in chapter 1, reducing this information gap is increasingly difficult. Amongst other reasons, due to increasing technological complexity, increasing business chain complexities and interdependencies and an increasingly dynamic and competitive environment, the information gap concerning potential threats is growing, and organizations in today’s society are facing increasing uncertainty. Besides increasing levels of uncertainty, there is also a shift in the type of uncertainty organizations have to deal with.

In literature, different categorizations of uncertainty exist. One such categorization is the distinction between known unknowns and unknown unknowns, originating from the field of project risk management (Wideman, 1992). Known unknowns are essentially foreseeable uncertainties. Although an organization might be uncertain about the likelihood of occurrence of the uncertain event, its potential consequences and so on, the organization is at least aware of the uncertain event and its potential occurrence. Unknown unknowns on the other hand are unforeseeable uncertainties. These are uncertain events which are completely unexpected for an organization, leading to unawareness about the events and their potential consequences. Managing known unknowns requires a different approach compared to the management of unknown unknowns. In contrast to known unknowns, contingencies can not be planned for unknown unknowns (Pich et al., 2002). In order words, it will be very difficult to prepare and plan for unknown unknowns since an organization will be unaware of such uncertainties.

Amongst other categorizations, Bedford & Cooke (2001) distinguish between model uncertainty and parameter uncertainty. Although model uncertainty is inherent to every model given that it is a representation and thus an interpretation of reality, there is also a structural element in model uncertainty. To illustrate the difference between structural model uncertainty and parameter uncertainty, consider an organization as a system facing potential threats from various sources, which might cause the system to fail. Structural model uncertainty in this perspective relates to insufficient information being available to generate an exhaustive set of models that describe the function of the system (i.e. an organization) and all its dominant failure mechanisms. Due to this lack of information it can be expected that new functional aspects and/or failure mechanisms appear during operation. The aim of the structural model uncertainty reduction is therefore not so much on the optimization of the system but on the capturing of new information to gain a better understanding of the (functional and dysfunctional) behavior of the system. Once there is a structural understanding of the functional and dysfunctional behavior of a system to a degree where (quantitative) models of how a system works are available and can be used in a (fine)tuning process, an organization will shift from structural model uncertainty to parameter uncertainty. Parameter uncertainty refers to the uncertainty on the values of certain parameters in these models (Bedford & Cooke, 2001).
As an example of parameter uncertainty, consider the parameters in a probabilistic risk model, e.g. the probabilities assigned to some uncertain events. Although these probabilities express the degree of uncertainty of the related events, there is a level of uncertainty inherent to the probabilities themselves.

Based on the uncertainty categorizations mentioned above (known unknowns versus unknown unknowns, structural model uncertainty versus parameter uncertainty) and in light of the industry wide trends discussed in chapter 1, it is claimed that management of unknown unknowns and structural model uncertainty is becoming increasingly relevant nowadays. To support this claim, consider that the current trends increase the level of uncertainty organizations are facing due to an information discrepancy between what is needed and what is available, as was demonstrated earlier. Given the increasing complexity and interdependencies in all aspects of operation, organizations lack available information on the potential ways the organization might be threatened. Subsequently, organizations will more and more face threats they are unaware of (unknown unknowns) and which are difficult to capture in existing models and require updated models (structural model uncertainty).

Since threats are increasingly unforeseeable for organizations in today’s society, increasing effort should be taken to detect potential threats organizations are facing, including those risks organizations are not expecting. Notwithstanding the contribution of risk preparation in effective proactive risk management, risk preparation as defined in the beginning of this chapter does require a certain level of understanding of the potential threats an organization will be facing. As mentioned by Mitroff et al. (1987), it will be difficult (though not impossible) to prevent or prepare for crises, i.e. organizational threats, that have not been detected yet, both systematically and comprehensively. This thesis consequently explores risk detection rather than risk preparation, in order to improve proactive risk management in industrial organizations. Though the particular relevance of risk detection for unforeseeable risks is stressed here, it should be noted that risk detection has added value for foreseeable risks or known unknowns as well.

2.1.2 Risk detection

Within organizations, detection can take on various forms. One such form is detection through (automated) detection systems, including computerized process control systems, plant/equipment monitoring systems or management information systems to name but a few (Mitroff et al., 1987). These detection systems are mainly of a preparatory and sometimes preventive nature. Other examples of detection systems include the fire and gas detection systems common in the process industry (Gruhn & Cheddie, 2006; Kletz & Amyotte, 2010). In case of a gas detection system, the main functionality of the system is not to prevent a gas release, but merely to indicate (e.g. through alarms) when and where one has already occurred (Gruhn & Cheddie, 2006). Consequently, fire and gas detection systems can be seen as a mitigation layer used to lessen the consequences of an event that has already occurred.

Most of the detection systems mentioned above are designed to prepare for and potentially prevent certain earlier established risks, e.g. gas leakage or malfunctioning safety equipment. Thus, according to the categorization in proactive risk management adopted in this thesis, i.e. risk detection and risk preparation, these (automated) detection systems are essentially part of risk preparation instead of risk detection. As a result, further exploration of such (automated) detection systems is considered to be outside the scope of this thesis.
Also, construction of (automated) detection systems requires a certain level of understanding of the type of risks the systems are designed for. Thus, in order to design such systems, risks should be (at least partly) foreseeable. However, in today’s society risks are becoming unforeseeable to a larger extent (unknown unknowns, structural model uncertainty), as was demonstrated in the previous section. This requires a different approach to risk detection.

The notion that risk detection can take on various forms is confirmed by numerous authors, including Bird & Loftus (1976) and Reason (1997). In his book *Managing the Risks of Organizational Accidents*, Reason (1997) describes how potential hazards can result in accidents by passing through so called ‘holes’ in the layers of defenses, barriers and safeguards that an organization has established; see figure 2.1. In his ‘Swiss cheese’ model of accident causation, these holes, which are dynamic rather than static, are due to both active failures (failures at the sharp end of the system, which directly affect system safety) and latent conditions (conditions setting the stage for active failures, which e.g. arise from strategic and top level decision making).

![Fig. 2.1: Accident causation model (Reason, 1997)](image)

Fundamental to Reason’s model is the principle of defense in depth, also known as layers of protection. It embodies the idea of multiple lines of defense along accident scenarios “to 1) prevent incidents or accident initiating events from occurring, 2) prevent these incidents or accidents initiators from escalating should the first barriers fail and 3) mitigate or contain the consequences of accidents should they occur” (Saleh et al., 2010). According to Reason (1997), defenses are designed to serve one or more of the following functions:

- Create understanding and awareness of the local hazards
- Give clear guidance on how to operate safely
- Provide alarms and warnings when danger is imminent
- Restore the system to a safe state in an off-normal situation
- Interpose safety barriers between the hazards and the potential losses
- Contain and eliminate hazards should they escape this barrier
- Provide the means of escape and rescue should hazard containment fail

In this overview, the functions listed first and third (creating understanding and awareness, provide alarms and warnings) point to the importance of detection as a defense.
Moreover, it demonstrates that detection is more than having an automated system that provides alarms and warnings when danger is imminent. First and foremost, detection is about understanding and being aware of the potential risks an organization is facing.

This viewpoint is shared by Bird & Loftus (1976), who define pre accident hazard identification as the single most important and characteristic element of system safety. According to these authors, successful hazard identification requires the coexistence of two conditions. Firstly, there must be a management structure and attitude which promotes the asking of questions relating to the potential hazards an organization is facing. Secondly, an organization should be (technically) capable of answering this question, e.g. by having structured identification and analysis methods in place.

**Conclusion**

Detection encompasses more than having an (automated) detection system in place. In fact, risk detection as regarded in this thesis excludes the exploration of (automated) detection systems since these are essentially part of risk preparation. Instead, risk detection is predominantly about being aware of and understanding the potential risks that threaten (industrial) organizations.

In light of risks becoming increasingly unforeseeable in today’s society, it is of particular interest for organizations to be aware of and understand *indications* of potential risks, preferably as early as possible in order to prevent or prepare for the potential threats. As Ansoff (1984) already stated, “at high turbulence levels, it becomes necessary to start the firm’s response while the environmental signals are still weak”. This points to the relevance of the identification and comprehension of early warning signals as an integral part of risk detection, as is acknowledged in crisis management literature (amongst others, see Hensgen et al., 2003; Mitroff et al., 1987; Mitroff, 1988).

Subsequently, this thesis explores the detection of these early indications of risk, also known as early warning signals. More specifically, given the general aim of this thesis put forward in chapter 1, the research interest lies in determining how an organization’s ability to detect such signals might be improved, thereby improving an organization’s ability to manage risk proactively. As a starting point, this requires more insight into early warning signals. This is the topic of discussion of the next section.

### 2.2 Early warning signals

The term ‘early warning signals’, also referred to as ‘weak signals’, is often employed in fields such as resilience engineering and crisis management, as a means to express the existence of some indication(s) preceding the (potential) occurrence of some undesirable event. However, often the term is employed without clearly defining what constitutes an early warning signal and what does not. This section begins by giving some of the definitions of early warning signals that exist in literature and by presenting the definition adopted in this dissertation. Next, the existence of such signals is briefly discussed given the hindsight bias inherent to the retrospective view on industrial accidents. Also, the cost-benefit assessment of early warning signal detection is shortly addressed. Then, this thesis’ scope on early warning signals and their detection is clarified, after which this section ends with a brief conclusion.
2.2.1 Early warning signals: exploration

Table 2.2 gives an overview of some of the definitions of early warning signals that can be found in literature. As is apparent in this non exhaustive overview, thoughts on what constitutes an early warning signal are somewhat mixed. For example, Hensgen et al. (2003) call it “a flashpoint or incident”, Ansoff (1984) “an early indication” and Coffman (1997) talks about “a half-hidden idea or trend”. For Vaughan (1996), it is not so much an incident as it is a piece of information, albeit informal and ambiguous.

<table>
<thead>
<tr>
<th>Literature source</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Vaughan, 1996)</td>
<td>“A weak signal is one conveyed by information that is informal and/or ambiguous, so that its significance is not clear”</td>
</tr>
<tr>
<td>(Hensgen et al., 2003)</td>
<td>“A 'flashpoint', or incident, that may signal the advent of crises in an effort to develop actions and measures intended to prevent an incident from evolving into a crisis”</td>
</tr>
<tr>
<td>(Ansoff, 1984)</td>
<td>“An imprecise early indication about an impending impactful event”</td>
</tr>
<tr>
<td>(Coffman, 1997)</td>
<td>“A half-hidden idea or trend that will affect how we do business, what business we do, and the environment in which we will work; a new and surprising signal from the receiver's vantage point; sometimes difficult to track down amid other noise and signals; a threat or opportunity to your organization...”</td>
</tr>
</tbody>
</table>

Despite these differences in perception, the definitions provided in table 2.2 together indicate some of the main characteristics of early warning signals. These main characteristics are:

1. **Indicative of potential risk(s)**

   Early warning signals point to (some of) the potential risk(s) that an organization is subject to and that might materialize into undesirable events. This implies the following. Firstly, early warning signals are present prior to the materialization of risk. This is acknowledged by numerous authors, including Ansoff (1984), Hensgen et al. (2003), Mitroff et al. (1987), Mitroff & Anagnos (2001), Pearson & Mitroff (1993) and Perrow (1984). Secondly, early warning signals are informative, meaning they convey information about the potential risk(s). Subsequently, if such signals are detected (i.e. identified and understood) early enough and appropriate resources are available, risk could be avoided (Perrow, 1984).

It is important to emphasize that in most cases, a set of conditions will lead to an undesirable event, instead of a single event happening in isolation. For example, this is true for most industrial accidents which are caused by a combination of technical, human, and organizational causes. Consequently, an early warning signal can point to one of the necessary conditions for the event to occur, a combination of conditions, or even all. In analogy to Fault Tree Analysis, this means that an early warning signal might be indicative of any basic event (or even all events) in a minimal cut set (see Bedford & Cooke, 2001). Similarly, multiple early warning signals might point to one particular condition within a set of conditions that will lead to a potential risk.
2. **Difficult to detect**

Another characteristic of early warning signals is that such signals are difficult to detect. This is demonstrated by the fact that most industrial accidents are preceded by a string of early warning signals which remain largely undetected until after the accident, as was the case for the Deepwater Horizon oil spill (Bea, 2010; Graham et al., 2011) and other industrial accidents such as the massive dust explosion at the Imperial Sugar plant (U.S. Chemical Safety and Hazard Investigation Board, 2009), for example. The difficulty in detection can partly be attributed to the tremendous amount of information most organizations are bombarded with. As a result, “for signal detection to be effective, the challenge is to learn how to separate those signals indicative of a looming crisis from the barrage of noise which is part of daily business” (Pearson & Mitroff, 1993). An additional complicating factor in detecting early warning signals lies in the nature of these signals, namely that they are both imprecise and early as will be discussed next.

3. **Imprecise**

Early warning signals are often described as being ‘vague’, ‘imprecise’, ‘ambiguous’ or ‘half-hidden’. As stated earlier, early warning signals convey information about the potential risk(s), but this information is characterized by a large degree of uncertainty and subsequently the meaning of this information is yet largely unclear for the organization. It hints at the outcome of a potential risk, but it is too early to tell how things will unfold. Subsequently, early warning signals are difficult to interpret due to their imprecise nature.

Ansoff (1975; 1984) acknowledges the imprecise nature of early warning signals. He states that when a potential threat first surfaces, an organization must be prepared for very vague information. This information will gradually develop and improve in time, which is expressed in five different states of knowledge; see table 2.3. The columns of table 2.3 correspond to the states of knowledge, whereas the rows correspond to the information content related to these states of knowledge. Since early warning signals are early indications of potential risk, these signals will encompass only a sense of the potential threat the organization is facing, at best with some understanding of the source of the threat. This corresponds to the lowest states of knowledge, i.e. level 1 and 2. As table 2.3 shows, information at these levels will be imprecise and vague. There will only be some conviction that potential threats are impending and at best, an organization is able to determine where the threat originates, which could be inside or outside the organization.

4. **Early**

The distinction between warning signals being either ‘early’ or ‘late’ is relevant when considering an organization’s window of opportunity to respond to impending risks. Roberto et al. (2006) refers to this as a “recovery window”, i.e. the time period between the first signs of a potential problem and a major failure. Early warning signals are the first indications of potential risk. Detecting these signals in a timely manner will allow an organization to prepare for an appropriate response, enlarging the organization’s response opportunity.
Table 2.3: States of knowledge under discontinuity (Ansoff, 1975; Ansoff, 1984)

<table>
<thead>
<tr>
<th></th>
<th>(1) Sense of threat</th>
<th>(2) Source of threat</th>
<th>(3) Threat concrete</th>
<th>(4) Response concrete</th>
<th>(5) Outcome concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conviction that discontinuities are impending</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Area of organization is identified which is the source of discontinuity</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Characteristics of threats, nature of impact, general gravity of impact, timing of impact</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Response identified: timing, action programs, budgets</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Profit impact and consequences of responses are computable</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

At the same time however, when signals are early, it will be more difficult to determine the most appropriate response, since the exact nature of the risk will unravel itself closer to the actual event, potentially decreasing response effectiveness. The opposite is true for late warning signals. Since these signals are closer in time to the major failure or other undesirable event, response opportunity will likely be smaller, but response effectiveness will likely be higher in comparison.

Clearly, an organization should take into consideration both the ‘early’ and ‘late’ signals of impending risk(s). They do however require a different approach. The later in time a signal is detected, the closer in time the undesirable event will occur, which means an organization is moving towards emergency measures or even containment type of approaches. Preparation and particularly containment will be the most important phases of risk management for such late signals. Given the early timing and imprecise nature of early warning signals, an organization should adopt a different strategy, and focus its attention to identifying and understanding these early indications of potential risk(s) in a timely manner in order to prevent or prepare for potential threats.

Concluding, early warning signals are indicative of potential risk(s), difficult to detect, imprecise and early. This description comes closest to the definition provided by Ansoff (1984). However, in his definition early warning signals are indicative of both threats and opportunities. Since this thesis specifically explores the proactive management of threats instead of opportunities, in particular for industrial organizations, early warning signals are defined in this thesis as “imprecise early indications of impending risk(s) that threaten an industrial organization”.

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2.2.2 Early warning signals in foresight and hindsight

When analyzing major industrial accidents, such accidents can often be attributed to some ‘logical’ sequence of (indications of) events that set the stage for the accident to happen. In retrospect, given this information, the accident might thus appear to be more predictable than it really is. In foresight however, such accidents are very difficult to predict, let alone prevent. In other words, an (undesirable) event might appear to be more predictable than it actually is, given knowledge of the outcome.

This phenomenon can be attributed to bias. As was demonstrated in the classical work by Tversky & Kahneman (1974), decision making under uncertainty is not merely a matter of rationality. Instead, judgment under uncertainty often rests on a limited number of simplifying heuristics and associated biases (Gilovich & Griffin, 2002). Though such heuristics, which one could regard as cognitive shortcuts, might prove to be simple and efficient, they can also act as a source of human error in decision making.

One particular kind of bias, related to the anchoring heuristic, is hindsight bias. Hindsight bias is the tendency for people to exaggerate the chances that they would have predicted the outcome of some event in advance (Chapman & Johnson, 2002). As Fischhoff (1982) states, “in hindsight, people consistently exaggerate what could have been anticipated in foresight”. In that sense, knowledge of the outcome acts as an anchor that influences judgments of the predictability of the outcome (Chapman & Johnson, 2002).

Some might argue that this ‘illusion’ of predictability extends to the existence of early warning signals. That is, early warning signals are the product of hindsight bias, and in reality are not present or are unable to be detected. This is not the case however. Numerous authors including Ansoff (1984), Hensgen et al. (2003), Mitroff et al. (1987), Mitroff & Anagnos (2001), Pearson & Mitroff (1993) and Perrow (1984) have acknowledged the existence of early warning signals prior to most industrial accidents, which is confirmed by the analysis of major industrial accidents such as Bhopal. Also, examples (though limited) are available in literature that describe the effectiveness of organizations in detecting early warning signals in a timely manner, thereby largely mitigating consequences. One such example is the response of Nokia to early warnings it received of a major supply disruption (Latour, 2001), which will further be discussed in the next chapter.

Rather, hindsight bias is present in the value assigned to signal detection as a means of accident prevention. In hindsight, people often overestimate the potential of signal detection to prevent an accident of occurring. This will not be possible in most cases though, given the imprecise and early character of early warning signals. This points to the difficulty in detection. Consequently, it cannot be claimed that early warning signal detection will lead to prevention of organizational threats. However, since such signals are often present and early detection might help an organization to proactively manage the associated risks (e.g. through consequence mitigation), it is worthwhile to determine how an organization might improve its ability to detect such signals.

2.2.3 Cost-benefit assessment of early warning signal detection

The need for proactive risk management, and consequently the need for early warning signal detection, has already been put forward in chapter 1 and section 2.1.
As was discussed, proactive risk management is a means to manage the increasing level of uncertainty organizations are facing nowadays. In order to do so however, an organization should be willing to invest, both financially and time wise, in proactive risk management.

Explicitly demonstrating the benefit of early warning signal detection (e.g. in monetary terms) is difficult though, particularly for organizational threats that might have severe impact, but are unlikely to occur. These are so-called ‘low probability – high consequence’ events. Most major industrial accidents fall in this category. For unforeseeable risks with major impact, the benefit of risk avoidance might be even harder to justify. On the topic of risk and vulnerability avoidance, Karydas & Rouvroye (2006) agree that benefits of investments in vulnerability avoidance are often difficult to assess or quantify, and “direct benefits only accrue after they are triggered by an unexpected event”. This is inherent to any investment in cost avoidance, including early warning signal detection. Sheffi (2005) notes that “since costs avoided do not show up on any financial statement, or any incentive system, and costs incurred are visible, there is little natural incentive to invest in cost avoidance”. The major challenge is thus to “put a value on avoiding a problem that you don’t have because you spent money to avoid it”.

To show the value of early warning signal detection in today’s society, first some common yet faulty rationalizations that management executives might apply (and have applied) in order to justify non investment in managing crises are presented (recall that Weick (1988) defines crises as “low probability, high consequence events that threaten the most fundamental goals of an organization”). Table 2.4 presents an extract of an overview of rationalizations presented by Pearson & Mitroff (1993).

<table>
<thead>
<tr>
<th>Category</th>
<th>Rationalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational properties</td>
<td>‘Our size will protect us’, ‘certain crises only happen to others’, ‘excellent, well managed companies do not have crises’</td>
</tr>
<tr>
<td>Environment properties</td>
<td>‘Nothing new has really occurred that warrants change’, ‘accidents are just a cost of doing business’</td>
</tr>
<tr>
<td>Crises properties</td>
<td>‘Each crisis is so unique that is not possible to prepare for them’, ‘it is enough to react to a crisis once it has happened’</td>
</tr>
<tr>
<td>Prior efforts in crisis management</td>
<td>‘In a crisis situation, we just need to refer to the emergency procedures we’ve laid out in our crisis manuals’</td>
</tr>
</tbody>
</table>

Stating that an organization will remain unaffected due to its size or that each crisis is so unique that no preparation is possible or needed is obviously erroneous, as the occurrence of many industrial accidents including the Deepwater Horizon oil spill have shown. The misconception of these and other rationalizations becomes even more apparent in light of the trends discussed in chapter 1. One particular trend that stands out with respect to the value of signal detection is the increasing complexity and dynamics of an organization’s environment. As a result, the number of unforeseeable risks an organization will be facing is increasing, which makes it more important for organizations to be aware of indications of such unforeseeable risk in a timely manner, through early warning signal detection.
On a more philosophical note, one can argue that Taleb (2007) draws the same conclusion in his book ‘The Black Swan: The Impact of the Highly Improbable’. According to Taleb, we are currently living in “Extremistan” instead of “Mediocristan”.

Contrary to Mediocristan, where the past might be a good indication of what will happen in the future, in Extremistan it is hard to predict what will happen in the future based on past information. As he states, “Mediocristan is where we must endure the tyranny of the collective, the routine, the obvious, and the predicted; Extremistan is where we are subjected to the tyranny of the singular, the accidental, the unseen, and the unpredicted”. Consequently, “the modern world, being Extremistan, is dominated by rare – very rare – events” (Taleb, 2007). Given the potential impact of these events, such events should not be disregarded as extreme outliers with no significant influence on the aggregate. In other words, such singular, rare, but impactful events can disproportionally affect organizations and even society as a whole. Though Taleb claims we should not pretend to be able to predict such events, they should not be disregarded as being only marginally influential. Consequently, an organization should take on an active approach and not simply ‘wait and see what happens’. One potential strategy is to prepare for that which is not expected, through being aware of and understanding early indications of potential threats. This is the viewpoint taken in this thesis.

2.2.4 Early warning signals and their detection: scope

The definition of early warning signals presented in section 2.2.1 already excludes a broad range of potential signals. For example, warning signals that portend natural disasters such as hurricanes or earthquakes do not fit the definition, since these signals are neither imprecise (the potential threat will be more or less concrete, and an organization will most likely know how to respond) nor will they be early in most cases. Thus, this thesis excludes indications of natural threats, and instead considers early indications of threats that are “man-made” (Turner & Pidgeon, 1997).

Nevertheless, a further discussion of this thesis’ scope on early warning signals and their detection is necessary, given this thesis’ interest in risk detection instead of risk preparation, and in light of risks becoming increasingly unforeseeable in today’s society. This discussion consists of two parts. The first part of the discussion relates to the nature of the signal itself. The relation between early warning signals and precursors is considered, and early warning signals of unforeseeable risks are discussed in further detail. The second part of the discussion relates to detection of the earlier mentioned signals. Early warning signals in the context of (automated) risk monitoring systems and the potential use of risk indicators to provide early indications of risk areas and potential threats are the main topics of interest here.

Early warning signals versus precursors

Closely related to early warning signals is the concept of accident precursors. Phimister et al. (2004) give a broad definition of precursors as the “conditions, events, and sequences that precede and lead up to accidents”. In the same book, Carroll (2004) defines accident precursors as “events that must occur for an accident to happen in a given scenario, but that have not resulted in an accident so far”. Given these definitions, precursors correspond to the conditions or basic events that in combination lead to the occurrence of some undesirable event (i.e. an organizational threat). In that respect, early warning signals as defined in this thesis can be considered as early indications of accident precursors.

However, Körvers (2004) defines precursors as “pre-warning signs of accidents”, more specifically as re-occurring (indirectly safety related) deviations in an operational process.
According to this definition, precursors can be regarded as early warning signals, albeit a specific class of early warning signals. Firstly, early warning signals as regarded in this thesis are not restricted to an organization’s operational process, but might affect and originate from all levels (strategic, tactical, operational) and all subsystems of an organization, as well as an organization’s external environment. Secondly, the signal itself might not necessarily be re-occurring. Thirdly, precursors as defined by Körvers (2004) mainly cover one particular category of risks, namely ‘high likelihood’, ‘low consequence’ risks. In comparison, early warning signals in this thesis mainly cover ‘low likelihood’, ‘high consequence’ risks such as major industrial accidents instead, which will be explained later in this chapter.

**Early warning signals of unforeseeable risks**

As stated earlier, an early warning signal can point to one of the necessary conditions for an undesirable event (i.e. a potential organizational threat) to occur, a combination of conditions, or even all. This also applies to early warning signals of unforeseeable risks, i.e. potential threats that are completely unexpected for an organization. The unexpected character of such risks might be attributed to one particular unexpected condition, or the unexpected effect of a combination of conditions. In the former situation, it is unlikely that an organization currently purposely captures information related to the unexpected condition, since it is difficult to actively capture information about threats which an organization is yet unable to grasp. In the latter situation, it is more likely that an organization is already capturing some information related to one of the conditions which combined have an unexpected effect. However, the relation between the currently available information and the potential threat is still largely unknown.

In others words, information with respect to unforeseeable risks, including early indications of these risks (i.e. early warning signals) is in all likelihood currently not purposely captured by organizations, or the relation between currently available information and the unforeseeable risk might be unknown. Either way, the main question is how such signals might be detected. For that purpose, two common approaches that organizations use to detect early warning signals of potential risks, i.e. (automated) detection by means of risk monitoring systems and the use of risk indicators, are discussed next.

**Early warning signals in the context of (automated) risk monitoring systems**

An important function of an organization’s active (automated) monitoring systems is to keep track of earlier established parameters and to indicate systematic changes to these parameters as early as possible. Consider a process control system, for example. Beyond the natural variability inherent to process parameters, a more systematic variability could occur that might cause the process mean to shift. If this is indeed the case, these systematic changes must be detected as soon as possible to allow for corrective action (Lewis, 1996). One of the ways in which an organization is able to gain early warning of these disturbing influences, is by applying the principles of Statistical Process Control and by setting control limits also known as operating levels for process parameters. During normal operation, parameters will vary between these lower and upper operating levels. However, if a process parameter gets too close to one of the operating levels, a (pre) alarm might be triggered and further action by a process operator might be required. Setting these operating levels and the associated alarms is challenging though, since these will need to be sensitive enough to respond to a systematic deviation as early as possible, without unnecessarily responding to the natural variability inherent to the parameters being monitored. A more in-depth exploration of process control systems within an organization’s safety system is beyond the scope of this thesis; the reader is
referred to Rouvroye (2001) for more information on this topic. For a basic introduction into Statistical Process Control, see e.g. Montgomery & Runger (1999).

This short discussion on process control systems illustrates the following. Firstly, given the definition of early warning signals provided in section 2.2.1, one can draw the conclusion that early indications of systematic changes in process parameter values that are captured in an organization’s (automated) monitoring systems fit the definition and thus might be considered as early warning signals. Secondly, by setting appropriate operating levels for the parameters of interest, these signals might be detected in a timely manner.

Though it is acknowledged that (automated) monitoring systems are designed, among other reasons, to capture and respond to early warning signals, this thesis excludes early warning signal detection by means of setting appropriate operating levels to known parameters. For one reason, as mentioned earlier, (automatic) detection by means of existing monitoring systems within organizations is considered to be part of risk preparation instead of risk detection, and is therefore outside the research scope of this thesis. Moreover, this type of detection requires a certain level of understanding of the type of risks the systems are designed for, resulting in the parameters of interest to be monitored and the related operating levels to be set. Given the fact that risks are increasingly unforeseeable in today’s society, it will be difficult to determine the parameters of interest indicative of such unforeseeable risks beforehand and to set appropriate operating levels. Consequently, this thesis explores other means of early warning signal detection beyond the (automatic) detection of systematic changes to known parameters.

Nevertheless, monitoring systems such as a process control system can still act as a source of early warning signals of unforeseeable risks, though they are not purposely designed to detect early indications of such risks. The trouble here lies in trying to understand the relation between the potential threat and the available information, and to filter out that which is relevant from the surrounding noise.

Early warning signals and risk indicators
An important element of an organization’s risk management system is the establishment of so-called risk indicators (also referred to as safety indicators in a safety management system). A risk indicator is “a measurable/operational definition of a risk influencing factor, i.e. an aspect (event/condition) of a system or an activity that affects the risk level of this system or activity” (Øien et al., 2011a). Its main purpose is to provide indications of risk areas and potential threats to organizations, to allow organizations to focus their resources on the problem areas (Körvers, 2004). A distinction that is often made nowadays is between lagging indicators and leading indicators. Lagging indicators (sometimes also called direct or reactive indicators) are after-the-event type of indicators, such as the number of accidents or near misses (Øien et al., 2011a). Such indicators are not very useful for early warnings. Leading indicators (sometimes also called indirect or proactive) provide feedback before-the-event, which is a type of active monitoring. Leading indicators are potentially very useful for early warnings. Table 2.5 gives some examples of leading indicators used in various industries, which may be restricted to e.g. operations or management or may be more generally applicable within industrial organizations.
Table 2.5: Leading indicators from a variety of industries (taken from Øien et al., 2011a, b)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Area</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>Operator specific</td>
<td>Maintenance quality index, Maintenance ambition index, Work order management index</td>
</tr>
<tr>
<td>Chemical</td>
<td>Corporate / management</td>
<td>Number of overdue inspections and tests, completion of major accident risks assessments, closure of major accident risk group recommendations</td>
</tr>
<tr>
<td>Energy</td>
<td>Organizational</td>
<td>Percentage of human performance issues getting root cause analysis, Ratio of unplanned to planned work orders, Number and duration of temporary modifications, Number of quality management observations</td>
</tr>
<tr>
<td>Aviation</td>
<td>Overall</td>
<td>Number of internal and external audits per year, Number of continuation or recurrent training per technician per year, Back-log (Hold Item List) per aircraft type per 100,000 flight hours</td>
</tr>
</tbody>
</table>

To obtain valid leading indicators is a major challenge though (Øien et al., 2011b). For one thing, most research on indicators has focused on personal safety instead of major accidents. Personal safety indicators are largely lagging (e.g. injury rates) and do not provide sufficient early warning of major accidents. As the Baker report in the aftermath of the BP Texas City accident showed, such indicators are however still prevalent in industries such as the refinery industry and are used as a measure of system safety (Baker et al., 2007). Moreover, Körvers & Sonnemans (2008) identified a gap between current safety indicators and pre-warning signals found in analyzed accident reports. This gap exists of information which is currently available in daily operation, of which it is unknown that it may lead to unsafe situations or accidents.

To summarize, leading indicators are potentially very useful for early warnings, but are difficult to obtain. Consequently, gaps exist between the current (leading) indicators and early warning signals. Though this gap exists due to the unknown relation between currently available information (e.g. originating from an operational process) and the potential occurrence of accidents or other threats, this gap is also present due to missing information. Since unforeseeable risks essentially relate to either missing information or insufficient understanding of available information, it can be stated that leading indicators are yet insufficiently capable of indicating unforeseeable risks and their early warnings. Also, establishing risk indicators is a way of risk preparation based on previously determined risk influencing factors, and does not constitute risk detection as discussed earlier. Since the focus in this thesis is on risk detection and not on risk preparation, the establishment and/or potential use of risk indicators as a means to detect early warning signals is not further explored.

2.2.5 Conclusion

As discussed in section 2.2.1, early warning signals are defined in this thesis as “imprecise early indications of impending risk(s) that threaten an industrial organization”. Though this definition largely excludes e.g. natural threats, it still includes a wide spectrum of signals and ways to detect such signals. Given this thesis’ interest in risk detection instead of risk preparation, and in light of risks becoming increasingly unforeseeable in today’s society, it was considered that detection by means of (automated) monitoring systems and detection by utilizing risk indicators are not suitable for early warning signal detection as regarded in this thesis. Instead, an additional means of detection is necessary.
As will be further discussed in the next two sections, an organization will largely depend on its people to detect early warning signals of unforeseeable risks. For example, consider a process operator who notices slight periodical deviations in a monitored process parameter, i.e. pressure. These deviations are small enough not to trigger an alarm in the control room nor trigger any other type of corrective action. Given the operator’s insight that these deviations in pressure might be a sign of undesirable vibrations, which consequently might affect the plant’s mechanical integrity, he might decide to visually inspect the plant to locate the source of vibration. In that sense, the periodical deviations in pressure can be regarded as an early warning signal of a potential threat to the plant’s integrity, which depends on the operator for detection, eventually resulting in action, i.e. a visual inspection.

The example above relates to information that is purposely captured by an organization but for which the relation between the available information and the potential threat is largely unknown. In this situation, detection and interpretation will largely depend on people within an organization instead of some sort of automated system. The same is true when information is not purposely captured, i.e. when information is missing. Fortunately, people within an organization are capable of seeking out information beyond existing information systems and to ‘pick up the most minute signals’ (Mitroff & Anagnos, 2001). Some further examples of such early warning signals might include: frequent earlier incidents prior to a major accident, such as earlier small-scale, low impact releases months before a major gas release; poorly motivated, even disgruntled, employees; inadequate quality assurance and quality control allowed to continue over a longer period, etc.

Given this thesis’ scope on early warning signals and their detection, the next section explores how early warning signal detection is currently incorporated in various risk management disciplines, including crisis management, enterprise risk management, safety management and resilience engineering, and which, if any, methods and tools are available in literature for early warning signal detection.

### 2.3 Early warning signal detection: insights from various risk management disciplines

In the next sections, literature from various risk management disciplines is reviewed. For the review, each risk management discipline is discussed based on the following subjects:

- **Incorporation.** Is early warning signal detection explicitly acknowledged in the reviewed risk management discipline as an integral part of risk management?
- **Guidelines.** Are guidelines to early warning signal detection given, either general or more specific, and if so, are these guidelines suitable for early warning signals and their detection as regarded in this thesis?
- **Methods and tools.** Beyond guidelines, are methods and tools available for early warning signal detection? If so, are these methods and tools suitable for early warning signals and their detection as regarded in this thesis?

The reviewed literature represents only a cross section of the large body of literature available on crisis management, enterprise risk management, safety management and resilience engineering. Nevertheless, it is believed that this cross section portrays the overall sentiment in the risk management disciplines with regard to the acknowledgement of early warning signal detection and the main suggestions or guidelines on how to detect such signals.
With regard to the potential methods and tools for signal detection, it should be noted that the intention of this section is not to provide an exhaustive overview, nor to describe these methods and tools in detail. Rather, the intention is to learn if more structured approaches beyond given guidelines are available, and if these approaches are suitable for early warning signals and their detection as regarded in this thesis.

2.3.1 Crisis management
Crisis management deals with the management of major events that have the potential to threaten organizations as a whole, as well as their stakeholders. These corporate crises tend to be precipitated by people, technology, organizational structures or by natural disasters (Elsubbaugh et al., 2004), and exact a major toll on e.g. human lives, property, financial earnings or an organization’s reputation (Mitroff & Anagnos, 2001).

Incorporation
Overall, the value of early warning signal detection as an integral part of the management of crises is acknowledged in crisis management literature (Elsubbaugh et al., 2004), (Hensgen et al., 2003), (Mitroff et al., 1987), (Mitroff, 1988), (Mitroff & Anagnos, 2001), (Pearson & Mitroff, 1993). As figure 1.1 in chapter 1 depicts, detection of early warning signals is one the two main phases in proactive crisis management.

Guidelines
Within crisis management, guidelines on how to detect early warning signals are abundant. Mitroff et al. (1987) stress the importance of having early warning systems in place, including computerized process control systems, management information systems and environmental scanning systems. Elsubbaugh et al. (2004) agree with the need for information systems, but at the same time note that environmental scanning requires experienced people who are supported by an information system. Mitroff (1988) states that a crisis sends off a trail of early warning signals and that crisis managers must be alert to those signals. Similarly, Mitroff & Anagnos (2001) indicate the ability of people to pick up the most minute signals when it is in their interest, making people within an organization one of the most valuable signal detection mechanisms an organization has. These various guidelines from crisis management literature imply that an organization depends on both people and information systems for early warning signal detection, though some authors might emphasize the particular contribution of one over the other.

Methods and tools
Beyond these guidelines, crisis management gives little support on how an organization can practically set up early warning signal detection, or which specific methods or tools might be employed to improve organizational signal detection. For example, Mitroff & Anagnos (2001) give recommendations such as the need for open communication and the need to reward signal detection and emphasize safety, but do not provide a structured approach to do so. Also, the importance of utilizing signal detection mechanisms already in place is emphasized, though it is to a large extent unclear how an organization might accomplish this.

2.3.2 Enterprise risk management
Enterprise risk management (ERM) is defined as “a process effected by an entity’s board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of
entity objectives” (COSO, 2004). Commonalities exist between crisis management and ERM, such as their focus on the organization or the enterprise as a whole, though differences exist as well. In contrary to crisis management for instance, ERM considers both threats and opportunities that affect the objectives of an enterprise; either hazardous, operational, financial or strategic in nature.

Incorporation

Figure 2.2 depicts the relation between ERM components (horizontal rows) and objective categories (vertical columns) across an entity’s units (enterprise levels, including division, business unit, and subsidiary) (COSO, 2004). As is apparent from figure 2.2, early warning signal detection is not explicitly mentioned as one of the ERM components. Of the ERM components indicated in figure 2.2, event identification would come closest to implicitly incorporate the detection of early warning signals as regarded in this thesis. However, according to the Casualty Actuarial Society (2003), event/risk identification in ERM involves documenting conditions and events that represent threats to the enterprise’s achievement of its objectives or potential areas for competitive advantage. The focus here is on documentation, and not so much on understanding the potential risk through being aware of the threats and opportunities an enterprise is facing. Hence, early warning signal detection as regarded in this thesis is not considered to be an integral part of ERM.

Guidelines, methods and tools

Since early warning signal detection is not an integral part of ERM, guidelines on detection are not readily available in ERM literature. Methods and tools to be used for risk identification are provided however. The left column of table 2.6 presents some of the techniques available for risk identification in ERM, which include auditing, benchmarking, brainstorming, surveys and scenario analysis to name but a few. A further discussion of each of these methods is beyond the scope of this dissertation though, since it is argued that these risk identification approaches are not suitable for detecting early warning signals. To explain, recall that early warning signals in this thesis are defined as imprecise early indications of impending risk(s) that threaten an industrial organization.
At best, risk identification approaches can identify parameter(s) of interest indicative of potential risks for which then one potential risk response strategy might be to include the parameter(s) in one of an organization’s early warning systems. This implies that, even in this best case scenario, risk identification methods are not suitable for signal detection, but merely act as input to risk response strategies.

<table>
<thead>
<tr>
<th>Table 2.6: Common risk identification techniques in literature</th>
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<tbody>
<tr>
<td><strong>Enterprise risk management</strong></td>
</tr>
<tr>
<td>Auditing</td>
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<td>Benchmarking</td>
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<td>Brainstorming</td>
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<td>Internal Workshops</td>
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<td>Questionnaires / Surveys</td>
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<td>Scenario Analysis</td>
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<td>SWOT Analysis</td>
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<td>Value Chain Analysis, Business Chain Analysis</td>
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Within the scope of this thesis, there are additional reasons not to explore risk identification approaches. Firstly, according to the distinction put forward in the beginning of this chapter between risk detection and risk preparation, application of risk identification approaches is considered to be a form of risk preparation. Since this thesis considers risk detection instead of risk preparation, such approaches are not further explored. Moreover, in light of risks becoming increasingly unforeseeable in today’s society, one can argue that these approaches are less suitable to identify unforeseeable risk (let alone early indications of such risk), given that input to these approaches is mainly limited to what people can imagine will happen to an organization based on their (previous) knowledge or experience (e.g. through brainstorming, survey methods) or an enterprise’s earlier exposure to risk (e.g. through benchmarking).

2.3.3 Safety management

According to Cameron & Raman (2005), safety management and safety management systems have two principal roles: occupational health and safety management and process safety management. Whereas occupational health and safety management is largely occupied with high probability, low consequence personal safety related issues such as slips, trips and falls, process safety management is more directed to low probability, high consequence safety related issues. These issues include potential (hazard) risks involved in handling hazardous substances as is common in e.g. the process industry, including gas leaks, fires and explosions. Given this thesis’ interest in proactively managing risk in industrial organizations, which constitutes the management of potential threats that may include but are not restricted to personal safety, the discussion on early warning signal detection in safety management below is targeted to process safety management instead of occupational health and safety management.

Incorporation

Similar to ERM, early warning signal detection is generally not explicitly incorporated in safety management. Cameron & Raman (2005) mention hazard identification as the single most important step in managing process risks, but hazard identification here mainly relates
to the selection and application of (a combination of) structured hazard identification tools. The right column of table 2.6 presents some of these tools including Hazard and Operability Analysis (HAZOP) and Failure Mode and Effects Analysis (FMEA). Although useful for identification, such tools are not suitable for early warning signal detection as was discussed in the previous section and are hence not considered in further detail.

**Guidelines**
Detection of early warning signals is implicitly included in process safety management, through (automated) process control systems capable of detecting early warning signals of earlier established parameters as is acknowledged by Cameron & Raman (2005). The ability of people within an organization to detect early warning signals is deemed relevant in safety management as well, and some guidelines on how to effectively accomplish this are available in literature.

For example, Burns (2002) notes that insufficient employee confidence in management and its disciplinary review process might lead to a “tendency toward deafness and blindness to early warning signals of potential problems”. This implies that people are an essential element to any effective system for capturing and evaluating ‘red flags’, such as performance deficiencies, that act as early warning signals indicating the potential for a serious incident (Burns, 2002). Bird & Loftus (1976) define pre accident hazard identification as the single most important and characteristic element of system safety. According to these authors, successful hazard identification requires the coexistence of two conditions, i.e. having a management structure and attitude in place which stimulates people to be critical of potential hazards, and at the same time having structured identification and analysis methods in place.

**Methods and tools**
The majority of the (hazard) risk identification techniques presented in the right column of table 2.6 are capable of identifying (hazards) risks and potential indications of these risks through the functional structure of a technical system, but do not explicitly incorporate organizational or social factors contributing to risk. Methods that are capable of incorporating such factors in risk identification and analysis are available though, and include amongst others Management Oversight and Risk Tree analysis (MORT analysis) and Tripod-Delta. MORT analysis (Johnson, 1980) is a safety analysis method compatible with complex, goal oriented management systems. Key element of the approach is a fault tree diagram which represents the causes of management oversights or omissions, assumed risks or the combination thereof, and includes approximately one hundred generic events and many more basic events. Analysis of the tree makes it possible to analyze accidents or other safety related events for root causes and additional contributing factors or evaluate (existing) safety programs. In the Tripod-Delta approach (Hudson et al., 1994; Reason, 1997), safety management is basically considered as an organizational control problem, with particular emphasis on the control of human and organizational factors. Tripod-Delta distinguishes between so-called General Failure Types (GFTs) and local triggering factors, of which the former are knowable in advance and thus potentially correctable. In total, 11 GFTs were selected; including but not restricted to hardware, design, maintenance management, procedures, communications, training and defenses. In a bottom-up approach, (organizational) safety assessment is derived from GFT checklists, for which task specialists provide input (identification of observable GFT indicators, checklist completion).
Both MORT analysis and Tripod-Delta are capable of proactively identifying and analyzing (indications of) risk, particularly organizational or human contributions to (safety) risk. However, these methods are not capable of detecting early warning signals as regarded in this thesis. Firstly, it should be noted that both methods essentially rely on techniques listed in table 2.6. Basically, MORT analysis relies on fault tree analysis, and Tripod-Delta relies on checklist analysis and ranking. Although useful for risk identification, fault trees and checklists are not suitable for early warning signal detection as regarded in this thesis, as was discussed earlier. MORT analysis and Tripod-Delta can provide valuable input to signal detection though, by indicating human and organizational factors most in need of (early) attention. By doing so, they partly address the ‘where’ aspect of signal detection, without addressing the ‘how’ aspect.

2.3.4 Resilience engineering

Resilience engineering is a paradigm for safety management (Woods & Hollnagel, 2006), which takes on a different approach to the management of (safety) risk illustrated above. Essentially, organizational resilience is “the intrinsic ability of an organization or system to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and/or in the presence of a continuous stress” (Hollnagel, 2006). Instead of trying to anticipate potential risk by using e.g. structured risk analysis techniques, resilience engineering accepts that some risks will be unexpected and urges organizations to be mindful about errors that have already occurred and to correct them before they worsen and cause more serious harm (Weick & Sutcliffe, 2007). This requires organizational flexibility, and more specifically the ability to 1) absorb strain and preserve functioning despite the presence of adversity, 2) recover or bounce back from untoward events and 3) learn and grow from previous episodes of resilient action (Weick & Sutcliffe, 2007).

Incorporation

As stated by Woods & Hollnagel (2006), it is easier to recover from a potentially destabilizing disturbance if it is detected early. Overall, the existence of early warning signals and the need to detect these signals as early as possible is acknowledged as one of the prerequisites for organizational resilience (Hollnagel et al., 2006; Sheffi, 2005).

This is also the case in a field closely related to organizational resilience, i.e. research on so-called High Reliability Organizations (HROs). Within HROs, the unexpected (including potential risks) is managed through determined efforts of ‘mindful’ actions. As stated by Karydas & Rouvroye (2006), “mindful organizations notice the unexpected in the early stages and disrupt its development. If unable to stop the unexpected, they focus on containing it. If containment of the unexpected is not effective, they focus on resilience and swift recovery of the organization”. Development of mindfulness in HROs requires the following basic principles (Weick & Sutcliffe, 2007):

- Preoccupation with failure
- Reluctance to simplify interpretations
- Sensitivity to operations
- Commitment to resilience
- Deference to expertise
The first principle refers to the need for organizations to embrace failure, which includes close attention to early warning signals of failure that may be symptomatic for larger problems (Weick & Sutcliffe, 2007). This explicitly indicates the need for early warning signal detection within HROs, which is also more implicitly incorporated in other principles such as commitment to resilience.

**Guidelines**
Sheffi (2005) stresses the relevance of having monitoring systems in place, supported by the principles of Statistical Process Control to detect early warning signals. However, he also notes that “although statistical process control charts can give an indication of an aberration, it typically takes a manager to decide the nature of the irregularity”. To enable managers and other people within an organization to recognize these early warning signals, this requires the analytical capability to understand ‘what does it mean?’ and a deep understanding of the system in which the business operates (Sheffi, 2005).

Weick & Sutcliffe (2007) emphasize the role of an organization’s personnel in spotting unexpected problems early, particularly maintenance personnel. Detection in this sense might start with a feeling that something is amiss. Checklists might be of further assistance to alert people where unforeseen events may surface.

**Methods and tools**
Although resilience and HRO literature do provide guidelines on how to detect early warning signals, more structured methods and tools for detection are generally not addressed. For instance, Weick & Sutcliffe (2007) describe that people need to be mindful in order to detect early warning signals, which means that “when people act, they are aware of context, of ways in which details differ (in other words, they discriminate among details), and of deviations from their expectations”. However, besides guidelines, a more structured approach to accomplish this is not discussed.

**2.3.5 Conclusions**
Table 2.7 presents the results of the review of how early warning signal detection is generally incorporated in various risk management disciplines. Based on this overview, it can be concluded that most disciplines acknowledge the need for early warning signal detection, either explicitly (crisis management, resilience engineering) or implicitly (safety management). As a means to detect such signals, (automated) systems, people, or the combination thereof are mentioned, although differences in emphasis exist among the disciplines. For example, the role of people in signal detection is stressed in resilience engineering and literature on HROs, whereas safety management highlights the value of process control systems. The role of people in detection is stressed in other disciplines as well. In e.g. strategic management, Ansoff (1984) states that detection of early warning signals “requires sensitivity, as well as expertise, on the part of the observers”, which extends beyond the managerial layer of an organization.

With regard to structured methods and tools for early warning signal detection however, literature provides little support. Though the use of Statistical Process Control to assist signal detection in process control systems is mentioned, structured approaches to support ‘human’ early warning signal detection are very limited. As was discussed, risk identification methods commonly used in risk management are not suitable for signal detection as regarded in this thesis.
Unlike risk identification methods, getting people to be ‘mindful’ of early warning signals, as discussed by Weick & Sutcliffe (2007), does give direction to early warning signal detection as regarded in this dissertation. Unfortunately, a structured approach to get people to be mindful of early warning signals is not presented by these authors. Recall that mindfulness implies that when people act, they are aware of context, and of deviations from their expectations. This notion, i.e. awareness of context and deviation, is also present in the concept of situation awareness (Endsley, 1995), which is closely related to the concept of mindfulness (Weick & Sutcliffe, 2007). Models of situation awareness that describe how situation awareness is obtained and which factors influence situation awareness are available in literature (Endsley, 1995; Endsley, 2000; Flin et al., 2008). Thus, in the context of early warning signal detection, a further discussion on situation awareness is in order, which is the topic of the next section.

Concluding, early warning signal detection as regarded in this thesis is acknowledged across various risk management disciplines, but beyond (general) guidelines on detection, no structured approaches (tools, methods) on how to conduct or improve this particular kind of detection in an organizational setting are available. However, the concept of mindfulness, and in particular the concept of situation awareness, appear to provide insight into how people detect early warning signals. Consequently, situation awareness is briefly explored in the next section.

### 2.4 Situation awareness

Based on her earlier work, Endsley (1995) defines situation awareness as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. Essentially, it refers to ‘knowing what is going on around you’ (Endsley, 2000), and can be considered as a cognitive skill of people (Flin et al., 2008). In the interest of this dissertation, the main question is how people can acquire and maintain situation awareness, how this process is influenced, and how these insights might be valuable in understanding (and potentially improving) early warning signal detection as regarded in this thesis. In order to answer this question, section 2.4.1 discusses a commonly applied model of situation awareness. Section 2.4.2 elaborates on how situation awareness relates to early warning signal detection in this thesis.
2.4.1 Model of situation awareness

Figure 2.3 presents Endsley’s model of situation awareness in dynamic decision making which is considered as the best-known and most widely accepted model of situation awareness (Endsley, 1995). As figure 2.3 shows, three levels of situation awareness can be distinguished (Endsley, 1995; Endsley, 2000):

- **Level 1: Perception of elements in current situation.** In order to know what is going on around you, one should first be perceptive of relevant environmental cues (i.e. status, attributes, and dynamics of relevant elements in the environment), which may be received through visual, aural, tactile, olfactory, or taste receptors. Amongst other things, perception requires attention to those cues of interest (e.g. with respect to an individual’s goals & objectives) amidst the huge amount of information available.

- **Level 2: Comprehension of the current situation.** Level 2 situation awareness goes beyond being merely aware of the relevant environmental cues that are present to include an understanding of the significance of those (integrated) cues to one’s goals and objectives.

- **Level 3: Projection of future status.** The highest level of situation awareness involves the ability to project from current events and dynamics to anticipate future events and their implications, and requires knowledge of the status and dynamics of the elements and comprehension of the situation, i.e. situation awareness levels 1 and 2.

Based on the description of these levels, it is apparent that situation awareness is acquired and maintained by individuals, which requires cognitive effort of those individuals. Good situation awareness will not necessarily lead to successful performance however, which is depicted in figure 2.3 by representing situation awareness as a stage separate from decision making and performance. For instance, an individual might be aware of what is going on around him (e.g. an alarm sounding), but still make the wrong decision based on this insight (e.g. deciding not to do anything or failure to notify others). As Endsley (2000) notes, many other factors come into play and will affect situation awareness, as well as decision making and performance.

Firstly, since situation awareness requires cognitive effort by individuals, it is affected by an individual’s cognitive processes, which include e.g. working memory, long term memory, mental models, and pattern matching. An in-depth discussion of these processes is beyond the scope of this thesis. The reader is referred to Endsley (2000) for an overview of available literature on the relation between situation awareness and cognitive processes. Secondly, situation awareness is affected by other individual factors, including e.g. a person’s goals and objectives, experience and training, as well as by an individual’s environment. Figure 2.3 indicates some of these environmental factors, specifically related to an individual’s tasks (e.g. stress, workload and complexity) and the (technical) systems utilized in support of these tasks (e.g. system capability and interface design).
2.4.2 Relation to early warning signal detection

The discussion above has made clear that situation awareness is acquired and maintained by individuals, which requires a cognitive effort (three levels of situation awareness) that will be influenced by many factors (individual, environmental,...). This provides some valuable insights for early warning signal detection as regarded in this thesis:

- Detection of early warning signals requires a cognitive effort by individuals, which goes beyond mere perception (situation awareness level 1), to at least include comprehension or understanding of the current situation (level 2), preferably with insight into the potential implications of the early warning signals (level 3).

- Early warning signal detection will be affected by many factors. These will not be limited to the influence of cognitive processes or other individual factors, but will include environmental factors too.

Besides providing some valuable insights, the situation awareness model of figure 2.3 also has its limitations with respect to explaining early warning signal detection:

- Situation awareness is a cognitive skill of people to perceive, comprehend, and project relevant environmental cues, which may be overt (e.g. a system alarm) or subtle (e.g. the slight change in the hum of an engine) (Endsley, 2000).
Consequently, situation awareness is not restricted to how people perceive, comprehend and project early warning signals, but covers the detection of other types of signals as well.

- As a result, it can not necessarily be assumed that the influencing factors mentioned in Endsley’s model will also affect early warning signal detection, or how these factors will influence detection.

- Moreover, besides individual factors, the situation awareness model of figure 2.3 solely takes into account the effect of an individual’s tasks or the (technical) systems employed to achieve these tasks on an individual’s ability to acquire and maintain situation awareness. Thus, the broader organizational context in which individuals acquire and maintain situation awareness is not accounted for. Early warning signal detection in this thesis is regarded within a broader organizational context though, given the focus on how industrial organizations might improve their ability to proactively manage risks (as was discussed in chapter 1).

Concluding, though the situation awareness model does provide valuable insights into early warning signal detection, the model itself is not suitable to describe early warning signal detection in an organizational context, as regarded in this thesis. This conclusion, together with insights drawn from the discussion of this thesis’ scope on early warning signals and their detection (section 2.2) and the related literature review (section 2.3), set the stage for the research objectives and research questions discussed in the next section.

### 2.5 Research objectives and research questions

As stated in chapter 1, the general aim of this thesis is to gain insight into how (industrial) organizations proactively manage risk, and more importantly, how to potentially improve an organization’s ability to proactively manage risk, given the societal trends discussed earlier.

Consequently, this chapter started with a discussion on proactive risk management. By applying the distinction put forward in Mitroff’s model (1988), it was possible to split the many activities encompassing proactive risk management in two main phases: risk detection and risk preparation. In light of the earlier mentioned trends, of which one consequence is that threats are increasingly unforeseeable in today’s society, it was argued that increasing effort should be taken to detect potential threats organizations are facing, including those risks organizations are not expecting. This resulted in this thesis’ focus on risk detection and more specifically, the need for organizations to be aware of and understand early warning signals of potential risks.

Section 2.2 discussed early warning signals and their detection in further detail. Early warning signals were defined and it was shown that there are several ways in which an organization can detect early warning signals, such as detection by means of (automated) monitoring systems and detection by utilizing risk indicators. However, given this thesis’ interest in risk detection instead of risk preparation and in light of risks becoming increasingly unforeseeable in today’s society, these particular ways of detection were considered to be outside the scope of this thesis. Rather, an (industrial) organization will largely depend on a different means of detection, i.e. early warning signal detection by the people within the organization.
A review of how early warning signal detection is incorporated in various risk management disciplines demonstrated that early warning signal detection as regarded in this thesis (i.e. detection by people instead of detection by means of (automated) systems and/or risk indicators) is acknowledged across various risk management disciplines. Beyond (general) guidelines on detection however, no structured approaches (tools, methods) on how to conduct or improve this particular kind of detection in an organizational setting are available.

Since the literature review pointed to the fact that people need to be mindful or aware of their environment in order to be able to detect early warning signals, the related concept of situation awareness was further explored in section 2.4. The discussion on situation awareness provided some valuable insights into organizational early warning signal detection as regarded in this thesis, namely that detection requires a cognitive effort by individuals which goes beyond mere perception, and that detection will be affected by many factors, including both individual and environmental factors. Nevertheless, situation awareness in itself insufficiently explains organizational early warning signal detection as regarded in this thesis, amongst other reasons due to the perspective on individuals in the presented situation awareness model, instead of a perspective on (people within) organizations.

As a result, the general aim of this thesis can be translated in a more specific aim which is conveyed by the following main research objectives:

**Research objectives**

1. To gain insight into how (industrial) organizations detect early warning signals, as regarded in this thesis
2. To indicate how (industrial) organizations might improve their ability to detect early warning signals, as regarded in this thesis

These objectives indicate that this thesis does not pursue insight into organizational early warning signal detection for purely theoretical purposes, but aims to use insight gained to potentially improve organizational early warning signal detection. As was mentioned earlier, in doing so, this thesis considers a particular means of detection, i.e. early warning signal detection by the people within an organization. Consequently, insight into organizational early warning signal detection also requires some insight into how individuals detect early warning signals within an organizational context. Nevertheless, the focus of this thesis is on how (industrial) organizations detect early warning signals, by means of a particular way of detection.

Consequently, this thesis does not attempt to explain in detail the human cognitive effort which is required to detect early warning signals as regarded in this thesis, but rather focuses on the underlying factors (both organizational and individual) that will affect organizational early warning signal detection. Though the model described in section 2.4.1 indicated several factors that influence situation awareness, it can not necessarily be assumed that the same factors will apply to organizational early warning signal detection.
Hence, the research objectives are translated in the following main research questions:

### Research questions

1. How do (industrial) organizations detect early warning signals, as regarded in this thesis?
2. How can underlying factors that influence organizational early warning signal detection be identified?
3. How can insight into these underlying factors be utilized for the purpose of improving an organization’s ability to detect early warning signals?

The research approach adopted to answer these questions is discussed next.

### 2.6 Research approach

When describing the research approach adopted in this thesis, it is important to take into account the general research approach (or research type) most appropriate to answer the research questions identified earlier, as well as the related research methods or strategies.

Bickman & Rog (1998) distinguish between two main research types, i.e. basic research and applied research. Though both types of research use scientific methodology, applied research uses it to develop information to help solve a (societal) problem, whereas basic research uses scientific methodology to create new knowledge about how fundamental processes work. The purpose of basic research is thus knowledge in itself. The purpose of applied research is to gain knowledge of a particular problem at hand, with the intent to use this knowledge to contribute to the solution of that problem. Since the main research objective of this thesis is to gain insight into organizational early warning signal detection for the purpose of potentially improving the ability of (industrial) organizations to perform early warning signal detection, the research in this thesis can be classified as applied research.

Besides basic versus applied research, Henry (1998) classifies research as exploratory, descriptive or analytic, depending on the nature of the research. Exploratory research is generally conducted to provide an orientation or familiarization with the topic of interest, such as to learn which variables are of importance for the study. It often acts as a preliminary activity to descriptive or analytic research. Descriptive research aims to provide estimates of variable attributes, such as variable relevance. Analytic research examines expected relationships between variables. The research described in this thesis can be classified as mainly exploratory in nature. The first research question addresses how industrial organizations detect early warning signals by means of a particular way of detection (i.e. the people within an organization). Unfortunately, literature provides little insight into how organizations detect early warning signals through their people, or how the organizational context might influence people’s ability to detect signals. The second research question refers to the identification of such (organizational) influencing factors of early warning signal detection.

Though section 2.3 provided some specific guidelines to early warning signal detection that potentially point to influencing factors, which include open communication, confidence in management, and the need to reward signal detection and emphasize safety, an overview of influencing factors of organizational early warning signal detection as regarded in this thesis is currently lacking.
Consequently, the research related to the first two research questions is exploratory in nature. The third research question is about using insight into the identified factors to improve organizational early warning signal detection. As will be discussed in chapter 6, this requires amongst other things insight into factor relevance. Research related to the third research question is hence more descriptive in nature. Overall however, the research in this thesis can be classified as applied, mainly exploratory, research.

Because qualitative methods are more appropriate for understanding phenomena about which little is yet known (Strauss & Corbin, 1990), research related to the first two research questions will mainly depend on qualitative methods. Since research related to the third research question builds on previous insight into influencing factors, it will be possible to use more quantitative methods for this descriptive research. It should be noted that Creswell (2003) acknowledges the mixing of both qualitative and quantitative methods within a single study. Hence, using one particular type of method does not necessarily exclude the other. Mixing of methods will be applied in the research related to the second research question. This involves the identification of influencing factors, which is an iterative process as will be demonstrated in chapter 4 and 5. Although it mainly involves the application of qualitative methods, the iterative process of knowledge (or theory) building allows the use of more quantitative methods further on in the identification process.

To a large extent, the qualitative and quantitative methods that will be applied to answer the research questions will depend on the particular data sources available that provide insight into organizational early warning signal detection. The three main data sources to be employed are literature, experts and case studies of major industrial accidents, the rationale for which will be discussed further on in the thesis. It is important to emphasize that although case studies of major industrial accidents are used as one particular input to gain insight into organizational early warning signal detection (and at the same time are a rather vivid account of the need for and difficulty in detecting early warning signals as was shown in chapter 1), this should not lead to the conclusion that this thesis’ findings only apply to the detection of signals related to low probability, high consequence events. Insight into (the potential) improvement of organizational early warning signal detection can be utilized for the detection of potential threats with a relative low level of consequence (e.g. smaller scale operational disturbances) as well. Hence, such insight can potentially find a broad application within industrial organizations.

Given these three main data sources (literature, experts, case studies), some research methods to be employed are obvious, such as literature review. With respect to case studies, these will be analyzed qualitatively, given the mainly exploratory nature of the research described in this thesis. The particular approach adopted for the analysis of case studies will be discussed in chapters 3 and 5, respectively. With regard to the use of experts, a variety of methods for expert consultation exist, both qualitative (e.g. interviews, focus groups) and quantitative (e.g. surveys) in nature. Consequently, the choice of method for expert consultation is not so obvious and needs to be justified. Depending on the research question to be answered, this thesis employs both qualitative and quantitative expert consultation methods. Specifically, in the research related to the second research question (i.e. identification of influencing factors), both a focus group and an internet based survey are utilized to get experts’ input, as will be explained in chapters 4 and 5, respectively. In order to gain insight into factor relevance, which is related to the third research question, an internet based survey is employed, the choice for which will be justified in chapter 6.
Summarizing, table 2.8 presents an overview of the adopted research approach. As is apparent from this overview, multiple data sources and methods as well as insights from various risk management disciplines are employed. By doing so, this research uses multiple lines of inquiry that converge into the main research findings. This process is called triangulation and adds to the validity and reliability of the results presented in this thesis. Patton (1987) distinguishes between four types of triangulation, namely data triangulation (the use of multiple data sources), methodological triangulation (the use of various research methods), theory triangulation (the use of multiple theoretical perspectives) and investigator triangulation (the use of multiple researchers to perform the research).

<table>
<thead>
<tr>
<th>Research question</th>
<th>How do (industrial) organizations detect early warning signals, as regarded in this thesis?</th>
<th>How can underlying factors that influence organizational early warning signal detection be identified?</th>
<th>How can insight into these underlying factors be utilized for the purpose of improving an organization’s ability to detect early warning signals?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research type</td>
<td>Applied, exploratory</td>
<td>Applied, exploratory</td>
<td>Applied, descriptive</td>
</tr>
<tr>
<td>Type of research method(s) employed</td>
<td>Qualitative</td>
<td>Mixed (mainly qualitative)</td>
<td>Quantitative</td>
</tr>
<tr>
<td>Related data sources</td>
<td>Literature</td>
<td>Literature</td>
<td>Experts</td>
</tr>
<tr>
<td></td>
<td>Case study</td>
<td>Experts</td>
<td></td>
</tr>
<tr>
<td>Research method(s) employed</td>
<td>Literature review</td>
<td>Literature review</td>
<td>Internet based survey</td>
</tr>
<tr>
<td></td>
<td>(signal detection)</td>
<td>(influencing factors)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analysis of case study</td>
<td>Focus group</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internet based survey</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analysis of case studies</td>
<td></td>
</tr>
<tr>
<td>Related chapter</td>
<td>3</td>
<td>4, 5</td>
<td>6</td>
</tr>
</tbody>
</table>

The research described in this thesis encompasses all four types of triangulation, though multiple researchers were only involved in some phases of the research process (such as refinement of the list of influencing factors obtained from a review of literature on various risk management disciplines, post-processing of factor group results, and analysis of survey findings and analysis of case studies as part of the influencing factor identification process) as will be further explained in the subsequent chapters.
3 Organizational early warning signal detection: developing a framework

Given this thesis’ main research objectives as stated at the end of the previous chapter, this chapter explores communication theory, organizational systems theory, and theory on the cognitive processing of warnings by individuals in order to construct a conceptual framework of organizational early warning signal detection. By means of case study analysis, the value of this framework in providing insight into organizational early warning signal detection is illustrated. Amongst other things, discussion of the framework, as well as the case study analysis, show that whether or not an organization successfully detects early warning signals depends on influencing factors from various categories, which can either positively or negatively affect detection. Identification of these influencing factors is the topic of interest of the next two chapters.

3.1 Introduction

As stated in the previous chapter, the focus of this thesis is on how (industrial) organizations detect early warning signals, by means of a particular way of detection (i.e. by the people within an organization). Although theory on situation awareness is helpful in understanding how individuals detect early warning signals, it does not provide insight into how organizations as a whole detect such signals. Consequently, this chapter explores organizational early warning signal detection and aims to develop a framework that provides insight into how an organization, by means of its people, detects early warning signals.

According to Schein (1970), an organization is “…the rational coordination of the activities of a number of people for the achievement of some common explicit purpose or goal…”. Robbins (2001) more or less applies a similar definition and states that an organization is a consciously coordinated social unit composed of multiple people that functions on a relatively continuous basis to achieve a common goal or set of goals. These definitions point to three main elements of an organization, i.e. 1) a group of people that 2) share some common explicit goal or goals, and 3) who through coordination (of the group itself and the group’s activities, as well as coordination of an organization’s external environment) try to achieve their goal or goals.

Hence, organizational early warning signal detection is essentially about how a coordinated group of people with some shared goal or goals detect early warning signals. In most cases, an organization will have multiple means of detection at its disposal, as was discussed in the previous chapter. For the particular means of detection as investigated in the context of this thesis (i.e. detection by the people within an organization), this implies that early warning signal detection by organizations is essentially not an isolated effort by individuals. Rather, organizational early warning signal detection requires detection by individuals in the context of a coordinated group of people.

In constructing the framework, section 3.2 thus firstly explores this particular context, by applying communication theory and systems theory to organizations. Though the focus of this thesis is not on individuals but on organizations, some understanding of how individuals detect early warning signals is needed to give further insight into organizational early warning signal detection.
signal detection. This is discussed in section 3.3. Next, section 3.4 presents a conceptual framework of organizational early warning signal detection. The particular value of the framework in the context of this thesis is illustrated by means of case study analysis, the findings of which are given in section 3.5. This chapter ends with a short discussion on the framework and its implications in section 3.6.

### 3.2 Organizations and detection

In order to obtain insight into how organizations detect early warning signals, this section applies communication theory and systems theory to organizations. In accordance with communication theory, an organization can be regarded as a communication system that processes early warning signals. The viewpoint of an organization as an open system, as is common in modern organization theory, further allows a holistic approach to organizational early warning signal detection, and helps to explain how the organization and its environment affect the specific detection mechanism regarded in this thesis.

Sections 3.2.1 and 3.2.2 discuss communication theory and its implications with respect to explaining organizational early warning signal detection, whereas section 3.2.3 discusses systems theory and its implications. By combining the insights from these subsections, section 3.2.4 discusses some further implications with respect to organizational early warning signal detection.

#### 3.2.1 Organization as a communication system: delineation and implications

Figure 3.1 presents the basic elements of a communication system, based on Shannon’s classical communication model (Shannon, 1948). This figure depicts communication as a process, which consists of the following elements:

- **Source.** An information source produces a signal or sequence of signals to be communicated to the receiving terminal.
- **Transmitter.** The purpose of the transmitter is to convert the signal produced by the source into a form suitable for transmission over the channel.
- **Channel.** The channel refers to the medium used to transmit the signal from transmitter to receiver. As the transmitted signal propagates over the channel, it is distorted due to the channel’s physical characteristics, as well as due to noise and interfering signals from other sources (indicated as noise source in figure 3.1). As a result, the received signal is a corrupted version of the transmitted signal (Haykin & Van Veen, 1999).
- **Receiver.** The receiver performs the inverse operation of that done by the transmitter, reconstructing the message signal from the source. The resulting estimate of the message signal is then delivered to the user destination.
- **Destination.** The destination is the person (or thing) for which the message is intended.
Despite the simplistic nature of the model (for instance, it excludes the possibility of feedback and does not consider the dynamics and complexity associated with communication in practice), the model helps to convey this thesis’ perspective on organizational early warning signal detection.

Figure 3.1 illustrates that essentially, a communication system is designed to bring signals from source to destination, by means of several signal processing entities (transmitter, channel, receiver). In light of this thesis’ aim to improve organizational early warning signal detection, a basic distinction between signal and signal processor within a communication system helps to explain that there are various strategies to improving signal detection.

One strategy is to focus on the signal processor (in this case, an organization as a whole) and to learn how to improve the processing of early warning signals by the signal processor. Another strategy is to consider the early warning signal itself. In this strategy, the main purpose is to try to improve signal strength directly, or in other words, to try to turn signals received by the signal processor (in this case, an organization) from ‘weak’ into ‘strong’, thereby improving an organization’s ability to detect such signals.

Adoption of the latter strategy leads to some major challenges. Amongst other things, directly targeting signal strength requires insight into the properties of both ‘weak’ signals and ‘strong’ signals, as well as the means to adjust these properties. Gaining such insight is difficult though. To start with, insight into the properties of early warning signals requires insight into the signal itself, which is difficult to obtain given the imprecise and early nature of early warning signals, especially given the wide variety of signals an organization is facing. Moreover, figure 3.1 indicates the dynamic nature of signals, in the sense that a signal that is communicated is constantly changing given the processing of the signal via transmitters and channels to the (intended) receiver(s). Hence, in focusing on the signal itself, the question is which signal is taken into account (signal from the information source, the transmitted signal or the received signal) and how each element in the communication process affects the signal (such as noise and interfering signals distorting the early warning signal). Given these major challenges, it was decided to focus on the signal processor (i.e. an organization) instead, to improve organizational early warning signal detection.

Consequently, this thesis does not explore (the process which results in the) early warning signal(s) as initially received by an organization, but explores the process by which an organization detects such signals. As a first step in explaining this process, an organization that detects early warning signals can be regarded as a communication system in itself, which is illustrated by briefly discussing the elements depicted in figure 3.1.
An early warning signal will originate from a signal source. Depending on the system boundaries (in this case, organizational boundaries), the signal source may be within system boundaries or outside system boundaries. When an early warning signal is considered to be within boundaries, it is referred to as an internal signal, whereas a signal outside system boundaries is referred to as an external signal. Internal early warning signals might for example originate from an organization’s process control systems (as was illustrated in section 2.2.5), or might be visually present within the organization (e.g. poor housekeeping as an indication of inadequate quality assurance and control). Both types of signals (internal and external) are considered in organizational early warning signal detection as discussed in this thesis.

Given the particular detection mechanism regarded in this thesis, organizational early warning signal detection starts with one or more individuals within the organization receiving the initial early warning signal and interpreting its meaning. The cognitive process by which individuals detect early warning signals is discussed in more detail in section 3.3. Since an individual in practice will receive many signals within an organizational context (including noise and other signals interfering with early warning signals), information filtering is an important element of this cognitive process.

As was stated in section 3.1, early warning signal detection by organizations is essentially not an isolated effort by individuals though. Rather, organizational early warning signal detection requires detection by individuals in the context of a coordinated group of people. This implies that after the initial early warning signal has been detected by one or more individuals, the resulting signal estimate(s) should be propagated within the organization, which requires signal communication. Consequently, the individual(s) that detected the initial early warning signal can be regarded as (new) transmitter(s) of signal estimates (i.e. their interpretation of the initial early warning signal) within the organization, which via an organization’s communication channels will reach other individuals (in this case, the signal receivers). For their part, the latter individuals again might act as signal transmitters in the further propagation of signal estimates within the organization, and so on.

This process of signal propagation will continue until the signal has been detected across the organization, which can be seen as the first and foremost destination of the early warning signal received by the organization. Also, the estimate of the early warning signal by the organization might be communicated outside the organization, e.g. to organizational stakeholders. Hence, an early warning signal might have various destinations, which might at least partly lie outside the organization.

Based on this short discussion, it is apparent that communication (i.e. the transference and understanding of meaning (Robbins, 2001)) is fundamental to explaining organizational early warning signal detection. Moreover, the discussion has demonstrated a key element in organizational early warning signal detection, which is early warning signal propagation within an organization. Supplementary to the general communication model depicted in figure 3.1, the next subsection elaborates on this topic, and discusses several aspects of organizational communication in order to illustrate early warning signal propagation within organizations.
3.2.2 Early warning signal propagation within organizations

As was stated in the previous subsection, organizational early warning signal detection requires propagation of the early warning signal across the organization. Since risk management (and thus early warning signal detection) involves not only an organization’s top management, but all levels within an organization, as was already noted in chapter 1, early warning signals should be propagated across all (managerial) levels within an organization.

De Leeuw (1986) distinguishes between three managerial levels within an organization, namely strategic management (management of the organizational continuity), tactical management (structural (adaptive) control of the organization, based on an organization’s strategic management), and operational management (‘routine’ control of the organization, given an organization’s strategic and tactical policy). These levels are interconnected, in the sense that strategic management will affect lower levels of management within the organization (tactical, operational), as is expressed in the description of these levels. However, the opposite is true as well, as e.g. practical insights from management at an operational level might lead to adjustments at the higher levels of management to better suit operational management.

For risk management (and thus for early warning signal detection), the same levels of management apply. Hence, organizational risk management requires management of risk at a strategic, tactical and operational level, as well as interaction between these levels. When risk management is limited to a single level (e.g. the strategic level) and not effectuated at other organizational levels, or when coordination among the various management levels is absent, it can be argued that organizational risk management at best will be suboptimal.

Consequently, organizational early warning signal detection requires detection at a strategic, tactical and operational level and interaction between these levels. This implies that propagation of the early warning signal across the organization is needed at all levels. The emphasis in propagation in this sense is on the transference of the understanding of the signal’s meaning across all levels, and not so much on the physical transference of the signal or signal estimate(s).

Depending on the signal and the organization in question, the particular path of propagation can take on numerous configurations and may range from direct propagation (where the early warning signal initially received by the organization is directly propagated to all levels) to some indirect form of propagation. One organizational aspect that will influence the way information is communicated within an organization is an organization’s communication structure, whether it is functional, matrix, network or hybrid (Hatch, 1997). However, other organizational aspects will affect signal propagation as well, as is illustrated in the next subsections.

Based on the discussion of an organization as a communication system in the previous subsection, and the notion that organizational early warning signal detection requires signal detection and propagation across an organization’s strategic, tactical and operational level, it is possible to generally describe early warning signal propagation within an organization. To illustrate this process, figure 3.2 shows how an external early warning signal is received by an individual at the tactical level, and consequently propagated across the organization. Clearly, this is but one potential configuration of organizational early warning signal detection.
For example, the early warning signal might be internal instead of external, and might be initially detected by more than one individual, from any of an organization’s managerial levels. Nevertheless, regardless of the particular configuration, early warning signal propagation consists of some basic elements, which are shown in figure 3.2.

The process depicted in figure 3.2 can be explained as follows:

- Given this thesis’ focus on how (industrial) organizations detect early warning signals by means of a particular way of detection (i.e. by the people within an organization), people take on a central role in figure 3.2. Consequently, other means of detection of early warning signals are not displayed.

- Figure 3.2 shows an individual receiving an external early warning signal as input, which is only one of many signals (both internal and external) an individual will receive. With respect to the early warning signal in question, these other signals (whether random noise or interfering signals from other sources) can be considered as noise, as is expressed in figure 3.2.

- To detect the external early warning signal, the individual should thus be able to filter the early warning signal from the surrounding noise and cognitively process the signal.
This will enable the individual to produce output, i.e. an estimate of the received early warning signal. The particular process by which an individual cognitively detects early warning signals is discussed in more detail in section 3.3.

- Next, the signal estimate is propagated within the organization, which requires signal communication. In figure 3.2, the signal estimate is firstly communicated to another individual at the tactical level. In this process, the individual that detected the initial external early warning signal can be regarded as a (new) transmitter of the signal estimate within the organization, which via an organization’s communication channels will reach other individuals. These individuals in their turn will need to detect the signal estimate, which involves being able to filter the signal estimate from the surrounding noise (i.e. (internal and/or external) interfering signals and random noise).

- The dotted circle connecting the individual that received the external early warning signal to others at the tactical level indicates the existence of some formal (communication) structure within an organization, which in this particular example affects the path of signal propagation. For instance, the dotted circle might represent some formal middle management consultation structure (e.g. weekly meetings), in which the individual shares his thoughts on the received signal, thereby propagating the signal at the tactical level. As the other dotted circles demonstrate, such structures might exist at other levels and across various levels as well.

- After propagation at the tactical level, figure 3.2 shows that signal estimates are then propagated across the organization, to the strategic and tactical level. Assuming that this propagation is not the mere physical transference of the signal estimates, but results in the propagation of the understanding of the signal’s meaning to the strategic and tactical level, the organization depicted in figure 3.2 has been able to detect the external early warning signal as initially received by an individual at the tactical level.

- The particular path of signal propagation to the strategic and operational level shown in figure 3.2 indicates that signal propagation is not restricted to an organization’s formal (communication) structure. For instance, signal estimates might be communicated informally, in whatever form (written, verbal, etc.). Hence, an organization’s formal (communication) structure only partly explains the way in which early warning signal propagation is affected. Other factors will influence signal propagation as well, as is further discussed in the next subsections.

Whereas early warning signal propagation within an organization is a key element in explaining organizational early warning signal detection, the model of figure 3.2 acts as the basis of the framework that describes organizational early warning signal detection, which is presented in section 3.4. To further develop the framework, the next subsections consider an organization from a systems perspective, to learn how an organization and its environment affect the specific detection mechanism regarded in this thesis.
3.2.3 Organization as an open system

Section 3.2.1 noted that an organization that detects early warning signals can be regarded as a communication system in itself. A systems perspective on organizations is common in modern organization theory, as is discussed by many authors including e.g. Hatch (1997), Jackson (1991), De Leeuw (1986), McAuley et al. (2007) and In ‘t Veld (1992).

The idea that an organization is essentially a system has its roots in the more general claim that all aspects of the natural and social world can be described as systems, as is expressed in General Systems Theory, which is generally attributed to Von Bertalanffy and further developed by others including Boulding. The intent of this theory is to deduce universal principles which are valid for all scientific phenomena (which are all regarded as systems) in all fields of science and thus involves generalizations at high levels of abstraction. Amongst other things, these generalizations include the notion that any system in itself consists of a number of elements or parts, called subsystems, and that these subsystems depend on each other and are related to each other (McAuley et al., 2007). For more information about General Systems Theory, see Von Bertalanffy (1973) and Boulding (1956).

The notion that an organization is a system comprising of interrelated subsystems is common in modern organization theory. Whereas classical organization theory concentrates on one or two aspects of the organization necessary for high performance (e.g. focus on task and structure, as in Taylor’s scientific management approach), modern organization theory takes into account all of an organization’s subsystems and their interrelation to try to improve organizational performance. This corresponds to a holistic approach to organizations, instead of the classical reductionist approach to organizations.

As stated by Hatch (1997), within the modern perspective, an organization is regarded as a living system that performs the functions necessary to survival and adapts to its environment. From a systems theory perspective, this corresponds to an open system that exists within an external environment, to which the system adapts and changes. This process of change and adaptation is two directional, since an open system will also influence its external environment. A closed system on the other hand is considered to be (relatively) independent of the outside world, and thus requires no adaptation.

Hence, modern organization theory considers an organization as an open system comprising of interrelated subsystems which interact with an organization’s external environment. When one regards the people of an organization as a primary subsystem (i.e. the human subsystem), as is done by Jackson (1991), the value of this viewpoint in explaining organizational early warning signal detection becomes apparent. Since organizational detection as regarded in this thesis is restricted to (cognitive) detection by the people within an organization, it is clear that these people affect and are affected by each other, an organization’s other subsystems, as well as an organization’s external environment. Consequently, the effect of these subsystems and the external environment on organizational early warning signal detection should be taken into account.

Figure 3.3 depicts an organization as an open system. Central to any organization are the people that together form the organization and who share some common goal(s).
In order to accomplish the organizational goal(s), an organization depends on coordination (of its people and their activities, as well as coordination of the external environment such as external stakeholders) through organizational subsystems. There is no commonly accepted way of classifying an organization’s subsystems. One approach might be to consider organizational units or departments as subsystems. In trying to explain how an organization as a whole might affect early warning signal detection as regarded in this thesis, such a distinction is less appropriate. Instead, this thesis considers the five core concepts that organization theorists rely on to construct their theories to determine an organization’s primary subsystems, i.e. environment, technology, structure, culture and strategy (Hatch, 1997).

![Fig. 3.3: Organization as an open system (adapted from Hatch (1997), McAuley et al. (2007))](image)

Of this list of five core concepts, all but environment can be considered as an organization’s primary subsystems, which are defined as:

- **Technology** ranges from an organization’s IT infrastructure to the kind of technologies used in manufacturing, through to the ways in which organizational members are expected to relate to the technology (McAuley et al., 2007).

- **Structure** relates to the way in which the organization is (formally) designed in order to fit the organizational goals (McAuley et al., 2007).

- **Culture** is “the specific collection of values and norms that are shared by people and groups in an organization and that control the way they interact with each other and with stakeholders outside the organization” (Hill & Jones, 2001).
- *Strategy* refers to the determination of the basic long-term goals and objectives of an organization and the adoption of courses of action and the allocation of resources necessary for carrying out these goals (Chandler, 1962).

### 3.2.4 Influencing factors of organizational early warning signal detection

By applying communication theory and systems theory to organizations, the previous subsections have demonstrated the following:

- An organization that detects early warning signals can be regarded as a communication system in itself. Early warning signal propagation within an organization is a key element in explaining organizational early warning signal detection. *(section 3.2.1)*

- Organizational early warning signal detection requires detection at a strategic, tactical and operational level and interaction between these levels. Hence, propagation of the early warning signal across the organization is needed at all levels. *(section 3.2.2)*

- An organization’s subsystems as well as an organization’s external environment will affect an organization’s ability to detect early warning signals. *(section 3.2.3)*

These insights contribute to explaining organizational early warning signal detection, by indicating the process by which organizations detect early warning signals and by demonstrating that this process is affected in various ways, both within the organization and outside the organization. The latter can be expressed by distinguishing between four main categories of factors that influence organizational early warning signal detection; see table 3.1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Level of aggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human factors</td>
<td>Individual</td>
</tr>
<tr>
<td>Internal environment</td>
<td>Organization</td>
</tr>
<tr>
<td>(subcategories Technology, Structure, Culture, Strategy)</td>
<td></td>
</tr>
<tr>
<td>External environment</td>
<td>Interaction organization-external environment</td>
</tr>
<tr>
<td>Exogenous</td>
<td>External environment</td>
</tr>
</tbody>
</table>

These factor categories can be described as follows:

- *Human factors*. Since early warning signal detection as regarded in this thesis involves detection by the people within an organization, factors that directly affect an individual’s ability to detect early warning signals constitute the first category of factors. An example of a potential factor in this category, taken from the field of situation awareness, is given by Fracker (1988), as he mentions biasing in the selection and interpretation of information due to a person’s mental model(s) as one potential source of error in situation awareness.

- *Internal environment*. These are factors active on an organizational level, which correspond to factors active in the four primary organizational subsystems indicated in figure 3.3.
Hence, the internal environment category is divided into four subcategories, namely Technology, Structure, Culture and Strategy. The discussion on early warning signal propagation within an organization in section 3.2.2 indicates one potential factor in this category, namely an organization’s formal communication structure.

- **External environment.** This category does not constitute factors that originate from an organization’s external environment, but incorporates influencing factors on the interface of an organization and its external environment. The extent to which an organization acknowledges the necessity of external environmental scanning for early warning signal detection, as put forward by Elsubbaugh et al. (2004) is an example of a potential factor active on the interface between an organization and its external environment.

- **Exogenous.** Hatch (1997) divides an organization’s external environment in different sectors, including an organization’s social, cultural, legal, political, economic, technological and natural environment. As is apparent from figure 3.3, an organization (and consequently, an organization’s ability to detect early warning signals) will be influenced by all of these sectors. Examples of such influencing factors originating from an organization’s external environment include the pace of technological innovation, legislation or political pressure, to name but a few. Despite the fact that such factors most likely will affect signal detection in some way or another, it can be argued that such factors to a large extent lie outside an organization’s area of influence. Since the main focus of this thesis is on gaining insight into organizational early warning signal detection to potentially improve an organization’s ability to detect such signals (and not to provide an all-encompassing overview of every way in which organizational early warning signal detection might be influenced), factors originating from an organization’s external environment are considered exogenous in this thesis.

The notion that influencing factors from these four categories affect organizational early warning signal detection is fundamental to explaining how an organization might improve its ability to detect early warning signals. Hence, these factor categories are incorporated in the conceptual framework that describes organizational early warning signal detection, which is presented in section 3.4. Since organizational early warning signal detection as regarded in this thesis depends on detection of early warning signals by individuals within the context of an organization, a framework that tries to give insight into organizational detection is considered incomplete without indicating how an individual detects early warning signals. The next section thus elaborates on the cognitive process that individuals employ to detect early warning signals.

### 3.3 Individual early warning signal detection

The discussion on situation awareness in the previous chapter showed that detection of early warning signals as regarded in this thesis requires a cognitive effort by individuals, which involves both perception and understanding of early warning signals’ meaning. This cognitive process of signal detection is influenced in various ways, by both individual and environmental influencing factors.

By exploring some of the major steps in the cognitive processing of warnings, this section tries to give an impression of how early warning signals are detected by individuals.
Most importantly, the purpose of this exploration is to show that for individuals in an organizational context, this process will be affected by influencing factors from the categories given in table 3.1. This focus on the way in which the process is influenced rather than on the process itself is in line with the research objectives stated earlier, i.e. to gain insight into organizational early warning signal detection in order to potentially improve an organization’s ability to detect such signals.

Before elaborating on the cognitive processing of early warning signals by individuals, the ability of one or more individuals within an organization to detect early warning signals is discussed in section 3.3.1. Next, the major steps in how individuals detect (early) warning signals, taken from Wogalter’s Communication-Human Information Processing (C-HIP) model (Wogalter, 2006), are presented in section 3.3.2. Section 3.3.3 discusses how this process is affected by influencing factors in the categories indicated in table 3.1.

### 3.3.1 Individual expertise and the ability to detect early warning signals

The focus of this thesis is on how (industrial) organizations detect early warning signals, by means of a particular way of detection (i.e. by the people within an organization). Hence, organizational early warning signal detection requires people to be able to detect early warning signals. A question that naturally arises is whether it can be assumed that one or more individuals within an organization are able to detect such signals. In this thesis, the answer to this question is considered to be yes, as will be explained next.

People within an organization will hold different positions, which will require a certain level of expertise that may vary depending on the particular kind of position. For example, an operator in a chemical plant will need to have in-depth knowledge of the (particular part of the) chemical process under his supervision. A chemical plant manager on the other hand will probably not need the same level of expertise as an operator, but needs a thorough understanding of the chemical plant in its entirety (which includes understanding of the chemical process).

In this thesis, it is assumed that people that hold a particular position within an organization have the level of expertise which is required for the position. The fact that organizations in general have various selection mechanisms (e.g. formal selection criteria, performance review procedures etc.) at their disposal in order to ensure an adequate level of expertise acts in support of this assumption. The process by which people acquire expertise which makes them suitable for their particular position is considered outside the scope of this thesis.

In the context of managing risk associated with the position, it can thus be assumed that an operator should be capable of managing operational risks associated with (the particular part of) the chemical process under his supervision, and that a plant manager should be capable of managing risks that affect the plant in its entirety. The same line of reasoning is applicable to proactive risk management, and the detection of early warning signals. For example, people specifically involved in risk management within an organization (such as risk managers) are assumed to have expertise in risk management, including expertise in the detection of early warning signals amidst surrounding noise (i.e. other interfering signals and random noise).

Hence, it can be assumed that within any organization, one or more individuals are able to detect early warning signals. In line with the viewpoint discussed at the beginning of section 3.3, this thesis is not so much concerned with the process which has led individuals to be
capable of detecting early warning signals, but is concerned with the way in which individual detection is affected by the particular organizational context. Namely, the fact that one or more individuals are able to detect early warning signals is no guarantee that these individuals will indeed detect early warning signals in the particular organizational context, which is considered a prerequisite for organizational early warning signal detection as regarded in this thesis. This is illustrated in the next subsections, by discussing the way in which individuals cognitively process early warning signals and how this process is affected.

3.3.2 Cognitive detection of early warning signals

To demonstrate how early warning signals are cognitively detected by individuals, a model commonly accepted in warning research, i.e. the Communication-Human Information Processing (C-HIP) model (Wogalter, 2006) is discussed. The C-HIP model consists of two main parts. The first part describes how a warning signal is transferred from the signal source to the human receiver, which corresponds to the first stages in a communication system (as presented in figure 3.1). The second part of the model describes how the human receiver cognitively processes that information, which is depicted in figure 3.4. Similar information processing models have been presented by others, including Lehto & Miller (1986) and Rogers et al. (2000).

![Cognitive processing of early warning signals](image)

Fig. 3.4: Cognitive processing of early warning signals (based on Wogalter, 2006)

Before proceeding to explain the C-HIP model, it is important to note that warning research is particularly directed to safety communications used to inform people about hazards in order to prevent or minimize undesirable consequences, such as signs, labels, face-to-face verbal statements and so forth. Clearly, these types of warning messages or signals differ from the early warning signals considered in this thesis. Nevertheless, it is assumed that the major steps in cognitively processing warnings (whether it be signs or early warning signals) are the same regardless of the particular type of warning, since these steps essentially describe how an individual receives and processes information. Hence, the C-HIP model is used to illustrate the major steps in the cognitive detection of early warning signals.

Figure 3.4 shows that individual early warning signal detection encompasses more than just the delivery of a signal to a human receiver, as was already apparent from the situation awareness model in chapter 2. Individual early warning signal detection as a prerequisite for organizational early warning signal detection requires the full range of signal processing steps to result in signal-directed behavior or action, which includes attention, comprehension, attitudes and beliefs, and motivation.
The first step in cognitively processing an early warning signal is the *delivery* of the warning signal to the (intended) human receiver. Here, delivery refers to the interface (or point of reception) of the warning(s) arriving to the receiver (Wogalter, 2006). Without delivery, the signal cannot be processed further. Amongst other things, signal delivery will be affected by other environmental stimuli (e.g. non warning stimuli in a human receiver’s direct physical environment, such as a conversation carried on by co-workers), which can be described as noise with respect to the early warning signal(s).

The next step in signal processing is *attention*. Someone may receive an early warning signal, but when a person’s attention is not drawn to the signal, no further processing will take place. Attention consists of two parts: attention switch and attention maintenance. A signal should not only attract attention (i.e. attention switch), but a person’s attention should be maintained for some time in order to extract information contained in the signal. With respect to attention, various factors play a role. For example, Thorley et al. (2001) claim that repeated, long term exposure to a warning may result in poorer attention at later times. The effect of an individual’s tasks and other environmental stimuli on attention switch to warnings is discussed by Wogalter & Usher (1999).

After attention, individual early warning signal detection requires the human receiver to understand the meaning of the early warning signal. This notion is expressed in the next two steps, i.e. *comprehension* and *attitudes and beliefs*. Firstly, comprehension in the C-HIP model refers to the human receiver’s basic ability to interpret the received warning correctly. This is a particularly relevant field of study for warnings as regarded in warning research (signs, labels, manuals), and depends amongst other things on an individual’s direct understanding of warning wording and symbols, and an individual’s background knowledge (i.e. language, reading and technical knowledge) (Wogalter, 2006). Next, beyond a basic understanding of the warning signal, successful processing requires the message to concur with the receiver’s (preexisting) beliefs and attitudes, which represent an individual’s perception of reality. A person’s risk perception is an example of how attitudes and beliefs can influence signal processing. Being risk averse will lead a person to assign greater value to the potential hazards associated with a certain risk compared to its potential benefits. The greater the perceived hazard, the more responsive people will be to warning signals (Wogalter, 2006). Other factors at the attitudes and beliefs stage include familiarity, prior experience, cognitive bias and social influence, to name a few (DeJoy, 1999; Riley, 2006).

Assuming an individual receives an early warning signal, has attention for the signal, comprehends its meaning and the signal concurs with the individual’s attitudes and beliefs, individual early warning signal detection will be unsuccessful if an individual is not motivated to act on the received early warning signal. *Motivation* is affected by many factors, which include the cost of (non-) compliance, social influence, and (mental) workload, as discussed by Wogalter (2006).

Successful early warning signal detection by an individual, in the context of organizational early warning signal detection, ultimately leads to *signal-directed behavior or action* by an individual. One of the potential actions is to propagate the individual’s signal estimate across the organization, as was discussed in section 3.2.2. However, an individual might also decide to try to strengthen the signal estimate, e.g. through some form of information gathering (for instance, by means of a visual inspection) before propagating the signal across the organization. Furthermore, an individual might decide to start up an emergency procedure after processing the signal.
In the latter case, the individual’s understanding of the signal’s meaning is propagated across the organization through the individual’s action, instead of the physical transference of the signal estimate in the organization, still allowing the organization to detect the early warning signal.

Cognitive processing of an early warning signal may not always lead to successful individual early warning signal detection though, as is illustrated in figure 3.4. Either deliberately or unintentionally, each step in cognitively processing an early warning signal prior to the behavior/action phase might lead to non-action. For instance, cognitive bias, which was earlier identified as a factor at the attitudes and beliefs stage, may cause an individual to disregard the early warning signal (e.g. due to overconfidence (Goodwin & Wright, 2004), which results in a ‘this cannot happen to us’ attitude).

Lastly, it should be remarked that although figure 3.4 tends to emphasize a linear sequence from source to behavior, later processing steps may influence earlier steps in the cognitive processing of early warning signals (which is illustrated by means of the feedback loops). For example, when an individual does not believe some product, task, or environment is hazardous and, as a result, does not (actively) consider potential warnings, an individual’s beliefs and attitudes affect the earlier stage of attention (Wogalter, 2006).

### 3.3.3 Cognitive detection in an organizational context

The previous subsection has illustrated that individual early warning signal detection requires the early warning signal to be cognitively processed through various steps, which (in the context of organizational early warning signal detection) should result in signal-directed behavior or action (e.g. communication of the detected signal within the organization). As was shown, these steps are influenced in various ways, both positively and negatively, which in the latter case might result in non detection. These influencing factors include, but are not limited to: (other) environmental stimuli, an individual’s tasks, (technical) knowledge, risk perception, familiarity, prior experience, cognitive bias, social influence, cost of (non-) compliance, and (mental) workload.

It can not necessarily be assumed that these specific factors will affect individual early warning signal detection, since previous research has shown the effect of these factors on the detection of warnings (i.e. signs, labels, etc.) only, and has not shown the effect on individual early warning signal detection. Nevertheless, this overview of factors does illustrate that the main steps in cognitively processing warnings (which are considered to be the same for individual early warning signal detection, as was previously discussed) are not solely influenced by individual factors, such as prior experience or cognitive bias, but are influenced by other non-individual factors as well. Consequently, it can be claimed that individual early warning signal detection is affected by both individual and non-individual factors as well.

In an organizational context, these non-individual factors relate to the influence of an organization’s internal environment and external environment on individual early warning signal detection. For example, the effect of (other) environmental stimuli on attention (which can be considered as noise with respect to early warning signals) points to the effect of an individual’s direct or indirect environment on signal processing. This refers to environmental stimuli both from within the organization, and from an organization’s external environment.
Another example is social influence, which affects the attitudes and beliefs stage. In an organizational context, social influence can refer to the influence of an organization’s particular social setting on detection, as well as to the broader social context in which individuals operate (which includes an organization’s external environment). Lastly, the effect of an individual’s tasks on attention is another example of the potential influence of an organization’s internal environment on individual early warning signal detection in an organizational context.

Hence, it can be concluded that individual early warning signal detection in an organizational context is not solely affected by individual factors, but also by the organization itself, and by an organization’s external environment as well. This corresponds to the categories of factors that influence organizational early warning signal detection identified earlier, presented in table 3.1. However, it is unclear which specific factors within these categories will influence individual early warning signal detection in an organizational context, and organizational early warning signal detection.

3.4 Organizational early warning signal detection

In trying to explain organizational early warning signal detection by means of the people within an organization, this chapter has explored communication theory, organizational systems theory, and theory on the cognitive processing of warnings by individuals in order to construct a conceptual framework of organizational early warning signal detection. Based on insights from these theories, figure 3.5 presents this conceptual framework.

The framework in figure 3.5 indicates that organizational early warning signal detection is basically characterized by three main elements, namely early warning signal propagation within an organization (discussed in sections 3.2.1 and 3.2.2), individual early warning signal detection in an organizational context (discussed in sections 3.3.2 and 3.3.3), and influencing factors that affect both organizational signal propagation and individual detection (discussed in sections 3.2.3, 3.2.4 and 3.3.3).

Early warning signal detection by organizations is essentially not an isolated effort by individuals, as was stated in section 3.1. Rather, organizational early warning signal detection requires detection by individuals amidst surrounding noise, in the context of a coordinated group of people. As was discussed in section 3.2.1, this implies that after an early warning signal has been detected by one or more individuals, the resulting signal estimate(s) should be propagated across the organization. The emphasis in propagation in this sense is on the transference of the understanding of the signal’s meaning across the organization, and not so much on the physical transference of the signal or signal estimate(s).

Consequently, early warning signal propagation within an organization is a key element in explaining organizational early warning signal detection, as was discussed in sections 3.2.1 and 3.2.2. As a result, the model of figure 3.2, which shows a simplified representation of early warning signal propagation within an organization, acts as the basis of the framework in figure 3.5. For an explanation of the process of signal propagation depicted in figure 3.5, the reader is referred to the explanation of the model of figure 3.2, which was given in section 3.2.2.
Since organizational early warning signal detection as regarded in this thesis depends on detection of early warning signals by people within an organization, a framework that tries to give insight into organizational detection is considered incomplete without indicating how an individual detects early warning signals in an organizational context. By exploring some of the major steps in the cognitive processing of warnings, section 3.3.2 discussed how cognitive processing of an early warning signal may result in individual early warning signal detection.

In that subsection, it was concluded that individual early warning signal detection, as a prerequisite for organizational early warning signal detection, requires the full range of signal processing steps to result in signal-directed behavior or action (such as communication of the detected signal within the organization). These processing steps include attention, comprehension, attitudes and beliefs, and motivation, as is depicted in the lower left corner of figure 3.5.

*Fig. 3.5: Conceptual framework of organizational early warning signal detection*
Based on the discussion of these cognitive steps in section 3.3.2, it was illustrated that these steps are influenced in various ways, both positively and negatively, which in the latter case might result in non-detection. For individual early warning signal detection in an organizational context, section 3.3.3 concluded that detection is not solely affected by individual factors, but also by the organization itself, and by an organization’s external environment as well.

This conclusion is in line with what was stated in section 3.2.3 (in which an organization was regarded as an open system), namely that an organization’s subsystems as well as an organization’s external environment will also affect an organization’s ability to detect early warning signals. The fact that organizational early warning signal detection is affected in various ways, both within the organization and outside the organization was expressed by distinguishing between four main categories of influencing factors. These four categories, which were described in section 3.2.3, are 1) Human factors (i.e. (individual) factors that directly affect an individual’s ability to detect early warning signals), 2) Internal environment (i.e. factors active on an organizational level, which correspond to factors active in an organization’s four primary subsystems Technology, Structure, Culture and Strategy), 3) External environment (i.e. factors on the interface of an organization and its external environment) and 4) Exogenous (i.e. factors originating from an organization’s external environment, which are considered exogenous in this thesis). These factor categories are indicated as numbered boxes in the framework presented in figure 3.5. As was stated earlier, influencing factors from these categories affect both organizational signal propagation and individual signal detection. However, for the purpose of readability, factor categories are not explicitly indicated for individual early warning signal detection, which is represented by the cognitive process depicted in the lower left corner of figure 3.5.

Although the conceptual framework of figure 3.5 has its limitations (as will be discussed in section 3.6), the framework is valuable in providing insight into organizational early warning signal detection, in particular on how an organization might improve its ability to detect early warning signals. This is illustrated by means of case study analysis in the next section.

### 3.5 Case study analysis

To illustrate the value of the conceptual framework of figure 3.5 in giving insight into organizational early warning signal detection, a case study, in which early warning signal detection played a crucial role for two different organizations in the management of a serious organizational threat, is analyzed. More specifically, the case study describes how two organizations, Nokia and Ericsson, reacted differently to an early warning signal received from a key component supplier.

Firstly, a description of the case is given in section 3.5.1. Next, Nokia’s response to the early warning signal received is analyzed in section 3.5.2, whereas Ericsson’s response is analyzed in section 3.5.3. Lastly, by comparing their responses, the value of the conceptual framework in giving insight into organizational early warning signal detection is discussed in section 3.5.4.
3.5.1 Nokia-Ericsson case: description

On March 17th, 2000, lightning struck an electric line in New Mexico leading to power fluctuations, which resulted in a small fire in a Philips semiconductor plant in Albuquerque (Latour, 2001; Norrman & Jansson, 2004). A furnace containing wafers sufficient for thousands of chips caught fire, destroying the wafers. In less than ten minutes, the fire was out due to the activated sprinkler system and a quick response from personnel.

Initially, Philips did not foresee that the fire would lead to major disruptions. It was projected that the plant would be back to normal operations within a week, and this message was informally communicated by phone to two of the plant’s major customers within a few days after the fire: mobile phone manufacturers Nokia of Finland and Ericsson of Sweden.

It turned out however, that the small fire had major consequences. Water damage and smoke entering the facility’s clean room contaminated millions of chips and resulted in the need for a major cleanup operation, which lasted for three weeks. Even after six months, production was only at fifty percent of what it used to be before the fire. For Nokia and Ericsson, this major supply disruption posed a serious organizational threat. Both organizations relied on the semiconductor plant for the production of several components, some of which were key components. Since Philips was unable to supply the amounts necessary, Nokia and Ericsson were facing a situation in which they would be unable to meet customer demand at a time when the mobile phone market was booming.

Given the sequence of events as they unfolded, the initial informal communication about the small fire at the semiconductor plant can be considered an (external) early warning signal of a serious organizational threat for both Nokia and Ericsson, namely a major supply disruption at a key component supplier which lasted several months.

Both organizations handled the early warning signal differently however. Whereas the early warning signal was by and large ignored (i.e. not detected) within the Ericsson organization, the early warning signal was detected across all levels (strategic, tactical, operational) in the Nokia organization. As a result, Nokia was able to take necessary precautionary measures based on the detected early warning signal, which in the end allowed them to keep mobile phone production on target despite the fire. Ericsson, on the other hand, came up millions of chips short and allegedly lost 400 million dollars in potential revenue (Latour, 2001).

The next subsections elaborate on the way in which the early warning signal was detected by the Nokia organization and was not detected by the Ericsson organization, as described by Latour (2001) and Norrman & Jansson (2004). The conceptual framework of figure 3.5 is used to demonstrate this process, as well as the way in which the particular organizational context affected this process.

3.5.2 Analyzing Nokia’s response

In a phone call to his office at Nokia headquarters, a component purchasing manager at Nokia was informed by a Philips account representative of the fire, saying that the company had lost “some wafers”, but that the plant would be back to normal in a week. Although the component purchasing manager wasn’t terribly alarmed, he relayed the news up Nokia’s chain of command, to Nokia’s chief supply trouble shooter.
The chief supply trouble shooter also did not anticipate a major problem yet, but still decided to act on the early warning signal, such as to put the components made at the Philips plant on a special monitor list and to further propagate the signal in the Nokia organization (Latour, 2001).

The process by which the early warning signal received from Philips propagated across the Nokia organization is presented in figure 3.6. Nokia’s particular organizational context affected this process in various ways, facilitating organizational early warning signal detection. This is indicated in figure 3.6 by means of the black boxes labeled A to F. These boxes represent the following:

A. *Nokia’s relation with its suppliers.* Nokia realizes the importance of supplier management, partly due to a major supply disruption a couple of years prior to the fire at the Philips semiconductor plant. Aware of its dependent relation with its suppliers of key components, Nokia is watchful of any signal they may receive from these suppliers, however seemingly insignificant the signal may appear to be. As a result, Nokia officials were able to notice a glitch in the flow of chips even before Philips’ phone call to Nokia’s component purchasing manager.

B. *Nokia’s earlier experience.* Nokia’s response to the early warning signal received from Philips was partly affected by Nokia’s prior experience with a major supply disruption, as stated above. Nokia was able to learn from this experience, and to take necessary measures in order to try to prevent a similar situation from occurring in the future. This points to Nokia’s ability to learn from the past, which can be considered a form of organizational learning.

C. *Quick and open communication.* Within Nokia, a formal communication structure is in place that facilitates quick and open communication throughout the organization. People are encouraged to pass on early warning signals to their superiors, even though the signal does not require immediate action. If it turns out that immediate action is necessary, it is possible to act quickly, e.g. due to top management’s involvement in the open communication loop. As is shown in figure 3.6, the initial early warning signal received from Philips was passed on from troubleshooter to top management, which resulted in top management notifying Philips executives of their concerns.

D. *Individual factors.* Nokia encourages its people to propagate early warning signals quickly within the organization, however seemingly insignificant the signal may appear to be. This requires people to have an attitude towards signals to ‘better check just in case, even though it is probably nothing’. It can be argued that whether or not an individual has such an attitude largely depends on the particular individual (i.e. individual factors), though an organization can certainly promote such an attitude among its people. For example, the decision of the component purchasing manager to relay the signal to the chief supply troubleshooter can at least partly be attributed to his individual capabilities. This corresponds to the line of reasoning put forward in section 3.3.1, in that individuals that hold a particular position within an organization can be assumed to have the level of expertise which is required for the position.
Based on the case description by Latour (2001) and Norrman & Jansson (2004), it is unclear which particular individual factors influenced the individuals’ decision to either act based upon the received signal or not. Hence, no further claim can be made with respect to which individual factors affected organizational early warning signal detection.

E. Responsibility and authority. Besides having a communication structure that allows quick and open communication, organizational early warning signal detection at Nokia is positively influenced due to the fact that people at Nokia are given the responsibility to communicate early indications of potential threats. In most cases, this responsibility is paired with the authority to make on-the-ground decisions based upon the received signal. For instance, Nokia’s chief supply troubleshooter had the means to act quickly upon receiving the news from the component purchasing manager, which amongst other things included the ability to allocate resources (such as committing Nokia engineers to the case).

F. Culture. Lastly, Latour (2001) mentions the influence of organizational culture on the way in which Nokia handled the supply disruption. While being strongly connected through their shared culture (they consider themselves Nokians), people at Nokia are not afraid to act upon signals individualistically. This allows for a quick response to signals received, as was the case in handling Philips’ early warning signal.
When considering the categories of influencing factors given in table 3.1, it is apparent that organizational early warning signal detection at Nokia was influenced by factors from various categories. For instance, Nokia’s relation with its suppliers can be considered an influencing factor in the External environment category, whereas quick and open communication is an example of an influencing factor from the Internal environment category (more specifically, the Structure subcategory). The short discussion above also more directly points to the influence of factor categories on organizational early warning signal detection at Nokia, such as the influence of individual factors (i.e. Human factors category) and culture (i.e. Internal environment category, subcategory Culture).

In Nokia’s case, these influencing factors and factor categories positively contributed to organizational early warning signal detection, which helped Nokia to manage the organizational threat they were facing. In the end, Nokia was able to keep mobile phone production on target despite the fire, by securing supplies from manufacturers in Japan and the U.S., as well as from other Philips plants. Also, some of the chips were redesigned so that they could be manufactured by other suppliers. Although in this case early warning signal detection at Nokia allowed the company to successfully manage the major supply disruption, it should be noted that organizational early warning signal detection is no guarantee for successful risk management however, which should include other activities beyond risk detection, such as risk evaluation, risk treatment/response, communication and monitoring (see table 2.1 in section 2.1).

3.5.3 Analyzing Ericsson’s response

Like Nokia, a component purchasing manager at Ericsson received a phone call from a Philips account representative about the fire, notifying Ericsson that the plant would be back to normal in a week. Contrary to Nokia however, Ericsson did not respond immediately to the early warning signal. Instead, the early warning signal was largely ignored and remained undetected in the Ericsson organization. Even after additional information from Philips about the seriousness of the problem, more time passed before Ericsson’s middle management fully briefed top management.

The process by which the early warning signal received from Philips propagated across the Ericsson organization is presented in figure 3.7. Ericsson’s particular organizational context affected this process in various ways, hindering organizational early warning signal detection.

This is indicated in figure 3.7 by means of the black boxes labeled A to C. These boxes represent the following:

A. Individual factors. The component purchasing manager at Ericsson received the same informal signal (i.e. a phone call from Philips) as the manager at Nokia. Ericsson’s purchasing manager did however not perceive the signal as important. At best, the signal was communicated informally to middle management, but the potential importance was not emphasized and no further action was taken. Ericsson’s middle management also did not understand the early warning signal’s meaning. In fact, the signal was disregarded and not further propagated to Ericsson’s top management. In considering the process of individual early warning signal detection as discussed in section 3.3.2, the purchasing manager’s and middle managers’ failure to understand the meaning of the early warning signal can most likely be attributed to the attitudes and beliefs phase.
In order words, the early warning signal did not concur with the purchasing manager’s and middle managers’ (preexisting) beliefs and attitudes. As was discussed in the same section, most of the factors that affect the attitudes and beliefs phase are individual factors, such as risk perception, familiarity, prior experience and cognitive bias. Thus, it is reasonable to assume that individual factors in some way affected organizational early warning signal detection at Ericsson, although it is impossible to say which particular factors affected non-detection by these individuals, based on the case material.

**B. Internal communication.** Initially, there was no communication by Ericsson’s middle management to top management on the received message from Philips about the fire. As a result, top management was unaware of the organizational threat they were facing and the Ericsson organization as a whole was unable to detect the early warning signal. Even after additional information about the seriousness of the problem was received, communication to top management remained slow. These events point to failing internal communication with respect to (potential) organizational threats.

**C. Culture.** Whereas Nokia took on an active approach to the management of the organizational threat, Ericsson was far more passive, which Latour (2001) mentions as a characteristic of Ericsson’s culture. Contrary to Nokia, people at Ericsson are less inclined to act upon early warning signals individualistically, and tend more to (group) consensus, rendering a quick response more difficult.
Although the case material (Latour, 2001; Norrman & Jansson, 2004) describes Ericsson’s response to the early warning signal from Philips in much less detail than Nokia’s response, it is still apparent that factors from various categories in table 3.1 influenced Ericsson’s response (Human factors, Internal environment). In Ericsson’s case, influencing factors mainly negatively contributed to organizational early warning signal detection. In the end, Ericsson responded too slowly and was ill prepared for the organizational threat, which made them incapable of satisfying customer demand in time.

3.5.4 Comparing Nokia’s and Ericsson’s response

When comparing Nokia’s and Ericsson’s response to the early warning signal received from Philips, the following conclusions can be drawn:

- Despite receiving the same early warning signal, organizations can respond very differently to the signal in question.
- As the analysis of both organizations’ responses demonstrated, these differences are apparent in the way in which the signal propagated across the organization, as well as the way in which individuals detected the early warning signal.
- Both individual detection and signal propagation within the Nokia organization and the Ericsson organization was affected by a variety of influencing factors, from various categories in table 3.1.
- For Nokia, these influencing factors positively contributed to organizational early warning signal detection, whereas influencing factors at Ericsson negatively contributed to Ericsson’s ability to detect the early warning signal. Hence, influencing factors can either positively or negatively affect detection.

In other words, analysis of the Nokia-Ericsson case has confirmed the role of individual detection, organizational signal propagation, and influencing factors that affect both, in organizational early warning signal detection. Depending on the particular organization, the combination of these basic elements of organizational early warning signal detection may result in the organization either detecting the early warning signal or not. Since the conceptual framework of figure 3.5 describes these basic elements in the context of an organization, it is thus claimed that the framework is valuable in providing insight into organizational early warning signal detection (as is shown in figures 3.6 and 3.7).

As was stated in section 2.5, the main purpose of gaining this insight is to learn how to potentially improve an organization’s ability to detect early warning signals. Analysis of the Nokia-Ericsson case has shown that whether or not an organization successfully detects early warning signals depends on influencing factors from various categories (Human factors, Internal environment, External environment, Exogenous), which can either positively or negatively affect detection. Hence, insight into influencing factors from these categories beyond those found in this single case study analysis can be considered as a prerequisite in trying to improve organizational early warning signal detection, as is further discussed in the next section.

3.6 Conclusion and discussion

The aim of this chapter is to provide insight into organizational early warning signal detection, thereby addressing the first research question put forward in section 2.5 (i.e. how do (industrial) organizations detect early warning signals, as regarded in this thesis?).
This insight is gained through the development of a conceptual framework of organizational early warning signal detection, the construction of which was described in sections 3.2 to 3.4. Fundamental to this framework are three main elements of organizational detection, namely early warning signal propagation within an organization, individual early warning signal detection in an organizational context, and influencing factors that affect both organizational signal propagation and individual detection. Case study analysis confirmed the role of these elements in organizational early warning signal detection, as was discussed in the previous section, thereby indicating the value of the framework.

The framework depicted in figure 3.5 has its limitations though. Firstly, it concerns a conceptual framework, which gives a simplified (high-level) representation of organizational early warning signal detection. As a result, the framework is able to provide only a basic understanding of organizational early warning signal detection, and does not consider the underlying (propagation & detection) mechanisms in great detail. Furthermore, the suitability of the framework to describe organizational early warning signal detection was demonstrated by means of the analysis of a single case study (i.e. the Nokia-Ericsson case). In that respect, additional case study analyses could further add to framework validation.

Despite these limitations, it is claimed that even a basic understanding of organizational early warning signal detection is valuable with regard to the aim of this thesis, i.e. to gain insight into organizational detection in order to learn how to potentially improve an organization’s ability to detect early warning signals. As is apparent from the framework discussion (as well as from the analysis of the Nokia-Ericsson case), whether or not an organization successfully detects early warning signals depends on influencing factors from the categories Human factors, Internal environment, External environment, and Exogenous (see table 3.1), which can either positively or negatively affect detection. More specifically, these factors can either positively or negatively affect organizational early warning signal propagation and individual early warning signal detection in an organizational context.

Consequently, in order to potentially improve an organization’s ability to detect early warning signals, insight into influencing factors from these four categories that will affect signal detection is needed. Though the case study analysis discussed in section 3.5 indicated several potential factors, and section 2.3 provided some specific guidelines to early warning signal detection that potentially point to influencing factors, an overview of influencing factors of organizational early warning signal detection as regarded in this thesis is currently missing in literature.

The next chapter proposes an approach to the identification of these underlying factors that influence organizational early warning signal detection. Application of the approach, including the resulting overview of influencing factors, is discussed in the next two chapters.
4 Approach to the identification of underlying factors: model development

As the previous chapter demonstrated, underlying factors in four main categories (Human factors, Internal environment, External environment, and Exogenous) exist that can both positively and negatively influence organizational early warning signal detection. This chapter firstly introduces a general approach to the identification of factors in these categories. Next, application of the first step of the proposed approach, i.e. model development, is discussed. In this thesis, model development is based on findings of both a literature study and a focus group, resulting in an initial overview of influencing factors. This overview acts as input to the next step of the proposed approach, i.e. model validation, which is discussed in the next chapter.

4.1 Proposed approach to factor identification

In literature, various approaches to the identification of influencing factors are described. In the field of crisis management, Elsubbaugh et al. (2004) utilize interviews and questionnaires to derive factors that influence crisis preparation. Sheaffer et al. (1998) present a framework of organizational crisis-causal factors based on review of crisis-and-decline literature, which is validated by means of case study analysis. These examples show that a variety of data sources and related data collection and analysis methods can be employed for factor identification.

Given the availability of various identification methods in literature, the next subsection firstly discusses criteria that the factor identification approach to be employed in this thesis has to meet. As will become apparent, given these criteria, a combination of multiple data sources and related methods are employed for factor identification. The resulting general approach to identification of influencing factors employed in this thesis is presented in section 4.1.2. Prior to discussing the application of the proposed approach in detail in the remainder of chapter 4 and in the next chapter, section 4.1.3 brings forward some important issues to be included in the discussion.

4.1.1 Criteria

As was explained in section 2.5, the main objective of the research described in this thesis is to gain insight into how (industrial) organizations detect early warning signals, in order to potentially improve their ability to detect such signals. To reach this objective, a mainly exploratory research approach is required, as was discussed in section 2.6. For the factor identification approach to be employed in this thesis, this implies the following criteria:

1. Capture insights across organizations and industries

   Purpose of the approach is to identify influencing factors that affect early warning signal detection by industrial organizations in general. Hence, the approach should be non-specific for any one particular organization. In other words, the approach should not be based on e.g. the execution of a single case study, but should be able to capture insights across organizations and across industries.
In that way, application of the approach to factor identification is expected to result in an overview of factors which gives an adequate representation of the various ways in which organizational early warning signal detection is overall affected in the particular industries considered.

Since the purpose of gaining such insight into influencing factors is essentially to try to improve organizations’ ability to detect early warning signals, the question how this insight gained across organizations and industries might be made specific to any one particular industry, and (on a lower aggregation level) to any one particular organization, should be addressed as well. This topic is further elaborated upon at the end of the next chapter, after application of the proposed approach to factor identification.

2. **Support exploratory approach to research**

To the best of the author’s knowledge, a comprehensive overview of factors that influence organizational early warning signal detection by industrial organizations is currently lacking, which merits an exploratory research approach. When little is known about which important variables (in this case, influencing factors) to examine, employment of qualitative research methods is appropriate and useful (Creswell, 2003; Strauss & Corbin, 1990). Thus, factor identification in this thesis to a large extent requires a qualitative approach to research.

3. **Utilize multiple sources of evidence: literature, experts, case studies**

According to Yin (1994), an important advantage of utilizing multiple sources of evidence is the development of converging lines of inquiry. This is particularly relevant when applying an exploratory research approach, since converging lines of inquiry can add to the validity of research findings, on a topic about which little is known. Hence, multiple sources of evidence are to be utilized in the adopted approach to factor identification, which corresponds to data triangulation as put forward by Patton (1987).

Within this thesis, the three main sources of evidence for factor identification are literature, experts and case studies. As was already discussed in chapter 2, although an overview of influencing factors of organizational early warning signal detection is not provided, guidelines on signal detection across various risk management disciplines do point to some potential influencing factors. As such, a more elaborate investigation of literature can act as a good starting point for factor identification.

As was explained in section 3.3.1, this thesis assumes that people that hold a particular position within an organization have the level of expertise which is required for the position. As a result, people specifically involved in risk management within an organization (either on an operational, tactical, or strategic level) are assumed to have expertise in risk management, including expertise in the detection of early warning signals within an organization amidst surrounding noise, and insight into related influencing factors (from their perspective). As such, these people (i.e. risk management experts) are considered a valuable source of evidence for factor identification.
In light of the first criterion given, i.e. that insight into influencing factors across industries and organizations should be captured, particularly the input of risk management experts assembled in expertise networks that transcend industries, e.g. professional risk management associations, is sought. The main rationale for this particular focus is that these expertise networks present a platform for consolidating knowledge of risk management across industries. This is accomplished by allowing experts in these networks to share their practical experience with managing risk with fellow experts and, at the same time, to learn from others’ insights. As a result, experts in such networks are expected to have insight into managing risk beyond the particular organization or even industry in which they are active. Besides that, from a practical point of view, such networks furthermore facilitate the process of getting these risk management experts from various industries together for research purposes.

Lastly, case studies of major industrial accidents form an essential data source. Since most major industrial accidents are well documented and investigated, including the sequence of events leading to the catastrophic event, such case studies generally have the required level of detail (both descriptive and analytical) to allow for analysis with respect to early warning signals and their detection, and related influencing factors.

Next to these industrial accidents, examples of how organizations are successful in proactive risk management and specifically the detection of early warning signals can also act as a source of evidence. One such example was already discussed in the previous chapter, i.e. how Nokia successfully responded to an early warning signal detected prior to a major supply disruption (Latour, 2001; Norrman & Jansson, 2004). Other examples of organizational excellence in this respect can be found both in practice and in literature. For instance, the UK 2012 Olympic Park and Athletes’ building project (UK Health and Safety Executive, 2011) is characterized by excellent proactive management of related (safety) risk, i.e. apparent from the fact that no serious accidents to date have been encountered, which can be considered exceptional for this type of large-scale building project.

In resilience engineering literature (which was already briefly discussed in section 2.3.4), Weick & Sutcliffe (2007) discuss how organizational ‘mindfulness’ can help High Reliability Organizations (HROs) to proactively manage the unexpected, which in part is accomplished by paying close attention to early warning signals of failure (called ‘preoccupation with failure’). Various examples of such ‘mindful’ organizations, although not always explicitly named, are provided by these authors.

Besides focusing on industrial accidents, this thesis takes such ‘success stories’ of proactive risk management into account in the process of factor identification as well. It does so both indirectly (by studying resilience engineering literature (as will be described in sections 4.2 and 4.3), in particular ‘mindful’ organizations’ practices and lessons learnt in proactive risk management as documented in literature) and directly (by case study analysis).
With regard to the latter, it is important to note that case studies of organizational excellence in proactive risk management with the descriptive and analytical detail required to allow analysis with respect to early warning signals and their detection are available in literature, but are very limited i.e. inherent to the field of reliability engineering and risk. As such, case study analysis mainly includes the analysis of industrial accidents, as will be further explained in chapter 5.

4. **Employ multiple research methods**

   Inherent to the use of these three diverse sources of evidence is the employment of various research methods associated with these data sources. Whereas utilizing multiple sources of evidence is one means of triangulation (i.e. data triangulation), employment of multiple research methods is another, namely methodological triangulation (Patton, 1987). This second means of triangulation further adds to the validity of the research on influencing factors.

5. **Provide structured framework**

   In order to try to obtain a comprehensive overview of influencing factors, results of (the combination of) multiple research methods need to be integrated. Integration of methods can occur in various ways. For example, research methods might be used concurrently, e.g. to offset the weaknesses inherent to one method with the strengths of another method. In this case, data collection often takes places concurrently, and integration only occurs at the interpretation phase (Creswell, 2003). Research methods might also be integrated sequentially, in order to elaborate on or expand the findings of one method with another method (Creswell, 2003). Lastly, an iterative approach to integration might be adopted, in which research methods are applied in various iterations, until ideally theoretical saturation is reached, i.e. when additional research results yield very little new insight. The proposed approach to factor identification should thus indicate the way in which integration occurs, which can be accomplished by providing a structured framework to factor identification.

Summarizing, the proposed approach to factor identification should be able to capture insights non-specific for any one particular organization, should support an exploratory approach to research, and should utilize both multiple data sources and multiple research methods, the integration of which is captured in a structured framework.

### 4.1.2 General approach to factor identification

Given the criteria put forward in the previous subsection, figure 4.1 presents the general approach to factor identification employed in this thesis. As is apparent from figure 4.1, factor identification is considered a structured process (*criterion #5*), encompassing two main phases or steps, namely model development and model validation. Such a process oriented perspective on factor identification is in line with the perspective on the development of new theory as put forward by Van der Zwaan & Van Engelen (1994), which is characterized by a trajectory consisting of several phases, starting with exploration and ending in validation. In this process, different research strategies might be pursued, and various data sources and methods, and combinations thereof, might be employed (Kerssens-Van Drongelen, 2001; Van der Zwaan & Van Engelen, 1994).
The first step in the proposed approach to factor identification is model development, the intention of which is to construct an initial model (in this thesis, an initial list) of factors that either positively or negatively affect organizational early warning signal detection. Characteristic for the model development step is the use of a concurrent qualitative strategy to construct the initial model.

Since employment of qualitative research methods is appropriate and useful in exploratory research as was discussed earlier, initial model development is based on a qualitative approach (criterion #2). This qualitative approach is not limited to a single source of evidence or one particular qualitative research method, but brings together various sources of evidence (criterion #3) and various qualitative research methods (criterion #4). More specifically, initial insights from literature, experts, and/or case studies across organizations and industries (criterion #1), extracted by means of qualitative research, are analyzed and interpreted to construct an initial list of influencing factors.

Fig. 4.1: General approach to factor identification employed in this thesis
When applying multiple research methods within a single research study, these methods combined should constitute an integrated strategy (criterion #5). As indicated in figure 4.1, integration of qualitative methods in the model development step of the proposed approach to factor identification takes place concurrently. By opting for a concurrent strategy, application of each qualitative research method separately yields insights into potential influencing factors of organizational early warning signal detection. After application, these insights are then integrated in order to establish an initial list of influencing factors.

Hence, a concurrent strategy allows model development along parallel paths, utilizing different sources of evidence. Although figure 4.1 depicts the concurrent employment of two qualitative research methods (L_i and L_{i+1}), additional qualitative methods might be applied for model development as well.

The output of the model development step, i.e. an initial list of influencing factors, then acts as input to the next step of the proposed approach, namely model validation. Characteristic for the model validation step is the use of an iterative mixed methods strategy to construct a validated list of influencing factors.

The main purpose of the second step of the proposed approach is to further validate the initial list of influencing factors. Again, multiple sources of evidence (criterion #3) across organizations and industries (criterion #1), and multiple research methods (criterion #4) are employed. In particular, model validation is achieved by applying multiple research methods with different sources of evidence as input (literature, experts, case studies) in various iterations. After each iteration, the initial list of influencing factors is adjusted, or ‘updated’, based on any new relevant insights gained. This process repeats itself until additional results of the latest applied method yield very little new insight, resulting in a validated list of influencing factors. Figure 4.1 depicts the iterative nature of the model validation step, by indicating that after each model update, a decision is made to either start a new iteration or to conclude the model validation step.

Whereas the first step of the proposed approach is limited to qualitative research, insights gained during this first step allow the use of more quantitative research methods in the model validation step. For example, it is possible to ascertain risk management experts’ opinion of the initial list of factors by means of a survey (i.e. a quantitative method). Hence, when such an initial model is available for review, research need not be limited to the application of qualitative methods. Instead, both qualitative and quantitative methods might be employed, which is desirable from a triangulation perspective (criterion #4). It is important to stress that using one particular type of method does not necessarily exclude the other, as Creswell (2003) acknowledges the mixing of both qualitative and quantitative methods within a single study. In figure 4.1, mixing of methods in the second step of the proposed approach is illustrated by means of the application of both quantitative methods (represented by N_j) and qualitative methods (represented by L_i) for validation.

4.1.3 Application

In the remainder of this chapter, and the next chapter, application of the proposed approach to factor identification in this thesis, which results in a validated list of influencing factors of organizational early warning signal detection, is discussed. Model development and the construction of an initial list of factors are discussed in sections 4.2 to 4.4. Model validation is the topic of interest of chapter 5.
As is apparent from figure 4.1, the general approach to factor identification does not prescribe which specific research methods to employ (other than the basic distinction between qualitative and quantitative methods). This leaves a wide variety of research methods to be potentially incorporated in the approach. Consequently, when discussing the data collection procedure associated with each method and the resulting insights from the (combined) data analysis, justification of the particular choice of applied research methods (which can partly be attributed to practical reasons) needs to be included as well.

Figure 4.2 gives an overview of the particular research methods employed for model development in this thesis. As will be explained in the next sections, the main data sources utilized for model development constitute literature on crisis management and resilience engineering, and risk management experts. Justification for the choice of a literature study and a focus group as concurrent qualitative methods to construct an initial list of influencing factors, as well as data collection and data analysis for both methods, are discussed (see section numbers indicated in figure 4.2).

Another important issue to address when describing the application of the identification approach is validity of the particular research methods employed. Though a separate model validation step is included in the proposed identification approach, this should not lead to the conclusion that concern for validation is limited to the second step of the approach. With regard to the model development step, validity and reliability of the employed literature study and focus group are discussed in sections 4.2.4 and 4.3.3, respectively.

After application of both the model development step (see this chapter) and the model validation step (see chapter 5), effectiveness of the approach to arrive at an overview of influencing factors of organizational early warning signal detection is discussed, thereby addressing the validity of the overall approach. This discussion is presented at the end of chapter 5, together with an exploration of how results obtained might be made specific to any one particular industry or organization for the purpose of signal detection improvement.
4.2 Model development: literature study

Review of literature from various risk management disciplines, as was discussed in section 2.3, demonstrated that although literature provides little support with regard to structured methods and tools for early warning signal detection, (general) guidelines on early warning signal detection are available. For instance, Mitroff & Anagnos (2001) mention the need for open communication and the need to reward signal detection and emphasize safety, in order to allow organizational early warning signal detection. Though not explicitly, these and other guidelines on signal detection across risk management disciplines do point to potential influencing factors. As such, a more elaborate investigation of literature can act as a good starting point for factor identification. Hence, it was decided to perform a study of risk management literature as part of the concurrent qualitative strategy to model development (i.e. the first step of the proposed approach to factor identification).

As was summarized in table 2.7, contrary to some of the other risk management disciplines considered, the particular fields of crisis management and resilience engineering explicitly acknowledge the need for early warning signal detection. Moreover, it was concluded that literature on crisis management and resilience engineering provides more insight into specific guidelines on signal detection compared to e.g. literature on enterprise risk management. For these reasons, it was decided to study crisis management literature and resilience engineering literature for potential influencing factors of organizational early warning signal detection.

The approach to literature study adopted in this thesis is discussed in the following subsection, the initial results of which are presented in section 4.2.2. Since most of the identified factors showed considerable overlap, a further refinement of the list of identified factors was needed. The process of refinement, including the resulting overview of influencing factors, is described in section 4.2.3. Lastly, validity and reliability considerations associated with the employed literature study and factor list refinement are addressed in section 4.2.4.

4.2.1 Approach to literature study

Literature on crisis management and resilience engineering, reviewed in section 2.3 with regard to early warning signal detection, acted as the point of departure for deduction of influencing factors. With the theoretical framework of organizational early warning signal detection (as presented in figure 3.5) in mind, and more specifically, the four identified main categories of influencing factors, references presented in section 2.3 were reviewed. The review process consisted of a qualitative analysis of the references’ content. In particular, findings with respect to early warning signal detection in an organizational context, such as guidelines provided for effective detection, were assessed in order to identify potential influencing factors.

Based on this initial review of literature, several observations were made. Firstly, almost without any exception, influencing factors were not described as such, but had to be extracted from textual descriptions. Secondly, influencing factors were derived from both general descriptions of the way in which signal detection is affected, and from particular illustrations. The latter refers to e.g. statements made based on the author’s auditing experience or conclusions drawn based on the analysis of situations in which organizational signal detection failed (e.g. analysis of industrial accidents). Thirdly, it was observed that influencing effects on organizational early warning signal detection were either positively or negatively phrased.
Positively phrased influencing effects point to ways in which early warning signal detection is positively affected. Examples of such positively phrased effects are candidness about failures (Weick & Sutcliffe, 2007) and the establishment of clear and open communication channels (Pearson & Mitroff, 1993). Negatively phrased influencing effects point to ways in which early warning signal detection is negatively affected. An example of such a negatively phrased effect is organizational imperviousness to bad news (Mitroff et al., 1987). Since the purpose of the literature study is to identify influencing factors in general, both positively and negatively phrased effects were marked as potential factors.

The next step in the adopted approach to identify influencing factors from literature was to extend the initial review of literature, and to include additional literature on crisis management and resilience engineering. In that way, additional factors could ideally be added to the list of influencing factors already obtained from the small scale initial literature review.

Through various sources, including (electronic) libraries, the Internet, information retrieval systems for academic publications, and by use of references available in the initially reviewed literature, a considerable list of potentially relevant scientific publications (books, journal papers,...) was generated. Extraction of potentially relevant publications from the large body of literature on crisis management and resilience engineering took place by firstly applying various combinations of search terms to find literature (e.g. ‘early warning signal(s)’, ‘weak signal(s)’, ‘signal detection’, ‘signal response’, ‘signal management’, etc.). Next, a quick scan of the literature found by application of these search terms was performed. Based on the publication’s abstract and/or conclusions, and a quick review of the publication’s content, the list of potentially relevant publications could be further narrowed down. The remaining list of publications was then subjected to the same review process as applied to extract influencing factors in the initial review. Based on the results of this review process, some publications on further consideration proved to be marginally informative with regard to influencing factors of organizational early warning signal detection, and thus were removed. The search and filtering process described above was then repeated, until no further relevant publications were found.

Review of the additional literature on crisis management and resilience engineering led to the same observations as made during the initial review of literature, in that influencing factors in nearly all cases had to be extracted from textual descriptions, were derived from general descriptions and particular illustrations, and that influencing effects were either positively or negatively phrased.

### 4.2.2 Initial results of literature study

Following the approach described above, the literature study resulted in the identification of 110 influencing factors of organizational early warning signal detection from twenty relevant publications in the field of crisis management and resilience engineering. Appendix 4.1 gives an overview of these identified factors, and the related literature sources. Factors are included in this overview as found in literature.

As is shown in appendix 4.1, influencing factors were mapped onto the four main categories of influencing factors identified in chapter 3, namely Human factors, Internal environment, External environment, and Exogenous. As was explained in section 3.2.4, these categories represent the following:
- **Human factors**: factors that directly affect an individual’s ability to detect early warning signals.

- **Internal environment**: factors active on an organizational level, which affect organizational early warning signal detection. More specifically, this category corresponds to factors active in four primary organizational subsystems, namely Technology, Structure, Culture and Strategy.

- **External environment**: influencing factors on the interface of an organization and its external environment.

- **Exogenous**: factors originating from an organization’s external environment. Since it was assumed that external factors will largely lie outside an organization’s area of influence, these factors are considered exogenous in this thesis.

For the majority of identified factors, based on the description of the influencing effect in literature, it was obvious to which category the particular factor belonged. In a small number of cases however, the distinction was not so clear-cut. In these cases, the described effect could be placed in various subcategories, most notably in either the Structure or Culture subcategories. Given the interrelatedness between an organization’s various subsystems, this type of discussion was anticipated though. For instance, communication of early warning signals within an organization was often mentioned in literature as an influencing effect on organizational early warning signal detection. However, communication both relates to structural elements within an organization (such as the establishment of formal communication lines or communication procedures) and cultural elements (such as the willingness of people within an organization to communicate early warning signals), and thus could be placed in either the Structure or Culture subcategory. By closely reviewing the context in which communication was mentioned as an influencing effect, the most appropriate subcategory (Structure or Culture) was determined. This same strategy was applied to other factors that could not immediately be categorized. Except for one factor, namely ‘Organizational internalization of early warning signals’ as mentioned by Sheffi (2005), this strategy led to the assignment of all factors to one particular (sub)category. Consequently, it was decided to place ‘Organizational internalization’ in both the Structure and Culture subcategories.

As was mentioned earlier, the influencing factors presented in appendix 4.1 were obtained from twenty relevant publications in the field of crisis management and resilience engineering. Although many more potentially relevant publications were selected, further review of these publications resulted in a considerable reduction of the list of relevant publications, since many of the potentially relevant publications after review proved to be marginally informative with regard to influencing factors of organizational early warning signal detection. It can be argued that obtaining 110 influencing factors from twenty relevant publications constitutes a satisfactory result of the literature study, especially since influencing factors of organizational early warning signal detection are not typically directly described in literature. For instance, in comparison, Jacobs & Van Moll (2007) describe the results of an elaborate literature search into influencing factors of defect introduction and defect detection in product development. Based on 26 relevant publications for defect introduction, and 12 relevant publications for defect detection (in which factors were both identified directly and from textual descriptions), they were able to identify 167 factors and 48 factors, respectively.
Though the literature study described in this thesis and the literature study by Jacobs & Van Moll (2007) are performed in different fields and each study was subject to its own considerations and limitations, obtaining 110 influencing factors from twenty relevant factors generally appears to be a reasonable result.

Besides the observations already discussed in the previous subsection, the literature study yielded some other interesting observations. Firstly, a majority of factors were found in crisis management literature. This is in accordance to what was expected, since detection of early warning signals has traditionally received more attention in crisis management literature. Consequently, relatively more publications on detection of early warning signals originate from crisis management literature compared to resilience engineering literature, which constitute a richer source of potential influencing factors. Secondly, the initial review of literature resulted in the identification of 43 out of the total of 110 influencing factors obtained in the full scale literature study. This confirms both the appropriateness of using the literature reviewed in section 2.3 as a starting point, and the added value of extending the initial review.

Thirdly, it was observed that there is relatively strong agreement in literature on the ways in which organizational early warning signal detection is affected. This sense of agreement is apparent from the large amount of duplicate factors found in literature. Furthermore, besides duplicates, factors were found that describe the same general effect on signal detection, but which are either positively phrased or negatively phrased. For instance, Pearson & Mitroff (1993) mention an organization’s recognition of the contribution of bad news messengers as a positive influencing effect on organizational early warning signal detection, whereas Sheaffer et al. (1998) mention the dismissal of bad news bearers as a negative influencing effect. These authors basically describe the same general influencing effect on signal detection, i.e. the way in which an organization handles bad news.

Lastly, influencing factors were found that referred to the same effect on signal detection, but which were either expressed in general terms or expressed in particular instances of the influencing effect. For example, the effect of (individual) cognitive bias on organizational early warning signal detection as regarded in this thesis is acknowledged by numerous authors. Whereas Roberto et al. (2006) directly mention cognitive biases as an influencing effect, and Schoemaker & Day (2009) talk about the effect of individual biases, other authors discuss particular instances of cognitive bias as having an influence on signal detection. Sheaffer et al. (1998) mark manager’s overreliance on past success as an influence effect, for example. Together with a person’s commitment to a chosen course of action as mentioned by Miller (1993), these phenomena represent examples of cognitive bias.

Given the latter observations (duplicate factors, and multiple factors that relate to the same general effect on signal detection), it was apparent that the list of influencing factors obtained from literature needed further refinement. The process of refinement, including the resulting overview of influencing factors, is discussed in the next subsection.

4.2.3 Refinement of the list of identified factors
Refinement of the list of identified factors was performed in two main stages, namely:

1. Performance of an initial factor grouping
2. Assessment of the initial factor grouping and expression of the resulting influencing factors in general terms
The rationale of each stage, together with a description of the adopted approach and the related results, is discussed next.

**Performance of an initial factor grouping**

Besides arranging identified factors according to the most appropriate factor category, (Human factors, Internal environment, External environment, and Exogenous), influencing factors indicated in appendix 4.1 received no further processing. As a result, a large number of duplicate factors can be found in the overview in appendix 4.1, as well as numerous factors that relate to the same general influencing effect, but are described in various ways (positively versus negatively, general versus specific instances). For that reason, it was decided to perform an initial grouping of factors within each category, to both remove redundancy and to initially classify factors according to their general influencing effect, in order to get a better understanding of which particular factors affect organizational early warning signal detection.

Factor grouping was executed in the following manner. For each factor category, the factor enlisted first in the overview in appendix 4.1 automatically constituted the first entry in the first factor group. Next, by assessing factor similarity based on the assessor’s knowledge and factor understanding, the second factor enlisted was either placed in the first factor group, or a second factor group was introduced. This procedure was repeated until all factors within a factor category (Human factors, Internal environment, External environment, and Exogenous) were placed in a factor group. The approach adopted to initial factor grouping is rather similar to open card sorting, where participants are asked to sort a series of cards labeled with a piece of content (in this case, factors identified in literature) into appropriate, non pre-established groups (Spencer & Warfel, 2004).

This process resulted in the identification of 23 initial factor groups, which are presented in appendix 4.2. For the most part, this proved to be a fairly straightforward exercise. Given the strong agreement in literature on the ways in which organizational early warning signal detection is affected, there was often little question of which factors described similar influencing effects (e.g. due to the use of similar keywords), and grouping was to a large extent limited to logically rearranging the factors presented in appendix 4.1. However, for some factors, factor grouping was less obvious and a certain level of interpretation by the researcher of the factor’s content was required. In those cases, a closer consideration of the context in which the particular factor was mentioned as an influencing effect contributed to the eventual grouping of all 110 identified factors.

**Assessment of the initial factor grouping and expression of the resulting influencing factors in general terms**

As is apparent from the description above, only a single researcher was involved in the initial factor grouping process. Mainly for practical reasons, it was decided not to involve additional researchers in this process. Most importantly, given the large number of factors identified in literature, it was preferred to first obtain a more manageable set of influencing factors, which could then act as input for further research ideally involving other researchers. By doing so, the anticipated review effort required by these researchers could be reduced. Since the factor grouping would mainly consist of removing duplicate factors and logically arranging factors, the decision to have the researcher that identified the 110 influencing factors in literature solely perform this grouping was considered justified.
Although being largely a straightforward exercise as was mentioned above, a certain level of interpretation by the researcher was nevertheless needed. Given the need for interpretation, bias is inadvertently introduced in the factor grouping. For example, information (on influencing factors) might be lost when two similar (but not identical) influencing factors are placed in a single factor group. This type of bias is inherent to any type of classification performed. However, if additional researchers had been involved in the classification process instead of having a single researcher perform an initial classification, it would have been possible to significantly reduce the likelihood of information being lost in the classification process. Consequently, the fact that the initial factor grouping was performed by a single researcher is considered a weakness of the literature study.

To address the issue of potential bias introduced in literature study findings due to this weakness, it was decided to include a second researcher to jointly assess the initial factor grouping. Besides reducing bias, assessment of the initial grouping served other purposes as well. Firstly, the initial factor grouping did not include a comparison of the factor groups obtained. As a result, it was uncertain whether or not the identified groups could further be combined into new groups due to some particular influencing effect acting as a common denominator, or whether further splitting of certain groups was necessary. Since such insight is pivotal to establishing an unequivocal list of influencing factors, assessment of the initial factor grouping included a comparison of factor groups for each factor category.

Secondly, as is obvious from appendix 4.2, initial factor groups were not labeled, but merely numbered. Although this was not a prerequisite for the initial factor grouping, factor groups that indicate a particular influencing effect on organizational early warning signal detection need to be defined, since each factor group represents a particular influencing factor to be incorporated in the resulting overview of factors identified in literature. Moreover, factor groups need to be expressed in general terms, because the aim of this research is to determine influencing factors that affect signal detection in general, and not to determine factors that either obstruct (i.e. negatively affect) signal detection, or stimulate (i.e. positively affect) signal detection. Hence, influencing factors, i.e. the factor groups resulting from the assessment of the initial factor grouping, were expressed in general, non-directional terms.

Assessment of the initial factor grouping, which included the comparison and definition of factor groups, was performed by two researchers. The second researcher was acquainted with the research on organizational early warning signal detection as discussed in the previous chapters, and the main factor categories (Human factors, Internal environment, External environment, and Exogenous) identified in chapter 3. In that capacity, a sufficient level of background knowledge for the second researcher to effectively contribute to the discussion on factor grouping was assumed. For practical reasons, and the fact that the initial factor grouping to a large extent had been a fairly straightforward exercise, no other people were involved in the assessment.

The assessment consisted of multiple rounds of deliberation between the researchers, characterized by in-depth discussions on the initial overview of factor groups and corresponding influencing factors. Deliberation took place in various group sessions, which were spread over a time period of several weeks to allow for sufficient time for reflection in between sessions. As a starting point of the deliberation process, the content of each factor group was discussed, and it was determined whether identified factors indeed belonged to their assigned group.
In a later phase of deliberation, the discussion shifted to the overall structure of factor groups and whether the overview of factor groups pointed to the potential exclusion of any relevant factor groups and consequently, the need for splitting earlier established groups. Lastly, deliberation focused on formalizing the tentative definitions of factor groups adopted during the assessment, and on removing any potential reference to the particular obstructing or stimulating effect of factor groups on signal detection from the chosen definitions. The process of deliberation continued until consensus was reached among the researchers, resulting in an overview of influencing factors expressed in general terms, to which both researchers agreed that it was an adequate representation of the influencing effects on organizational early warning signal detection found in literature.

Table 4.1 presents the results of the assessment process. As is shown in this table, the assessment resulted in the identification of 18 factor groups, where each factor group represents a particular influencing factor of organizational early warning signal detection. These influencing factors are expressed in general terms, i.e. without reference to the factor’s positive or negative effect on signal detection. References related to these influencing factors can be found in appendix 4.3. Also, the effect of an organization’s external environment on early warning signal detection was confirmed (see group #23 in appendix 4.2). Since factors originating from an organization’s external environment are considered exogenous in this thesis, no further attempt to group such factors was made.

<table>
<thead>
<tr>
<th>Factor category</th>
<th>Factors identified in literature</th>
<th>Related factor group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human factors</td>
<td>Cognitive Bias</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Risk Attitude</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Level of Stress</td>
<td>2</td>
</tr>
<tr>
<td>Internal environment</td>
<td>System Coverage</td>
<td>4</td>
</tr>
<tr>
<td>Technology</td>
<td>System Span</td>
<td>5</td>
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<tr>
<td></td>
<td>System User Interface</td>
<td>6</td>
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<tr>
<td>Structure</td>
<td>Training</td>
<td>7</td>
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<tr>
<td></td>
<td>Communication</td>
<td>8</td>
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<td></td>
<td>Responsibility &amp; Authority</td>
<td>9</td>
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<td></td>
<td>Procedures</td>
<td>10</td>
</tr>
<tr>
<td>Culture</td>
<td>Organizational Risk Attitude</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Organizational Learning</td>
<td>11</td>
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<tr>
<td></td>
<td>Internal Stakeholder Involvement</td>
<td>12, 13</td>
</tr>
<tr>
<td></td>
<td>Management Style</td>
<td>14, 15, 16, 17</td>
</tr>
<tr>
<td>Strategy</td>
<td>Management Commitment</td>
<td>19</td>
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<tr>
<td></td>
<td>Vision</td>
<td>20</td>
</tr>
<tr>
<td>External environment</td>
<td>External Stakeholder Involvement</td>
<td>21</td>
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<tr>
<td></td>
<td>External Communication Channels</td>
<td>22</td>
</tr>
<tr>
<td>Exogenous</td>
<td></td>
<td>(23)</td>
</tr>
</tbody>
</table>
As is apparent from table 4.1, assessment of the initial factor grouping for the most part confirmed the initially identified factor groups. However, one initial factor group was removed (group #3, see appendix 4.2), another was split into two separate influencing factors (Risk Attitude and Level of Stress), and within the Culture subcategory, several initial factor groups were combined into a single influencing factor (Internal Stakeholder Involvement and Management Style). These actions require some further explanation:

- **Removal of factor group #3.** In factor group #3, the influencing effect of a person’s expertise and/or experience on organizational early warning signal detection is captured. This factor group was interpreted by both researchers as pointing to expertise in signal detection, or in other words, to how capable a person is in detecting early warning signals. In that viewpoint, factor group #3 was regarded as being marginally informative with regard to the particular way in which a person’s capability in signal detection is influenced. Hence, it was decided to remove factor group #3 as an influencing factor.

- **Risk Attitude & Level of Stress.** Factor group #2 in appendix 4.2 pointed to several aspects of the personal psychology of human signal receivers, most of which were mentioned in a paper by Sheaffer et al. (1998). In this paper, factors that obstruct signal detection within organizations were directly listed as such, in most cases without discussing them in further detail. Though this generally did not lead to any difficulty in interpreting the factors’ meaning, both researchers were less certain of the particular effect of some of the factors pointing to the personal psychology of human signal receivers, such as managerial arrogance. Consequently, it was decided to single out the factors within factor group #2 for which the particular effect on signal detection was considered apparent. As a result, Risk Attitude and Level of Stress were indicated as separate influencing factors in the Human factors category.

- **Internal Stakeholder Involvement.** Both factor group #12 and #13 point to the way in which an organization’s culture can influence the degree of exchange of information within the organization with regard to early warning signals, encompassing the willingness to communicate early warning signals to others (intradepartmental and interdepartmental) and the degree to which an organization allows (the sharing of) divergent viewpoints. Hence, it was decided to combine these cultural aspects into a single influencing factor, i.e. Internal Stakeholder Involvement.

- **Management Style.** The influencing factor Management Style, also labeled as Leadership, refers to an organization’s attitude towards the detection and management of early warning signals. It includes various cultural aspects, which are more diverse in nature than the aspects captured under Internal Stakeholder Involvement. Management Style includes both managerial and organizational biases towards signal detection (group #14 and #16), an organization’s overall attitude towards bad news (group #15), and the way in which an organization empowers its people with regard to the detection and management of early warning signals (group #17). Though both researchers felt comfortable in capturing these more diverse cultural aspects under a single factor, it was also realized that this particular factor would rank high on the list of potential candidates in need of further consideration.
Concluding, the literature study initially identified 110 potential influencing factors, which after an initial factor grouping and a further refinement resulted in an overview of 18 influencing factors. Furthermore, the literature study confirmed the effect of an organization’s external environment (considered exogenous in this thesis) on organizational early warning signal detection.

4.2.4 Validity and reliability of the literature study

In order to assess the quality of the literature study, which is performed as one of the concurrent paths in the model development step of the proposed approach to factor identification, validity and reliability of the literature study are addressed in this section. Whereas validity refers to the question whether or not one’s measurement of a phenomenon is ‘true’, reliability refers to the degree to which a measurement can be replicated (Hunter & Brewer, 2003).

In literature, various types of validity are distinguished. Teddlie & Tashakkori (2003) present a non-exhaustive list of 35 types of validity in qualitative and quantitative research, compiled from various sources. Not all of these validity types will be relevant to discuss here though. In particular, validity of the theoretical constructs employed (i.e. construct validity) and generalizability of the literature study results (i.e. external validity) need to be discussed.

Construct validity
Since influencing factors for the most part had to be extracted from textual descriptions, the literature study depended on the qualitative analysis of the publications’ content. As such, two types of construct validity in content analysis (as identified by Krippendorff (1980) and put forward by Jacobs & Van Moll (2007) in the discussion on the validity of their literature study) were assessed: semantic validity and sampling validity. Semantic validity is defined as “the degree to which the analytical categories of texts correspond to the meaning these texts have for particular readers or the roles they play in a chosen context” (Krippendorff, 2004). Sampling validity is concerned with any sampling that occurred when selecting relevant publications and the particular textual descriptions to be reviewed.

Krippendorff (2004) states that semantic validity is reduced by two kinds of errors: errors of omission (the failure to retrieve relevant texts), and errors of commission (the retrieval of irrelevant texts). Although it can not be claimed for certain that these errors were not made in the literature study, it is believed that the literature review process acted as a sufficient safeguard, resulting in an acceptable level of error. Recall that the review process was characterized by an in-depth initial and extended review of relevant publications on organizational early warning signal detection, the results of which led to an initial factor grouping that was assessed together with a second researcher. The rationale for performing an initial factor grouping was to remove redundancy in the list of 110 factors extracted from literature, and to initially classify factors that relate to the same general influencing effect, but which were described in various ways (positively versus negatively, general versus specific instances). This redundancy points to confirmation of the same influencing effect on signal detection by various sources, adding to the plausibility of the claim that these factors and the texts from which they were derived can be considered relevant. With regard to the validity of the initial factor grouping performed, it is important to note that only a single researcher was involved in the process, as was explained earlier. This acts as a potential source of bias in the initial grouping results, which is considered a weakness of the literature study.
To try to overcome this bias, as well as for other reasons, an assessment of the initial factor grouping was performed. This assessment comprised of the joint assessment of the various factor groups and corresponding influencing factors, which included a further review of the particular textual descriptions from which factors were extracted that caused some discussion between the two researchers. In this way, it is expected that any missing relevant factors would have surfaced during the assessment. Furthermore, it is reasonable to assume that the resulting overview of 18 influencing factors does not contain any irrelevant factors.

Another aspect of semantic validity is whether the meaning of the identified factors is adequately conveyed by the way in which these factors are expressed (i.e. in concise, general terms). This particular concern was addressed by involving two researchers in the process of expressing factors in general terms, both of which had to agree with the chosen definition. In practice, it took several rounds of deliberation until agreement on all factor definitions was reached, indicating that this is not a simple exercise. In that respect, it is believed that involving additional researchers in this discussion could have led to an even more thorough assessment of factor definitions, by allowing additional, more diverse viewpoints to be taken into account, thus further decreasing the likelihood of factor meanings being unclear. For practical reasons, other researchers were not involved though. Instead, in order to tackle any potential problems with unclear factor meanings later on, each influencing factor was also provided with a short description. Descriptions of the influencing factors that result from the combined interpretation of the literature study and focus group findings (the latter to be discussed in the next section) are presented in section 4.4.

With regard to sampling validity, it should be remarked that the relevant publications reviewed for this literature study were selected from a substantial group of potentially relevant publications, identified by application of a search process that covered a large body of literature on crisis management and resilience engineering, from various sources and by combining various search terms. The study resulted in the initial identification of 110 factors from 20 relevant publications, which can be considered a reasonable result compared to other literature studies designed to identify influencing factors (as was discussed in section 4.2.2). Although this suggests reasonable sampling validity, a critical remark is in order.

Despite the fact that a large body of literature was covered in the literature study, it is impossible to prove that this particular sample is an adequate representation of the total body of literature on organizational early warning signal detection. This is confirmed by the fact that some of the influencing factors identified in the literature study were also mentioned in fields of study other than crisis management and resilience engineering. For example, in the field of strategic planning and future studies, the influence of internal stakeholder involvement, external stakeholder involvement, and expertise on signal detection is acknowledged (Ansoff, 1984; Saul, 2006). Hence, exploration of other fields of study than crisis management and resilience engineering might contribute to the identification of influencing factors from literature. However, this contribution is expected to be marginal, given the degree to which other fields of study cover early warning signal detection (as the literature review described in section 2.3 demonstrated).

**External validity**

As mentioned earlier, external validity refers to the generalizability of research results. Merriam (1998) suggests providing a “rich, thick description” of the research performed as a strategy to ensure external validity. More specifically, this entails providing detailed accounts of the rationale, employed approach, and obtained research results, in order to allow fellow
researchers and other interested parties to assess whether findings are transferable to their particular situation. It is believed that the level of description of the literature study performed, including the rationale, approach and results of the literature review, initial factor grouping and assessment of the initial factor grouping, should provide others with sufficient means to assess the degree of transferability.

**Reliability**

Reliability concerns the degree of repeatability of the literature study. Reliability is separately discussed for the literature review and the refinement of the list of influencing factors extracted from literature.

A review of literature is considered reliable, when repeating the adopted review approach as described yields consistent results. To ensure reliability, several strategies may be adopted (Merriam, 1998). Firstly, the context and the focus of the research, as well as the researcher’s role, need to be explained in detail (known as “researcher’s position”). The rationale for performing a literature study, in particular in the fields of crisis management and resilience engineering, was explained at the beginning of the section. Also, the way in which the researcher performed both the initial and extended literature review was discussed in detail. Secondly, triangulation is another means of ensuring reliability. The different types of triangulation were already discussed in section 2.6. In the literature review, triangulation was only obtained through the review of multiple fields of study. Since the literature review otherwise relied on a single data source (i.e. literature), a single researcher and application of the same research method, no other forms of triangulation were applied. Thirdly, providing detailed descriptions of the adopted approach to data collection and analysis, thereby allowing others to perform a similar study, is another strategy to ensure reliability (known as “audit trail” (Merriam, 1998)). Detailed accounts were provided for the initial review, the search process by which potentially relevant publications were identified in the extended review, and the filtering process that resulted in the selection of relevant publications, as well as the way in which these relevant publications were analyzed in order to identify influencing factors. Overall, despite the limited degree of triangulation, it is thus assumed that the measures taken to ensure reliability of the literature review should allow others to yield similar results when repeating the literature review.

With regard to the refinement of the list of factors, the same strategies to ensure reliability as mentioned above were employed. The rationale for the initial factor grouping and the assessment of this grouping together with a second researcher was explained, as well as the researchers’ roles in this process. By involving a second researcher, researcher triangulation was obtained. Lastly, detailed descriptions were provided for data collection and analysis as executed within each of the steps in refinement of the initial overview of influencing factors from literature (see section 4.2.3). Despite the fact that these strategies certainly add to the reliability of the refinement of the list of factors initially identified in literature, reliability is reduced by the approach adopted to assess the initial factor grouping. Instead of using some well-established research method designed for grouping data, such as clustering methods, assessment rather resulted from a deliberation process between the two researchers consisting of multiple group sessions spanning a period of several weeks. Hence, it cannot be claimed that repeating the process of refinement would necessarily yield similar results.
Unfortunately, in retrospect, an opportunity was missed to give more insight into the reliability of the assessment of the initial factor grouping, by means of (quantitatively) expressing reliability in a reliability measure. After each deliberation round, merely the factor groups and the (tentative) definitions adopted for each group were documented, and information on the number of agreements and disagreements between the two researchers was not captured. Consequently, it was not possible to construct a reliability measure such as proposed by Miles & Huberman (1994), thereby rendering a more quantitative evaluation of the assessment’s reliability impracticable.

4.3 Model development: focus group

As was explained in section 4.1.1, development of an initial list of influencing factors of organizational early warning signal detection in this thesis depends on the concurrent application of multiple (qualitative) research methods. Whereas literature acts as one valuable source of evidence for factor identification, it was argued that the input of risk management experts assembled in expertise networks transcending industries, such as professional risk management associations, is another valuable source. Hence, it was decided to consult people in such expertise networks, who are actively involved in managing risk as part of their position within an organization (either on an operational, tactical, or strategic level), for the purpose of model development. It should be stressed that expert consultation in that sense is not based on the evaluation of a pre-established list of influencing factors (such as the one obtained from literature). Rather, expert consultation is about providing a platform which allows people to express their insights into organizational early warning signal detection, thus encouraging people to indicate those factors which they consider to affect signal detection, based on their expertise and experience in risk management.

In literature, various means to elicit knowledge from experts are described (see e.g. Hoffman et al. (1995) for a discussion on available knowledge elicitation techniques). A distinction often made is between direct knowledge elicitation (observing expert behavior or directly asking experts’ opinion, for example) and indirect knowledge elicitation (analyzing an expert’s tasks, for example). For the purpose of getting experts’ insights into organizational early warning signal detection, a direct means of knowledge elicitation is considered most appropriate, where people are asked to express their opinion on the topic of interest.

There are several ways to provide experts with a platform to express their opinion on organizational early warning signal detection, such as interviews, surveys or group sessions. Given the fact that experts assembled in expertise networks were to be consulted, coming from different backgrounds and having their own viewpoints on organizational early warning signal detection, expert collaboration and interaction at some point during the consultation process was considered essential. For that reason, the use of a group session as a platform for expert consultation was deemed most appropriate.

Specifically, a focus group was used to gather the opinion of risk management experts. Based on the features of a focus group as presented by Krueger & Casey (2009), a focus group can be defined as a group of people with some commonly shared characteristics that provide qualitative data in a focused discussion to help understand the topic of interest. In the scope of this thesis, a focus group is employed to get together a group of people from a variety of industries who are actively involved in risk management, in order to provide insight into influencing factors of organizational early warning signal detection across industries and organizations in a structured manner.
A key element of any focus group which sets it apart from other groups is the explicit use of group interaction as a means to provide insights on a particular topic of interest that otherwise would be difficult to gather (Morgan, 1997). Whereas this constitutes one particular reason for employing a focus group, another reason is the usefulness of a focus group in exploratory research. According to Wilkinson (1998), one of the most common research designs involves the use of focus groups in the exploratory phase of research. Fern (2001) distinguishes between three types of focus group tasks, one of which is exploratory in nature, such as contributing to the development of (theoretical) models. Since the latter constitutes the main aim of consulting experts in this thesis, employment of a focus group for expert consultation can be regarded suitable.

The design of the focus group is discussed in section 4.3.1, with emphasis on the selection of group participants, the effectuation of group interaction, and the role of the focus group moderator. Next, section 4.3.2 describes the focus group findings, and presents the overview of influencing factors resulting from the combined interpretation of the influencing factors identified in the literature study and focus group. Lastly, partly by discussing the outcome of an evaluation of the focus group performed by the participants, validity and reliability of the focus group is addressed in section 4.3.3.

### 4.3.1 Focus group design

In this section, the focus group as it was designed for the purpose of model development is described in detail. In particular, the following focus group elements are discussed:

- Focus group participant selection
- Structure of the focus group, in particular the effectuation of group interaction
- Role of the focus group moderator

#### Focus group participant selection

A critical success factor of any focus group is participant selection. As Krueger & Casey (2009) indicate, a focus group should include participants with similar characteristics, while at the same time it should be ensured that the particular selection will include sufficient variation to allow for contrasting opinions to be expressed. Taking into account the fact that the focus group was specifically employed as a means to consult risk management experts assembled in expertise networks across industries, this criterion could be met by recruiting participants from one particular expertise network, namely a Dutch professional association for risk analysis and reliability. On the one hand, this ensured that all participants involved were able to provide insight into influencing factors of organizational early warning signal detection, based on their expertise and experience with managing risk (either on a strategic, tactical, or operational level).

On the other hand, it also ensured that sufficient variation among the participants who are actively involved in managing risk was achieved, since members of the association are not only active in managing risk at different organizational levels, but are active in a variety of industries (including transport, aerospace, energy, infrastructure and civil engineering) as well.

Moreover, the particular expertise network consulted both included people involved in risk management as part of their position in industry, or as part of their position in science. The latter refers to people who have performed research into risk management, in particular in
cooperation with industry, and as such are expected to provide a valuable contribution to the discussion on organizational early warning signal detection. In that way, by selecting members of this professional association as participants for the focus group, it was possible to further increase the level of variation among focus group participants.

Given the reliance on risk management experts for model development by means of a focus group, it is important to stress that a certain level of (expert) bias in the focus group results can hence not be avoided. Nevertheless, various strategies were employed to limit the potential effect of this source of bias on focus group findings.

One such strategy was to recruit experts from an expertise network transcending industries. As was explained in section 4.1.1, risk management expertise networks offer a platform for consolidating knowledge on managing risk, amongst other things due to the exchange of insights and lessons learnt by risk management experts active in various industries. As such, members of the professional association for risk analysis and reliability are assumed to be less biased towards (influencing factors of) organizational early warning signal detection, in the sense that they are expected not to limit their identification of influencing factors to those factors directly apparent from the particular organizational context in which they are active. Instead, they are expected to be able to identify factors of influence in a broader (industrial) context.

In the focus group meeting introduction, an additional measure was taken to limit the effect of expert bias. This is discussed in the next section, in which the structure of the focus group is described.

**Structure of the focus group**

Figure 4.3 presents the focus group structure, designed to allow a focused discussion on influencing factors of organizational early warning signal detection, with the intention to utilize participants’ input to the fullest. As is apparent from figure 4.3, the focus group consisted of several parts, including activities prior to and after the focus group meeting. These activities encompassed the following:

**Part 0: Focus group preparation**

Well before the focus group, participants received a pre-focus group email, explaining the nature of the focus group, as well as providing details on meeting logistics (time, location, etc.). In this email, it was briefly explained that the focus group meeting would be targeted to one specific aspect of risk management, namely the detection of early warning signals as regarded in this thesis. Instead of providing an introduction into the theory behind organizational early warning signal detection (i.e. the conceptual framework presented in chapter 3), this was simply illustrated by means of some practical examples of (non-) detection of signals by organizations.

Also, in the e-mail participants were asked to think of examples based on their own experience, in which early warning signals had played a prominent role, either in the successful or unsuccessful proactive management of risk. Participants were requested to do so, since these examples would act as one of the inputs to factor identification in the focus group (in particular, in part 2 of the survey: Identification of influencing factors by means of case study analysis). Further information on this is provided in the discussion of part 2 of the focus group.
Besides preparing participants for the focus group by means of a pre-focus group email, preparation also included selection of appropriate case studies (see part 2: Identification of influencing factors by means of case study analysis), preparing focus group materials (e.g. case descriptions and answering forms to capture participants’ comments) and setting up focus group logistics, such as determining the amount of time to be spent on each part of the focus group meeting.

**Part 1: Introduction**

The focus group meeting was split into several parts, each with its own function, and the language of communication was Dutch. In the first part of the focus group, an introduction into organizational early warning signal detection was given. For that purpose, a concise overview of the theory behind organizational early warning signal detection as discussed in chapters 2 and 3 was presented. Also, the Nokia-Ericsson case study as described in chapter 3 was briefly discussed, to demonstrate the different ways in which organizations handle early warning signals, and how (non-) detection is affected by underlying factors from various factor categories (Human factors, Internal environment, External environment, Exogenous).

A short theoretical introduction was provided for several reasons. Firstly, it was used to set the stage for the remainder of the focus group. Since early warning signal detection can take on various forms within an organization (as was explained in chapter 2), an introduction was given so that all participants were aware of the particular means of detection considered in the focus group, i.e. detection by means of the people within an organization.
Secondly, the main factor categories as indicated in the conceptual framework were briefly discussed at the beginning of the meeting, to ensure participants would consider a broad array of potential influencing factors in the identification process (i.e. part 2 of the focus group), instead of only considering e.g. factors on an individual level. It is important to note that by focusing on these main factor categories instead of particular influencing factors such as identified earlier in the literature study, the potential anchoring effect on the overall focus group findings of having a theoretical introduction prior to factor identification is reduced.

Thirdly, by asking participants to identify influencing factors in the context of the conceptual framework (i.e. by taking into account the main factor categories discussed in section 3.2.4), focus group participants had to consider early warning signal detection in a non familiar context. In that way, they were stimulated to respond based on their experience rather than their usual frame of reference, which is expected to further limit the effect of expert bias on the identification process. The identification process employed in the focus group is discussed next.

*Part 2: Identification of influencing factors by means of case study analysis*

After the plenary introduction, the second part of the focus group concentrated on the identification of influencing factors by the focus group participants. In order to facilitate the identification process, participants were asked to analyze a selection of real-world (industrial) accidents, in particular on how detection of early warning signals specific to these cases was (negatively) affected. The choice for case study analysis as a vehicle to stimulate factor identification was motivated by the anticipated difficulty participants would have in trying to identify potential influencing factors, when the theoretical framework (more specifically, the main factor categories as discussed during the introduction of the focus group) would act as their only point of reference. Furthermore, case study analysis allows participants to share their often divergent viewpoints on what contributed to (non-) signal detection in each case, thereby stimulating discussion between participants on potential influencing factors. The latter was further facilitated by splitting up participants in smaller groups to analyze and discuss each case study.

Given the fact that case study analysis was used as a means to stimulate factor identification, participants were not required to give a complete account of the particular circumstances that led to the real-world accident. Rather, participants were asked to filter the available case material for early warning signals and to determine how detection of these signals was negatively affected by factors in the main factor categories Human factors, Internal environment, and External environment. Though factors belonging to the Exogenous category could have played a role in any of these cases (as was already explained to the participants during the introduction), participants were not explicitly asked to identify factors in this category, as they are considered outside the scope of this thesis.

Case study analysis was not performed individually, but collectively. For that purpose, participants were split up in smaller sized groups (maximum of five people), where one person in each group was assigned the role of moderator. Before the start of the focus group, the focus group moderator took apart participants who had been contacted earlier and had agreed to take on the role of group moderator, to explain what was expected. Most importantly, the function of the group moderator was to ensure that the discussion of the case studies remained focused on early warning signal detection and its influencing factors, instead of performing a causal analysis of the accidents.
Also, group moderators were responsible for tracking potential influencing factors mentioned by group members, by means of the provided answering forms. Lastly, group moderators were asked to keep track of time, to avoid a disproportionate amount of time being spent on any single case, thus leaving little time for the analysis of other cases.

Selected case studies

Given the time restrictions of the focus group due to participant availability, in combination with the amount of analysis (and time) required for factor identification, it was expected that each group at best would be able to analyze and discuss two case studies. The first case study was predetermined, in the sense that participants were asked to analyze a major industrial accident for which case material was provided. The second case study concerned the analysis of examples provided by the participants based on their own experience, in which early warning signals had played a role in either successful or unsuccessful proactive risk management. Besides these two case studies, a backup case study was prepared, in case a group had sufficient time left to analyze another case study. Similar to the first case study, the backup case study was predetermined. Selection of each of the case studies is discussed next.

In the selection of the first case study and the backup case study, several criteria were used, namely 1) access to investigation reports and other material describing in detail both the accident and the events leading to the accident, 2) indication of the existence of early warning signal(s) prior to the accident, based on the available case material, and 3) the general appeal of the case study for the intended audience. Based on these criteria, the following case studies were selected. The first case study concerned a propane explosion at a convenience store and gas station in West Virginia, leading to the death of four people and the serious injury of five people (U.S. Chemical Safety and Hazard Investigation Board, 2008). The backup case study concerned the crash of a Turkish Airlines airplane at the Dutch airport Schiphol late February 2009, causing the death of nine people (Dutch Safety Board, 2010).

For both these cases, the case material given to each group consisted of a short description of the accident and relevant background information, as well as a full technical investigation report. These reports presented information on the sequence of events leading up to the respective accidents, and hence could assist participants in putting together the details of the accident (including early warning signals present prior to the accident). Additionally, a video that provided an official reconstruction of the accident described in the first case study was shown to the participants. An example of the case material for the first case study can be found in appendix 4.4.

With regard to the second case study, participants were asked prior to the focus group to come up with one or two examples from their own experience, in which early warning signals had played a role in either successful or unsuccessful proactive risk management (as was mentioned in part 0: Focus group preparation). In line with the analysis of the other case studies, after a brief introduction of the example by the respective participant, each group discussed the particular example(s) put forward to determine how (non-) detection was affected by factors in the main factor categories Human factors, Internal environment, and External environment.
The rationale for including examples proposed by the participants in the case study analysis, was to avoid any restriction or bias on the identification of influencing factors due to the specific circumstances (and hence, specific influencing factors) that affected non-detection of early warning signals in the two case studies mentioned above. Nevertheless, it might be argued that this approach actually introduces (expert) bias in the findings of the focus group, since expert specific viewpoints are more or less directly taken into consideration in the identification process. The potential biasing effect hereof on focus group results, although acknowledged, is expected to be limited however.

For one thing, participants were not asked to directly give examples of influencing factors they considered to be relevant, but to provide their fellow focus group participants with practical case study material, which would act as a means to stimulate further discussion on influencing factors of organizational early warning signal detection. More importantly, participants come from various industries and from various backgrounds, and are active on various organizational levels (operational, tactical, strategic). As such, they are considered to have varying viewpoints on risk management. These varying viewpoints are expected to be reflected in the examples provided by participants and in the factors identified based on the practical case material provided, which will consequently be reflected in the overall focus group results as well.

Part 3: Deliberation
In each group, results of the case study analysis, i.e. an overview of influencing factors in the main factor categories Human factors, Internal environment, and External environment, were captured by means of poster-size answering forms for each case study. These forms acted as input to the next part of the focus group, namely a plenary discussion in which each group presented their results to all other participants in the focus group. By discussing influencing factors identified in each factor category (instead of discussing each case study separately), participants were invited to comment on the other groups’ results.

Also, based on their own insights either from case study analysis or from experience, participants were encouraged to propose any additional influencing factor(s) to the ones already identified. This process of deliberation continued until all groups had presented their results and overall group consensus was reached, i.e. when all focus group participants agreed on the resulting overview of influencing factors of organizational early warning signal detection.

Part 4: Evaluation of the focus group
To help assess the effectiveness of the focus group, participants were invited to give their opinion on the focus group by filling in an evaluation form at the end of the session, after the group discussion. The evaluation form can be found in appendix 4.5. Besides indicating their area of expertise, participants were asked to evaluate the overall effectiveness of the focus group in identifying influencing factors, and in increasing participant awareness and understanding of organizational early warning signal detection. Also, participants were asked to give their opinion on each part of the focus group (introduction, case studies, deliberation). Evaluation results are presented in section 4.3.3, in which validity and reliability of the focus group are discussed.
Part 5: Post-processing focus group results & feedback to participants
After the focus group meeting was finished, results of the focus group were processed, which is discussed in the next subsection. In an e-mail sent to all participants a couple of weeks later (amongst other things to thank people for their participation), feedback on the results of the focus group was given by including the resulting overview of influencing factors. Participants were invited to share any comments they may have based on this overview with the researcher, which, depending on the comment(s), could lead to a reconsideration and (potential) modification of the overview of influencing factors.

Role of the moderator
Focus groups are normally chaired by a focus group moderator, whose main responsibilities include: making sure all participants have the same understanding of the topic of interest, keeping the discussion focused on the topic of interest, making sure all participants contribute to the discussion, and time management. The researcher took on the role of moderator, given his knowledge of the topic of interest, and previous experience with chairing similar meetings, though for different purposes. Consequently, the researcher gave the introductory presentation on organizational early warning signal detection, explained the outline of the focus group, acted as one of the group moderators during the case study analysis, and chaired the deliberation session at the end of the focus group. Since the level of involvement of the researcher in the focus group made it difficult to manage group logistics effectively, a second person assisted with this task. This person made sure that results from the case study analysis and deliberation session were documented, that time available for each part was properly managed, and that the moderator did not inadvertently (actively) participate in the focused discussion.

4.3.2 Focus group results
In total, 18 people attended the focus group, which lasted more than three hours. Participants were all members of a professional association for risk analysis and reliability, coming from various backgrounds (transport, infrastructure, civil engineering and aerospace), and all with wide experience in the field of risk management and reliability (as was explained in section 4.3.1: Focus group participant selection).

Given the size of the focus group, participants were split into four groups for the second part of the focus group, i.e. case study analysis. For each of these groups, figure 4.4 shows the number of influencing factors identified within each factor category (Human factors, Internal environment, External environment) during the case study analysis. Also, the number of influencing factors identified during the deliberation session is indicated.

As is apparent from figure 4.4, the total number of influencing factors identified during case study analysis is higher than the number of influencing factors obtained during the deliberation session, for each factor category. This result is in line with what was expected, since it was assumed that various groups would indicate similar influencing factors based on the case study analysis, which was confirmed during the deliberation session. The particular ratio between the number of influencing factors identified in each factor category is another observation worth mentioning. As figure 4.4 indicates, the majority of factors were identified in the category Internal environment, whereas the least number of factors were identified in the category External environment. This result is in accordance with the ratio between the number of influencing factors in each factor category, as identified in the literature study.
A closer examination of the influencing factors identified during the focus group led to the conclusion that a further analysis of the information obtained from the case study analysis and deliberation session was in order. Firstly, not all factors identified during the case study analysis (as indicated on the answering forms of each group) were mentioned during the deliberation session. Although this could partly be attributed to factor similarity, some factors were distinctly different from the factors mentioned in the group discussion. Hence, it had to be determined whether or not these factors needed to be included in the overview of influencing factors from the focus group.

A potential explanation for the fact that these factors were not mentioned during deliberation lies in the dynamics of the group session in which, although purposely pursued, it proved difficult to include all 18 participants directly in the discussion. Secondly, identified factors, in particular those identified during the case study analysis, in some cases raised questions on whether they indeed could be marked as influencing factors of organizational early warning signal detection, or whether they rather represented factors contributing to the accident described in the case study (i.e. causal factors of the accident). Thirdly, it appeared that some of the identified factors described similar effects on signal detection, and thus potentially could be combined into a single influencing factor. Fourthly, it was found that some factors could be assigned to a factor category other than their current category.

For these reasons, results of the case study analysis and deliberation session were further processed after the focus group was conducted. Such post-processing of the information obtained from the focus group is common in focus group research (Krueger & Casey, 2009).
Post-processing of identified influencing factors was performed by three researchers, which were all knowledgeable on organizational early warning signal detection and were acquainted with the results of the literature study. In two separate meetings shortly after the focus group, these researchers collectively reviewed each influencing factor documented during the focus group meeting per factor category. Points of discussion included whether or not the identified factor indeed could be marked as an influencing factor of organizational early warning signal detection, whether or not the identified factor was assigned to the right factor category, and whether or not certain identified factors could be combined into a single influencing factor. Furthermore, identified factors were compared to the influencing factors obtained from the literature study, in order to assess to what extent factors identified in the focus group corresponded to influencing factors identified in literature.

Since the language of communication in the focus group was Dutch (as mentioned in section 4.3.1, part 1: Introduction), factors identified were also given and documented in Dutch. Hence, besides solely focusing on the content or meaning of the factors suggested in the focus group, the researchers also had to interpret the extent to which these factors in Dutch corresponded to the factors earlier identified in English. This additional need for interpretation is a potential source of bias. Nevertheless, the effect of this bias on (the post-processing of) factor group results is expected to be limited for various reasons. Firstly, given the degree of overlap between English and Dutch (technical) risk management jargon, largely similarly phrased factors to the ones identified in the literature study were named in the focus group meeting. Hence, the overall need for interpretation was limited. Secondly, besides capturing factor naming, documentation of the focus group findings which acted as input for post-processing also included additional information on the factors’ meaning, facilitating the interpretation process. This documentation was prepared soon after the end of the focus group meeting by one of the researchers that had been present, and was verified by the other researchers who had also attended the meeting. Thirdly, post-processing was performed by three researchers, all fluent in Dutch (native speakers) and English (non-native speakers), and acquainted with the results of the literature study. As such, they were considered capable of performing the interpretation.

Post-processing of the focus group results continued until all researchers agreed with the resulting overview of influencing factors, which was the case at the end of the second meeting. Based on the post-processing of the influencing factors identified in the focus group, it was concluded that the focus group yielded comparable results to the literature study. Overall, the focus group results confirmed the existence of influencing factors already obtained from literature, such as the potential influence of Cognitive Bias, Training, Procedures, Organizational Risk Attitude and Internal Stakeholder Involvement, to name a few. However, some influencing factors were identified that were not indicated in the overview of factors presented in table 4.1. Moreover, focus group results suggested the restructuring and renaming of some of the influencing factors in table 4.1.

Consequently, in order to obtain an initial list of influencing factors based on the combined interpretation of the literature study findings and focus group findings (i.e. the output of the model development step of the proposed approach to factor identification; see figure 4.2), some modifications to the overview of influencing factors presented in table 4.1 were needed. These modifications are discussed next, per factor category.
**Human factors**

In the Human factors category, knowledge, expertise and experience were named explicitly as influencing factors by participants in all four groups. These concepts are strongly related to each other. According to Hornby et al. (2000), knowledge concerns “information, understanding and skills that you gain through experience and education”. Consequently, it was decided to mark Experience and Education as influencing factors of early warning signal detection, given their effect on a person’s knowledge and/or expertise. Experience relates to a person’s prior (in)direct involvement in or exposure to risk (e.g. industrial accidents) and its management. Education relates to a person’s formal or informal education in the management of risk, either within or outside the context of the organization.

The influence of a person’s expertise and experience was already confirmed in the literature study described in section 4.2, specifically as factor group #3 in appendix 4.2. Since this factor group was mistakenly interpreted in the assessment of the initial factor grouping as pointing to expertise in signal detection (or in other words, to how capable a person is in detecting early warning signals), it was wrongfully decided not to include it as an influencing factor in the overview presented in table 4.1.

With regard to other influencing factors in the Human factors category, Cognitive Bias was confirmed as an influencing factor, as was the influence of personal characteristics such as a person’s risk attitude. However, focus group participants also emphasized the importance of other personal characteristics on organizational early warning signal detection, such as a person’s ‘systems thinking’ ability. Hence, it was decided to capture these various characteristics (including Risk Attitude and Level of Stress) under a single factor called Personal Characteristics. For other examples of personal characteristics that have an influencing effect on signal detection, see factor group #2 in appendix 4.2.

**Internal environment**

For the Internal environment category, participants mainly identified factors that were included in the subcategories Structure and Culture of the factor overview indicated in table 4.1. Factors identified belonging to the Internal environment category that were not incorporated in this factor overview could be assigned to the subcategories Structure and Culture as well.

Firstly, the influence of procedures on signal detection (as mentioned by Axelsson, 2006; Barton, 1993; Regester, 1987; Hale et al., 2006; Schoemaker & Day, 2009; Sheaffer et al., 1998; Weick & Sutcliffe, 2007) was acknowledged by focus group participants. However, it was emphasized that the effect of procedures on signal detection is apparent in both the existence of formal procedures, and compliance with established procedures. Hence, besides Procedures (the degree to which procedures are known and formalized within an organization), Compliance (the degree to which people within an organization comply with established procedures) was added as an influencing factor.

Secondly, additional factors in the subcategory Culture were mentioned. Group Behavior was included. This factor encompasses the development and functioning of groups, particularly the interactions between groups and the individuals within a group (Stranks, 2007). Groupthink, as indicated in factor group #14 in appendix 4.2 and originally captured under Management Style (also known as Leadership), is an example of how group behavior can negatively affect early warning signal detection (Schoemaker & Day, 2009; Sheaffer et al., 1998; Westrum, 2006).
Thirdly, Empowerment was added as a Culture influencing factor as well, based on the input of the focus group participants. Empowerment refers to the degree to which people within an organization have the power and freedom to make decisions and perform effectively (Stranks, 2007). As was also the case for Groupthink, Empowerment was already identified in the literature study as an influencing factor of organizational early warning signal detection (factor group #17 in appendix 4.2). However, it was initially part of Management Style (or Leadership), under which various diverse cultural aspects were captured, as was explained in section 4.2.3.

Fourthly, participants emphasized the general effect of an organization’s technical systems on signal detection, distinguishing between the effect of the system(s) and the effect of system user interaction. Whereas the earlier identified factor System User Interface directly points to the effect of system user interaction on signal detection, the effect of an organization’s technical systems was not directly captured in a single influencing factor, but was partly expressed in the factors System Coverage and System Span, which both refer to certain characteristics of the technical systems’ architecture. Hence, in order to directly capture the effect of an organization’s technical systems on signal detection, it was decided to combine System Coverage and System Span into a single influencing factor, namely System Architecture.

**External environment**

Identifying External environment factors proved to be quite difficult. Most participants initially characterized factors active within an organization’s external stakeholders as External environment factors. However, as was explained in section 3.2.4, only influencing factors active on the interface between an organization and its external environment are regarded as External environment factors in this thesis. These include factors that indicate an organization’s willingness to interact with its external stakeholders (expressed in the factor External Stakeholder Involvement) and the means an organization has to interact, i.e. to communicate with its external environment (expressed in the factor External Communication (Channels)). Factors active within an organization’s external stakeholder(s), from the perspective of the organization, belong to the Exogenous factor category.

After clarifying the difference between the various factor categories, focus group participants appreciated the distinction and acknowledged the existence of External environment factors. In particular, the effect of External Stakeholder Involvement on signal detection was emphasized.

**Exogenous**

As mentioned above, some factors originating from an organization’s external environment were inadvertently marked as External environment factors by the focus group participants, such as third party procedures and business dynamics. These factors belong to the Exogenous category though. Despite the influence of such factors on organizational early warning signal detection, which was confirmed by the focus group participants, they are considered outside the scope of this thesis, as was explained in section 3.2.4.
For a small number of identified factors, further deliberation on whether or not to incorporate them as influencing factors of organizational early warning signal detection (and in which category), was needed. These identified factors included but were not limited to (political, time, work) pressure and information (over)load. The main difficulty with these factors lies in the fact that although they can be considered Exogenous to a large extent, pressure and information overload are not restricted to an organization’s external environment.

For instance, take work pressure. It might be considered exogenous, due to the nature of the business in which the organization is active. However, work pressure might also result from a combination of assigned responsibility and a lack of authority (related influencing factor: Responsibility & Authority), or a competitive company culture, to name just a few options. The same is true for information (over)load. It might be considered exogenous, since a substantial part of the information an organization and its people receive will originate from an organization’s external environment. However, the degree of information (over)load is also affected by e.g. the amount of information that an organization’s technical system delivers to system users (related influencing factors: System Architecture and System User Interface), and the ability of a person to process large amounts of information received (related influencing factor: Personal Characteristics).

These examples indicate that pressure and information (over)load can not be directly labeled as influencing factors. Rather, they point to particular circumstances that may affect organizational early warning signal detection, to which the people within an organization, an organization’s subsystems (Technology, Culture,...) and/or an organization’s external environment contributed. This contribution is apparent in the influencing factors already identified in the four main factor categories (Human factors, Internal environment, External environment, and Exogenous).

Lastly, post-processing of the focus group results suggested the slight renaming of some of the influencing factors in table 4.1 to better convey the factor’s meaning. This concerned the factors Internal Stakeholder Involvement (renamed Internal Stakeholder Engagement), External Stakeholder Involvement (renamed External Stakeholder Engagement) and External Communication Channels (renamed External Communication). With regard to the factor Management Style (also labeled as Leadership), it was decided to refer to the factor as Leadership instead. Since both Group Behavior and Empowerment, originally placed under Management Style, were marked as separate influencing factors based on the focus group findings, it was believed that the remaining concept placed under the factor Management Style (i.e. an organization’s attitude to bad news and its messenger(s)) was more adequately represented by Leadership (style).

Based on the modifications described above, an initial list of influencing factors based on the combined interpretation of the literature study findings and focus group findings could be established. This list is presented in section 4.4, together with an overview of definitions of the influencing factors. Firstly however, section 4.3.3 addresses the validity and reliability of the focus group.
4.3.3 Validity and reliability of the focus group

In order to assess the quality of the focus group, and consequently the quality of the focus group results obtained, this section discusses the validity and reliability of the focus group. In determining focus group validity, focus group participants act as an important source of evidence. Hence, an evaluation was performed at the end of the focus group meeting, in which participants were asked to give their opinion on the effectiveness of the focus group in identifying influencing factors of organizational early warning signal detection, amongst other things. The results of this evaluation are discussed next. Afterwards, other issues with regard to focus group validity and reliability, such as participant expertise, number of focus group meetings, and post-processing of the focus group results, are discussed.

Focus group evaluation

At the end of the focus group meeting, participants were asked to fill in an evaluation form to determine focus group effectiveness. The evaluation form can be found in appendix 4.5. Besides indicating their area of expertise, participants were asked to evaluate the overall effectiveness of the focus group in identifying influencing factors, and in increasing participant awareness and understanding of organizational early warning signal detection. For that purpose, participants were asked to answer the following questions on a four-point scale, ranging from 1 (‘not at all’) to 4 (‘to a large extent’), including the option ‘Do not know’ (in case the participant was unable to answer the question):

1. How much has this workshop helped increase your knowledge about organizational early warning signal detection?
2. How effective was this workshop in identifying the majority of the organizational factors that affect early warning signal detection?
3. How effective was this workshop in identifying the most relevant organizational factors that affect early warning signal detection?
4. To what extent do you think you can apply what you learned from the workshop to your work?

Also, participants were asked to give their opinion on each part of the focus group (introduction, case studies, deliberation) on a four-point scale (poor, fair, good, excellent), based on the scale used by Crichton (2009) for workshop evaluation. Results of this evaluation are shown in table 4.2.

Eleven out of the 18 participants filled in the evaluation form, coming from various areas of expertise (transport, infrastructure, energy, aerospace, civil engineering). With regard to the main aim of the focus group, i.e. factor identification, two questions were asked, namely question 2 (effectiveness in identifying majority of factors) and question 3 (effectiveness in identifying most relevant factors). A median score of 3.0 was obtained for question 2, indicating that on average the focus group was rather effective in identifying the majority of factors. However, based on this result, it cannot be claimed that the focus group by itself resulted in a comprehensive overview of influencing factors, as this would require an average score towards the top of the scale. This supports the need for other means of factor identification besides the focus group, which is characteristic for the general approach to factor identification employed in this thesis (see figure 4.1).
Table 4.2: Descriptive statistics for focus group evaluation

<table>
<thead>
<tr>
<th>Evaluation item</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Knowledge increase</td>
<td>3.0</td>
<td>3.0</td>
<td>2-4</td>
</tr>
<tr>
<td>2. Identification of majority factors</td>
<td>3.0</td>
<td>3.0</td>
<td>2-4</td>
</tr>
<tr>
<td>3. Identification of most relevant factors</td>
<td>2.0</td>
<td>2.0</td>
<td>2-4</td>
</tr>
<tr>
<td>4. Ability to apply to own work</td>
<td>3.0</td>
<td>3.0</td>
<td>1-3</td>
</tr>
<tr>
<td>Organization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Introduction</td>
<td>3.0</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>6. Case 1: Propane explosion</td>
<td>3.0</td>
<td>3.0</td>
<td>2-4</td>
</tr>
<tr>
<td>7. Case 2: Own experiences</td>
<td>2.0</td>
<td>2.0-3.0</td>
<td>1-3</td>
</tr>
<tr>
<td>8. Deliberation</td>
<td>3.0</td>
<td>3.0</td>
<td>2-3</td>
</tr>
</tbody>
</table>

* Four point scale, from 1 (‘not at all’) to 4 (‘to a large extent’)
** Four point scale (1=’poor’, 2=’fair’, 3=’good’, 4=’excellent’)
*** Both ‘fair’ and ‘good’ were the most frequently observed values in the data set for this question, so two modes are indicated

Responses on question 3 indicated some disagreement among participants with regard to the focus group’s ability to identify the most relevant influencing factors of organizational early warning signal detection. On the one hand, five participants indicated that the focus group was little effective in doing so, which contributed to a median score of 2.0 on question 3. Participants that assigned a low score on question 3 indicated that they found it difficult to determine whether or not the most relevant factors were identified during the focus group, since a focused discussion on factor relevance was not incorporated in the focus group meeting. Though initially planned, time available for the focus group unfortunately did not allow such a discussion. For other participants, despite the lack of a focused discussion, it was apparent that indeed the most relevant factors were identified, resulting in higher scores given on question 3 (two participants gave a score of 4, and two other participants gave a score of 3). The latter might be attributed to the extent to which influencing factors proposed by participants were incorporated in the resulting overview of influencing factors after the deliberation session though. Hence, overall a careful interpretation of the score on question 3 is in order, leading to the conclusion that the relevance of influencing factors could neither be confirmed, nor disproved.

Besides factor identification, the focus group also aimed to increase participant awareness and understanding of organizational early warning signal detection. The scores on questions 1 and 4 suggest that on average, the focus group helped to increase participants’ understanding of the concept, and that overall participants believed that they could apply the concept of organizational early warning signal detection to some extent to their work. With regard to question 4, it should be mentioned though that two participants indicated that they could not at all apply the concept (yet) to their work. On the topic of concept application, one of these participants stated “…perhaps later when I grasp the idea. I recognize the need for a different view, paradigm shift for myself…” This comment suggests an appreciation of the concept, but the difficulty to currently apply it in the context of one’s work activities. A potential explanation for the expected difficulty in application is the fact that the concept of organizational early warning signal detection constitutes a conceptual framework based on existing theory, and was presented as such (although explicated by means of various case studies).
Moreover, practical implications of the concept were not stressed during the focus group. Overall however, the appreciation of the concept was shared by the other participants, most of whom did not expect major difficulty in application, as is apparent from the median score of 3.0 on question 4.

With regard to the main elements of the focus group, the introduction, the first case study analysis, and the deliberation session were overall marked as ‘good’ (median scores of 3.0) by the focus group participants. Lastly, focus group participants on average rated the analysis of the second case study, in which participants’ own experiences were discussed, somewhere between ‘fair’ and ‘good’ (median score of 2.0, but two modes of respectively 2.0 and 3.0). As was observed during the focus group, most groups during the case study analysis spend a large amount of the time available for analysis on the first case study (i.e. the propane explosion accident). Since the purpose of the case study analysis was to stimulate the identification of influencing factors and not to analyze in detail all of the provided case studies, this was not considered a problem. In practice, the decision whether or not to proceed to the analysis of another case study was left to the discretion of the group moderators. A consequence of the large amount of time spent on the first case study was that unfortunately little time was left for the second case study, let alone the third (backup) case study on the Turkish Airlines crash. This is one potential explanation for the relatively lower scoring of the second case study analysis.

Overall, the evaluation results suggest that the focus group was rather effective in identifying the majority of factors, but that it cannot be claimed that the focus group by itself resulted in a comprehensive overview of influencing factors. On the relevance of the identified factors, no clear conclusion could be drawn. However, this does not affect the insights gained from the focus group with regard to influencing factors of organizational early warning signal detection. Lastly, whereas the focus group introduction, the first case study analysis, and the deliberation session were overall marked as ‘good’ by the participants, the second case study analysis received relatively lower scores, most likely due to practical reasons.

**Participant expertise, number of group meetings, and post-processing of focus group results**

By describing in detail the rationale for employing a focus group to elicit expert knowledge, focus group design and the analysis (i.e. post-processing) of the focus group results, (external) validity and reliability of the focus group is partly ensured (Merriam, 1998). In the detailed description of the focus group, some concerns with regard to validation and strategies to handle these concerns were already implicitly discussed, such as the reduction of expert bias, the effectuation of group interaction and the avoidance of moderator influence. However, some additional concerns need to be addressed.

Firstly, members of a professional association for risk analysis and reliability were recruited as participants, amongst other reasons because these members in general have been working in the field of risk management and reliability for many years, and as such have the level of expertise required for the focus group. Based on his association with the professional association and its members, the researcher could attest to the participants’ expertise, as he was by and large familiar with their current positions and background. For this reason, specific questions relating to a participant’s knowledge and experience with managing risk were not part of the focus group evaluation.
In retrospect, this is considered a weak point of the focus group, as more explicit insight into the participants’ expertise in managing risk could have further strengthened the validity of the focus group. In the elicitation of expert knowledge in the model validation step of the factor identification approach, as will be discussed in the next chapter, this issue was addressed.

Secondly, most focus group studies consist of multiple group meetings, with varying combinations of participants, ideally until no new insights are gained (Krueger & Casey, 2009). However, having more than one focus group meeting is not a strict prerequisite for a focus group study, as Fern (2001) states that the number of groups required for a focus group study may range anywhere between 1 and 30, depending on the research purpose. Since the researcher only had the opportunity to get together members of the professional association in a single focus group meeting due to practical (time, planning, availability) reasons, it was not possible to organize additional focus group meetings. As a consequence, it was not possible to ascertain whether additional meetings would have yielded any new insights, and no strong claim can be made as to whether the single focus group meeting led to theoretical saturation. To partly overcome this shortcoming, focus group participants received feedback by e-mail on the results of the focus group a couple of weeks after the focus group meeting, including the resulting (post-processed) overview of influencing factors. Participants were invited to share any comments they may have based on this overview with the researcher, which, depending on the comment(s), could lead to a reconsideration and (potential) modification of the overview of influencing factors. Besides feedback in which participants expressed their appreciation of the focus group meeting, no comments on the overview of influencing factors were received. The fact that no comments were received is non-conclusive with regard to theoretical saturation though, as other considerations (e.g. lack of time) may have caused participants not to respond.

Although theoretical saturation hence can not be directly claimed given the limited number of focus group meetings, the single focus group meeting held did yield comparable results to the literature study performed as part of the model development step. In particular, the existence of factors identified in crisis management and resilience engineering literature was confirmed (as was described in the previous subsection). As a result, a sufficient level of theoretical saturation appears to have been achieved in the single meeting, rendering results obtained valid for the purpose of model development without the need for additional focus group meetings in this respect.

Thirdly, a potential threat to focus group validity is the need for post-processing of the focus group results, which may introduce researcher bias. In order to reduce the threat of researcher bias, post-processing of identified influencing factors was performed by three researchers, which were all knowledgeable on organizational early warning signal detection and were acquainted with the results of the literature study.

4.4 Model development: initial list of influencing factors and factor descriptions

Based on the combined interpretation of the literature study findings (discussed in section 4.2) and focus group findings, which was discussed in section 4.3.2, an initial list of 21 influencing factors of organizational early warning signal detection was obtained. An overview of these factors is presented in table 4.3.
It is important to emphasize that table 4.3 only presents a limited (initial) overview of the ways in which organizational early warning signal detection as regarded in this thesis (i.e. by means of detection by people within the organization) is affected. Namely, only influencing factors on the signal processing/receiving side (i.e. the organization in this context) are taken into account. However, detection also depends on, and is hence affected by, the particular early warning signals received. As such, research into the properties or attributes of these signals is worthwhile, as it can give insight into how ‘weak’ signals might be turned into ‘strong’ signals, thereby positively affecting an organization’s ability to detect such signals. This type of research is outside the scope of this thesis though, as was explained in section 3.2.1.

Table 4.3: Initial list of influencing factors, based on the combined interpretation of the literature study findings and focus group findings

<table>
<thead>
<tr>
<th>Factor category</th>
<th>Influencing factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human factors</td>
<td>Education</td>
</tr>
<tr>
<td></td>
<td>Experience</td>
</tr>
<tr>
<td></td>
<td>Cognitive Bias</td>
</tr>
<tr>
<td></td>
<td>Personal Characteristics</td>
</tr>
<tr>
<td>Internal environment</td>
<td>System Architecture</td>
</tr>
<tr>
<td>Technology</td>
<td>System User Interface</td>
</tr>
<tr>
<td>Structure</td>
<td>Procedures</td>
</tr>
<tr>
<td></td>
<td>Compliance</td>
</tr>
<tr>
<td></td>
<td>Communication</td>
</tr>
<tr>
<td></td>
<td>Responsibility &amp; Authority</td>
</tr>
<tr>
<td></td>
<td>Training</td>
</tr>
<tr>
<td>Culture</td>
<td>Internal Stakeholder Engagement</td>
</tr>
<tr>
<td></td>
<td>Organizational Risk Attitude</td>
</tr>
<tr>
<td></td>
<td>Organizational Learning</td>
</tr>
<tr>
<td></td>
<td>Leadership</td>
</tr>
<tr>
<td></td>
<td>Group Behavior</td>
</tr>
<tr>
<td>Strategy</td>
<td>Empowerment</td>
</tr>
<tr>
<td></td>
<td>Management Commitment</td>
</tr>
<tr>
<td></td>
<td>Vision</td>
</tr>
<tr>
<td>Exogenous</td>
<td>External Stakeholder Engagement</td>
</tr>
<tr>
<td></td>
<td>External Communication</td>
</tr>
</tbody>
</table>

When directly comparing table 4.3 to table 4.1, one gets the impression that a significant difference between results of the literature study and results of the focus group was observed, in terms of influencing factors identified. However, this is not the case, as was already explained in section 4.3.2. ‘Factors’ mentioned in table 4.1 were namely the result of a factor grouping performed on the list of 110 factors initially identified in literature, for the purpose of redundancy removal and classification. This factor grouping caused some factors initially identified not be presented in table 4.1, either due to removal (e.g. Experience) or due to the fact that multiple factors were captured under a single factor group (as was the case for Group Behavior, for example).
Consequently, the difference between the overview of factors in table 4.1 and table 4.3 can mainly be attributed to the initial factor grouping performed on the literature study findings. On the level of individual factors identified in the focus group and in the literature study (see appendix 4.1), comparable results were obtained and the focus group was able to confirm the existence of factors obtained from literature (see section 4.3.2). For that reason, it was decided to accept the overview of factors in table 4.3 as an initial list of factors that could act as input to the next step of the proposed factor identification approach, i.e. model validation.

Descriptions of the influencing factors in table 4.3 are provided in table 4.4. Where possible, descriptions of influencing factors were directly based on definitions of related concepts provided in literature. The description of Cognitive Bias is based on the definition provided by Pohl (2004). Descriptions for Procedures and Communication are based on Davoudian et al. (1994). Descriptions for Training, Group Behavior and Empowerment are based on Stranks (2007). The description for Organizational Learning is based on the definition provided by the Federal Emergency Management Agency (2003). Descriptions for the influencing factors Experience, Personal Characteristics, System Architecture and System User Interface were based on descriptions of similar concepts found in general works of reference (dictionary, encyclopedia). For the remaining influencing factors, suitable descriptions could not immediately be obtained from literature. In these cases, a close review of the context in which the influencing factor was mentioned, in the focus group and in the risk management literature reviewed in section 4.2, led to the descriptions indicated in table 4.4. This review process was jointly performed by two researchers, both knowledgeable on organizational early warning signal detection, acquainted with the results of the literature study, and present at the focus group meeting.

### Table 4.4: Descriptions of the identified influencing factors

<table>
<thead>
<tr>
<th>Influencing factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Education</td>
<td>Education relates to a person’s formal or informal education in the management of risk, either within or outside the context of the organization.</td>
</tr>
<tr>
<td>2. Experience</td>
<td>Experience relates to a person’s prior (in)direct involvement in or exposure to risk (e.g. industrial accidents) and its management.</td>
</tr>
<tr>
<td>3. Cognitive Bias</td>
<td>Cognitive Bias refers to distortions in the human mind that lead to a perception, judgment, or reliability that deviates systematically, involuntarily, and rather distinct from ‘reality’.</td>
</tr>
<tr>
<td>4. Personal Characteristics</td>
<td>Personal Characteristics refers to the combination of intrinsic factors and characteristics, which is unique for any particular individual.</td>
</tr>
<tr>
<td>5. System Architecture</td>
<td>System Architecture refers to the way in which the hierarchical structure, relationships, and the functional behavior of an organization’s technical systems are organized.</td>
</tr>
<tr>
<td>6. System User Interface</td>
<td>System User Interface refers to the way in which access to and interaction of users with an organization’s technical systems is organized.</td>
</tr>
<tr>
<td>7. Procedures</td>
<td>Procedures refers to the extent to which rules, procedures, and/or standardized methods with regard to risk management are known and formalized within an organization.</td>
</tr>
<tr>
<td>8. Compliance</td>
<td>Compliance refers to the degree to which people within an organization comply with established procedures.</td>
</tr>
</tbody>
</table>
Table 4.4: Descriptions of the identified influencing factors (cont.)

<table>
<thead>
<tr>
<th>Influencing factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Communication</td>
<td>Communication refers to the degree to which formal exchange of information within an organization with regard to potential risks and associated early warning signals is organized.</td>
</tr>
<tr>
<td>10. Responsibility &amp; Authority</td>
<td>Responsibility &amp; Authority refers to the extent to which people’s responsibilities and authorities with regard to managing risk within an organization are formally implemented (e.g. in clearly defined tasks) and connected.</td>
</tr>
<tr>
<td>11. Training</td>
<td>Training refers to the extent to which learning (i.e. the systematic development of attitude, knowledge and skills in managing risk) is formally structured and incorporated within an organization.</td>
</tr>
<tr>
<td>12. Internal Stakeholder Engagement</td>
<td>Internal Stakeholder Engagement refers to the level of interaction and (informal) exchange of information (in particular, information on potential risks and associated early warning signals) among the people within an organization, both interdepartmental and intradepartmental.</td>
</tr>
<tr>
<td>13. Organizational Risk Attitude</td>
<td>Organizational Risk Attitude refers to an organization’s position towards risk, or the degree to which an organization is either risk-averse or risk-seeking.</td>
</tr>
<tr>
<td>14. Organizational Learning</td>
<td>Organizational Learning refers to the degree to which an organization is able to learn from its past experiences and situations experienced by others, and to make adjustments when facts dictate, assumptions change, and when more complete information becomes available.</td>
</tr>
<tr>
<td>15. Leadership</td>
<td>Leadership refers to the way in which an organization exerts leadership in managing risk, in particular the way in which an organization handles bad news and its messenger(s).</td>
</tr>
<tr>
<td>16. Group Behavior</td>
<td>Group Behavior refers to the degree to which interaction between groups and between individuals within a group affects an organization’s ability to manage risk.</td>
</tr>
<tr>
<td>17. Empowerment</td>
<td>Empowerment refers to the degree to which people within an organization have the power and freedom to make decisions and perform effectively.</td>
</tr>
<tr>
<td>18. Management Commitment</td>
<td>Management Commitment refers to an organization’s strategic commitment to risk management.</td>
</tr>
<tr>
<td>19. Vision</td>
<td>Vision refers to the extent to which risk management is incorporated in an organization’s long-term strategic planning.</td>
</tr>
<tr>
<td>20. External Stakeholder Engagement</td>
<td>External Stakeholder Engagement refers to an organization’s willingness to interact and communicate with its direct and indirect external environment.</td>
</tr>
<tr>
<td>21. External Communication</td>
<td>External Communication refers to the level of interaction and exchange of information of an organization with its direct and indirect external environment.</td>
</tr>
</tbody>
</table>
4.5 Summary and conclusion

In this chapter, the general approach to factor identification employed in this thesis is introduced, thereby addressing the second research question put forward in section 2.5 (i.e., how can underlying factors that influence organizational early warning signal detection be identified?). As part of the effort to demonstrate the effectiveness of the approach in identifying influencing factors, and to try to obtain a comprehensive overview of influencing factors, the first step of the factor identification approach, i.e. the model development step, is performed. The main aim of the model development step is to obtain an initial list of influencing factors by application of a concurrent qualitative approach, which acts as the input to the next step in factor identification, i.e. model validation. Execution of the model validation step is discussed in the next chapter.

The main data sources utilized for model development constitute literature on crisis management and resilience engineering, and risk management experts. For that purpose, an extensive literature study and focus group were performed, the rationale for which was explained in the introductions to section 4.2 and 4.3, respectively.

The focus group yielded comparable results to the literature study. Overall, focus group findings confirmed the existence of influencing factors already obtained from literature, such as the potential influence of Cognitive Bias, Training, Procedures, Organizational Risk Attitude and Internal Stakeholder Involvement, to name a few. However, focus group findings also pointed to other influencing factors, and suggested the restructuring and renaming of some of the influencing factors obtained from the literature study. The combined interpretation of the literature study findings and focus group findings resulted in an overview of 21 influencing factors of organizational early warning signal detection.

Given the high degree of consistency between results obtained in the literature study and focus group on the level of individual factors, it was decided to accept this resulting overview as an initial list of factors which would act as input to the next step of the proposed approach to factor identification, i.e. model validation. This is the topic of interest of the next chapter. Conclusions with regard to the effectiveness of the employed approach in identifying influencing factors of organizational early warning signal detection are presented at the end of chapter 5.
5 Approach to the identification of underlying factors: model validation

As part of the effort to demonstrate the effectiveness of the proposed approach in identifying influencing factors, this chapter discusses application of the second step of the approach, i.e. model validation. With the initial list of influencing factors presented at the end of the previous chapter as input, model validation in this thesis is performed by means of an iterative mixed methods approach. More specifically, an internet based survey and analysis of a selection of (industrial) accidents from various industries were performed, resulting in a validated list of influencing factors. Based on the overall (model development and model validation) results of the application of the proposed approach, conclusions with regard to the effectiveness of the approach in identifying underlying factors of organizational early warning signal detection are drawn at the end of this chapter.

5.1 Model validation as part of the factor identification approach

As was already explained in section 4.1.2, the main purpose of the second step of the proposed approach to factor identification is validation of the model developed in the first step of the approach (i.e. an initial list of influencing factors; see figure 4.1 in chapter 4). For this purpose, multiple sources of evidence (across organizations and industries), and multiple research methods are to be employed, as was also the case for model development.

The model validation step differs from the model development step in several respects though. Firstly, since an initial model is available for review, model validation need not be limited to the application of qualitative methods. Instead, both qualitative and quantitative methods might be employed, which is desirable from a triangulation perspective. Secondly, model validation is not performed concurrently, but in various iterations. After each iteration, the initial list of influencing factors is adjusted, or ‘updated’, based on any new relevant insights gained. This process repeats itself until additional results of the latest applied method yield very little new insight, resulting in a validated list of influencing factors.

Application of the model validation step of the proposed approach to factor identification is discussed in this chapter, as part of the effort to demonstrate the effectiveness of the approach in identifying factors, and to arrive at a validated list of influencing factors. As will be explained, the main data sources utilized for model validation constitute risk management experts and case studies, mainly concerning major industrial accidents. Figure 5.1 gives an overview of the particular research methods employed for iterative model validation.

Since the analysis of case studies did not yield any new insights with regard to factor identification, model validation as part of the research described in this thesis involved two iterations, as is apparent from figure 5.1. The resulting validated list of influencing factors based on these two iterations is presented at the end of section 5.5, after which effectiveness of the proposed approach in identifying influencing factors of organizational early warning signal detection is discussed in section 5.6. In this section, the issue of how insight gained into influencing factors might be made specific to any one particular industry or organization for the purpose of signal detection improvement is addressed as well. This chapter concludes by presenting the summary and conclusions in section 5.7.
5.2 Survey: design and setup

Of the three main sources of evidence available for factor identification in this thesis (literature, experts and case studies), consultation of risk management experts assembled in expertise networks transcending industries was employed first to validate the initial list of influencing factors obtained. As was explained earlier in chapters 3 and 4, this thesis assumes that people that hold a particular position within an organization have the level of expertise which is required for the position. As such, people that are actively involved in managing risk within an organization are assumed to have expertise in risk management, regardless of the organizational level (strategic, tactical, operational) on which they operate. For that reason, it was decided to consult people in risk management expertise networks for model validation purposes, to learn whether or not they perceive the identified factors as influencing factors of interest and whether in their opinion any influencing factors are missing in the initial list.

For expert consultation, various methods might be employed, such as interviews, surveys or group sessions. Within this thesis, for multiple reasons, a survey was chosen as the instrument to obtain experts’ insights for the purpose of model validation.

Firstly, by means of a survey, individual experts’ opinion on the initial list of factors can be captured, more so than what is expected by employment of a group session to assess model validation. Secondly, a potentially larger group of experts compared to the group of experts consulted for model development might be reached.
Thirdly, methodological triangulation was sought, triangulation being one of the cornerstones of the proposed approach to factor identification. Hence, an expert consultation method other than the one utilized for model development (i.e. a focus group) was preferred. Fourthly, practical reasons also played a role in the choice for a survey, such as restrictions on the arrangement of physical meetings with experts.

In the remainder of this section, design and setup of the survey employed for model validation are discussed. Related topics include survey sample and minimum sample size (section 5.2.1), survey mode (section 5.2.2), main survey elements (section 5.2.3), and measures taken to control for bias (section 5.2.4). Pretesting of the survey is further discussed in section 5.2.5.

5.2.1 Population, survey sample and sample size

As indicated above, the survey was designed to capture experts’ opinion on the initial list of influencing factors for validation purposes. The target population of the survey hence concerns risk management experts, i.e. people that are actively involved in managing risk in industrial organizations, on either a strategic, tactical, or operational level.

Survey sample

Out of the total population of interest, the survey was aimed at a particular sample of the target population. Firstly, since the research project is conducted in the Netherlands, only Dutch respondents were included in the survey. Secondly, experts assembled in an expertise network transcending industries were consulted. This expertise network concerned a professional association for risk analysis and reliability, where experts come together to share their experience with managing risk with fellow experts, and to learn from the experience and insights of others, either from the same industry or from other industries.

Members of this expertise network come from different backgrounds and different industries, and in general have been working in the field of risk management and reliability for many years, at various organizational levels (strategic, tactical, operational). Through their experience with managing risk, members of this network are assumed to have the level of expertise required to contribute to model validation. To support this assumption, more explicit insight into the respondents’ expertise in managing risk was gained by determining respondents’ subjective knowledge of risk management and number of years of experience with (proactive) risk management, which is further discussed in the next section.

Minimum sample size

To determine the absolute minimum sample size, sample sizes of similar expert surveys designed to measure the importance of influencing factors reported in literature acted as a point of reference. Also, requirements on sample size due to statistical analysis to be performed on survey data were taken into account.

Because similar expert surveys to determine the relevance of influencing factors of early warning signal detection could not be found in literature, other fields of study were considered. In the field of software reliability, Jacobs & Van Moll (2007) performed a review of expert surveys designed to measure influencing factor importance, and found sample sizes ranging from 9 to 40. As a result, they opted for a minimum sample size of 20.
Given the need to analyze the validity of the subjective knowledge construct applied in the survey (see section 5.2.3), statistical factor analysis is required. To be able to use factor analysis, the absolute minimum sample size is 50 respondents, or at least five times the number of observations used for factor analysis (Hair et al. 2006), i.e. 15 (5x3 items). From the perspective of analysis requirements, the minimum sample size would thus be 15.

Based on these findings, it was decided to arbitrarily set the absolute minimum sample size to 25 respondents.

5.2.2 Survey mode

Surveys can be conducted in-person, by telephone, by mail or through the internet, each mode of survey administration with its own advantages and disadvantages. For the research described in this thesis, an internet based survey was most convenient since members of the professional association have access to the internet and their e-mail addresses are known to the association board. Also, costs are limited compared to sending out a survey by mail or conducting the survey in-person.

An overview of other advantages, and disadvantages, of internet-based surveying is provided by Reips (2002). One of the disadvantages concerns the possibility of multiple submissions by the same respondent, which might potentially threaten survey validity. To control for multiple submissions, respondents’ IP addresses were logged, and any potential multiple entries from the same IP address were to be removed before further analysis. Also, time spent on completing the survey was logged, and it was chosen to exclude responses which took less than five minutes to complete the survey (approximate time needed to complete the survey was estimated to be 15 minutes) to control for ill considered responses.

All members of the professional association were invited by e-mail to participate in the internet based survey by clicking on a html link provided in the e-mail. The e-mail invitation satisfied the requirements set out for cover letter design (De Leeuw et al., 2008), which include explaining 1) the aim of the study, 2) the way results are processed, 3) the authority conducting the study, 4) privacy issues, 5) required time and 6) contact details.

5.2.3 Main survey elements

The survey consisted of three main parts (not taking into account the introduction and the end), each containing of a group of questions, which are discussed next. For an impression of the survey and each of its main parts, see appendix 5.1 in which screenshots of the survey are presented.

Part 1: Background information and subjective expertise measurement

At the start of the survey, respondents were asked to give some personal information such as the type of industry they are active in, and the organizational level on which they are active. These questions were asked to get some insight into the background of respondents, to determine whether or not the respondent group is representative or if e.g. one particular industry or level of operations (operational, tactical, strategic) is overrepresented.

These questions were placed at the beginning of the survey, since De Leeuw et al. (2008) suggest that questions in a survey should be ordered like a parabola, with the easier-to-answer questions at the start and at the end of the survey. This corresponds to Reips’ (2002) discussion of a warm-up phase in surveys, and is opposite to having a high hurdle to survey participation (by placing motivationally adverse factors close to the beginning of the survey).
Besides acquiring background information on respondents, part 1 of the survey was also designed to gain more explicit insight into respondents’ expertise in managing risk. For that purpose, respondents’ experience with and knowledge of managing risk was ascertained. With regard to the former, respondents were asked to indicate their number of years of experience with managing risk. With regard to the latter, a multi-item scale to measure respondents’ perceived level of knowledge of risk management was utilized, thereby assessing respondents’ subjective knowledge. The multi-item scale consisted of three items that reflect the subjective knowledge construct, in the form of statements for which respondents had to indicate on a seven-point Likert scale whether they agree with the statement or not. This scale was adjusted from a validated multi-item subjective knowledge scale as suggested by Flynn & Goldsmith (1999) and applied by Keijzers (2010), but was not further validated prior to use. For more information on the particular items in the subjective knowledge construct, see appendix 5.1 in which screenshots of the survey are presented.

Part 2: Factor relevance

In part 2 of the survey, for each influencing factor, respondents were asked to indicate whether or not they considered the particular factor as an influencing factor of proactive risk management or in other words, whether or not they considered the factor as being relevant for proactive risk management. The term ‘proactive risk management’ was used in the survey instead of the term ‘organizational early warning signal detection’, as the former term was thought to be more recognizable to potential survey respondents, i.e. those people actively involved in managing risk. The main rationale behind this decision was consequently to lower the threshold for respondents to participate in the survey, thereby potentially increasing the survey’s response rate.

As was explained in chapter 2, organizational early warning signal detection is but one aspect of proactive risk management though. Amongst other things, proactive risk management also encompasses risk preparation for instance, which is distinctly different from risk detection. Hence, a potential drawback of the particular wording used is that respondents might rate factor relevance with the wider scope of proactive risk management in mind. If this were the case, their answers may not necessarily represent their perception of the relevance of the presented factors for organizational early warning signal detection.

To overcome this drawback, various measures were taken. Firstly, the fact that the survey was targeted to a specific aspect of proactive risk management, namely early warning signal detection, was explicitly mentioned in the survey introduction, by explaining the research context (see appendix 5.1). Secondly, a hyperlink to a document giving further insight into the research, including the conceptual framework of organizational early warning signal detection, was added to the introduction. Through these measures, it was expected that potential respondents would have sufficient indications of the survey’s particular focus on organizational early warning signal detection. These measures do require participants to (carefully) read the survey introduction though. Since not all respondents might be likely to do so, this can be considered a weakness of the survey.

Before presenting the factors, the main factor categories Human factors, Internal environment and External environment were briefly described. For each category, the corresponding factors were presented next, including factor descriptions (see table 4.4 in the previous chapter). Next, respondents were asked to answer the following question: “Is the factor described below in your opinion relevant with respect to proactive risk management?” (Yes, No, Don’t know/No opinion).
If respondents answered “Yes” to this question, a second question appeared asking: “To what extent is this factor relevant with respect to proactive risk management?” (5-point Likert scale, 1=low degree of relevance, 5=high degree of relevance). Although not directly in line with the main purpose of the survey, i.e. model validation, the latter question was posed nevertheless, as the survey provided an excellent opportunity to learn more about a particular factor characteristic of interest, namely the (perceived) degree of influence of factors on organizational early warning signal detection. The degree of influence of factors on signal detection, referred to as factor relevance in this thesis, is elaborated upon in the next chapter. In that chapter, results of the survey related to factor relevance are further discussed.

Hence, when describing the findings on the second part of the survey in section 5.3, only the results related to the first question posed are discussed, which gives insight into the extent to which respondents perceive factors in the initial list as being influencing factors of organizational early warning signal detection.

Part 3: Extension of the initial list of influencing factors

To further validate the initial list of influencing factors, respondents were also given the opportunity to indicate whether in their opinion influencing factors of organizational early warning signal detection were missing from the overview of factors presented in the survey. Consequently, in part 3 of the survey, an overview of the factors introduced in the second part was presented, arranged per factor category (Human factors, Internal environment, External environment). For each category, the following question was posed: “In your opinion, are relevant factors with respect to proactive risk management missing in this category? (No, Yes, namely:). When people answered “Yes, namely:”, a text box would appear allowing respondents to describe which factor(s) they believe should be included in the particular category.

5.2.4 Controlling for bias

Various forms of bias related to conducting surveys exist. Whereas the survey employed was targeted specifically to risk management experts, expert bias in the survey is briefly addressed. Firstly however, the way in which the survey controlled for nonresponse bias is discussed.

Two main strategies are often used to cope with nonresponse bias, i.e. reduction and adjustment (De Leeuw et al., 2008). In this thesis, the former strategy was adopted, and various measures were taken to increase survey response. Firstly, the e-mail invitation for the survey was distributed by the board of the professional association among its members, in which the support of the board for the survey was explicitly mentioned. Secondly, prior to receiving the e-mail invitation, members received a notification of the upcoming survey at the general meeting of members. Thirdly, an incentive for participation was offered, by drawing a price of €100 in gift vouchers among the respondents that completed the survey. Fourthly, the relevance of the survey was emphasized, and communication of survey results afterwards was indicated. Fifthly, the survey was in Dutch, to lower the threshold for experts to respond.

Although the rationale for having the survey in Dutch was to lower (nonresponse) bias, the required translation of both factor naming and factor descriptions from English to Dutch acts as another potential source of bias, in that factors’ meaning (and/or respondents’ understanding thereof) inadvertently may be altered due to the translation process. For that reason, translation of all 21 influencing factors was firstly performed in close cooperation by two researchers, both fluent in Dutch (native speakers) and in English (non-native speakers).
In a process involving various iterations, mainly due to some discussion on a particular small subset of factors, the researchers were able to reach agreement on the translated factor naming and factor descriptions. As part of the pretest of the survey that followed, an assessment of the translated factors was then performed by two groups of people (one group familiar with the research content, another group non familiar with the content). This is described in further detail in section 5.2.5. By following this approach, (potential) bias introduced into the survey due to the need for translation was reduced to a level perceived as acceptable, although at the same time the added value of additional measures in the translation process is acknowledged (e.g. the use of an official translator).

Besides nonresponse bias and bias introduced due to translation, another source of bias concerns expert bias, which given the reliance on risk management experts for model validation is inevitable. Nevertheless, a measure was taken against expert bias by targeting experts assembled in an expertise network transcending industries. In that way, it was ensured that experts active in various industries, in various disciplines, and at various organizational levels (strategic, tactical, operational) participated in the survey. Furthermore, experts were asked to share their thoughts on influencing factors of organizational early warning signal detection within the context of the framework developed in this thesis. In this way, experts had to consider early warning signal detection in a non-familiar context, thereby stimulating them to respond based on their experience rather than their usual frame of reference.

5.2.5 Pretest survey

Both the appearance and general suitability of the designed survey to reach the intended goal (i.e. validation of the initial list of influencing factors) was tested before sending out the survey invitation. Two groups of people were used in the pretest. The first group (n=5) consisted mostly of people with limited understanding of the survey topic, but who are experienced in using surveys and therefore can comment on general survey design issues such as the cover letter (e-mail), introductory text, appearance of the survey, background information, etc. Based on their comments, some adjustments were made to the survey design, and the introductory text. Furthermore, some additional explanatory texts to further assist respondents in the process of filling out the survey were added.

People in the first group also were asked to assess the degree of consistency between translated factor naming and factor descriptions. For one factor, i.e. System User Interface, it was indicated by several people that based on the provided description, System User Interaction would be a more adequate factor naming. Whereas this influencing factor relates to the potential effect of the interaction between an organization’s technical systems and its users, of which system user interface is one particular aspect, it was decided to adopt the proposed change. Consequently, factor naming was changed to System User Interaction. For the other factors, the first pretest group concluded that factor naming and factor descriptions were consistent.

Next, a second group of people (n=3) was given the adjusted version of the survey, as part 2 of the pretest. These people shared many characteristics with the target population and were familiar with the research content. They were asked to review all aspects of the survey, but to pay particular attention to whether the translated factor descriptions provided would be clear enough for the survey’s target audience, in terms of adequately conveying the original (non-translated) factors’ meaning. Based on their input, some final minor textual adjustments were made, and the survey was put online.
5.3 Survey: results

The survey was placed online on March 19, 2010, and remained online for several weeks. Prior to placing the survey online, 229 members of the professional association for risk analysis and reliability received an e-mail invitation through the association’s board. Approximately one week later, a reminder e-mail was sent using the same channel.

In total, 37 respondents completed the survey. After filtering out responses based on time spent completing the survey and IP address logging (see section 5.2.2), 34 responses remained. Analysis of incomplete responses (n=17, not included in the filtered group of 34 responses) showed that the incomplete responses could mainly be attributed to either not filling in anything (simply clicking on the link, n=10) or dropping out early (n=5).

For these 34 responses, respondent characteristics are presented in section 5.3.1. Respondents’ subjective knowledge on managing risk is the topic of interest of section 5.3.2, in which amongst other things, validity of the subjective knowledge construct is discussed. Findings regarding the validation of the initial list of underlying factors identified in chapter 4 are presented in sections 5.3.3 and 5.3.4, respectively. Conclusions based on the survey results, including the updated list of influencing factors, are given in section 5.3.5, in which validity of the survey findings is also addressed.

5.3.1 Respondent characteristics

An overview of the characteristics of the respondents is shown in table 5.1. 34 people out of the 229 people that received the invitation completed the survey, which is above the absolute minimum sample size of 25 (see section 5.2.1). Industry demographics indicate that people from various industries participated in the survey, and that most people were active in civil engineering (32.3%). Furthermore, table 5.1 shows a rather balanced distribution of participants with regard to the organizational level on which they are actively involved in managing risk, with the tactical level being represented the most (44.1%). These findings suggest that the respondent group does not appear to be biased towards a single industry or organizational level.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of respondents</td>
<td>34</td>
</tr>
<tr>
<td>Demographics: Industry</td>
<td>Transport: 8.8%</td>
</tr>
<tr>
<td></td>
<td>Infrastructure: 8.8%</td>
</tr>
<tr>
<td></td>
<td>(Semi) government: 8.8%</td>
</tr>
<tr>
<td></td>
<td>Energy: 5.9%</td>
</tr>
<tr>
<td></td>
<td>Chemical industry: 11.8%</td>
</tr>
<tr>
<td></td>
<td>Civil engineering: 32.3%</td>
</tr>
<tr>
<td></td>
<td>Other (Food, ICT, Defense,…) : 23.5%</td>
</tr>
<tr>
<td>Demographics: Organizational Level</td>
<td>Strategic: 29.4%</td>
</tr>
<tr>
<td></td>
<td>Tactical: 44.1%</td>
</tr>
<tr>
<td></td>
<td>Operational: 26.5%</td>
</tr>
<tr>
<td>Average number of years of experience with risk management</td>
<td>13.9 years (standard deviation: 7.4)</td>
</tr>
</tbody>
</table>
On average, respondents have almost 14 years of experience with managing risk, with eight respondents indicating over 20 years of experience; see table 5.2. Moreover, over 80% of the respondents reported more than ten years of experience. Based on these results, the respondent group overall is considered a group of highly experienced people within the field of risk management.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 years of experience</td>
<td>3</td>
</tr>
<tr>
<td>5-9 years of experience</td>
<td>2</td>
</tr>
<tr>
<td>10-19 years of experience</td>
<td>14</td>
</tr>
<tr>
<td>20-29 years of experience</td>
<td>6</td>
</tr>
<tr>
<td>&gt;30 years of experience</td>
<td>2</td>
</tr>
</tbody>
</table>

* The total does not sum up to 34, since the related question was optional

Through their experience, respondents are assumed to have expertise in risk management, and as such these respondents are considered a rich source of information for the purpose of model validation. Besides experience, further insight into respondents’ expertise was gained by measuring respondents’ subjective knowledge of risk management. These results are further discussed in the next subsection.

### 5.3.2 Respondents’ subjective knowledge on risk management

As explained in section 5.2.3, a multi-item scale was used to measure respondents’ perceived level of knowledge of risk management. The scale consisted of three items (Knowledge_1, Knowledge_2, Knowledge_3), in the form of statements for which respondents had to indicate on a seven-point Likert scale whether they agree with the statement or not (1=completely disagree, 7=completely agree). Prior to combining the results on each of the subjective knowledge measurements into a mean subjective knowledge score representing the respondent group’s overall subjective knowledge of risk management however, validity of the three subjective knowledge measurements employed in the survey needs to be investigated. For that purpose, statistical factor analysis was performed (Hair et al., 2006).

Various conceptual and statistical assumptions underlie the application of factor analysis (Hair et al., 2006), which need to be checked first. One of the conceptual assumptions was already discussed, i.e. the minimum sample size required to perform factor analysis (see section 5.2.1). Since the sample size is 34, the minimum requirement of 15 respondents for factor analysis was met. Other recommendations put forward by Hair et al. (2006) were also met, such as having at least ten observations per item and having more observations than items, where a ratio of 20:1 is considered acceptable.

For testing the applicability of factor analysis, two statistical measures are widely used, namely the Measure of Sampling Adequacy (MSA) and Bartlett’s test of sphericity (Hair et al., 2006). These measures were employed to determine whether sufficient correlation among the items exists, which required a resulting overall MSA value above 0.5 and a significant Bartlett’s test of sphericity. Scores on both measures are presented in table 5.3. As is apparent from this table, requirements on both measures were met, showing a sufficient degree of correlation among the items, which indicates that factor analysis may be employed.
Table 5.3: Assumptions check factor analysis

<table>
<thead>
<tr>
<th>Measure</th>
<th>Requirement</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaiser-Meyer-Olkin Measure of Sampling Adequacy</td>
<td>&gt;0.5</td>
<td>0.709*</td>
</tr>
<tr>
<td>Bartlett’s Test of Sphericity</td>
<td>Significant</td>
<td>Chi-Square: 34.046</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sign: 1.938*10^-7</td>
</tr>
</tbody>
</table>

* MSA values on individual items also exceeded 0.5

Statistical factor analysis was performed in PASW®, the detailed results of which are shown in appendix 5.2. These results show that one component was extracted, which indicates that all three subjective knowledge items load on the same factor. Hence, it was concluded that the subjective knowledge construct employed in the survey can be considered valid.

Next, reliability of the subjective knowledge construct was measured. For that purpose, Cronbach’s alpha, inter-item correlations, and item-total correlations were computed. The requirements to be met on these measures in order to conclude that the construct is reliable were taken from Hair et al. (2006). These requirements are indicated in table 5.4, together with the obtained scores on each measure. Based on these results, it can be concluded that requirements on all measures were met, and that consequently the subjective knowledge construct is reliable.

Table 5.4: Reliability of the subjective knowledge construct

<table>
<thead>
<tr>
<th>Measure</th>
<th>Requirement</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s alpha</td>
<td>&gt;0.70</td>
<td>0.811</td>
</tr>
<tr>
<td>Inter-item correlations</td>
<td>&gt;0.30</td>
<td>0.55-0.66</td>
</tr>
<tr>
<td>Item-total correlations</td>
<td>&gt;0.50</td>
<td>0.66-0.74</td>
</tr>
</tbody>
</table>

 Whereas the subjective knowledge construct employed in the survey is both valid and reliable, a mean subjective knowledge score for the overall respondent group could be calculated, based on the combination of results on each of the subjective knowledge items. Given the negative wording of Knowledge_3, scores for this item were reversed in order to calculate a mean score on subjective knowledge. This resulted in a mean score of 6.05 on a 7-point scale on subjective knowledge, 7 being the highest.

Based on this outcome, it was concluded that on average, respondents consider themselves quite knowledgeable in the field of risk management. Combined with the fact that the respondent group overall can be characterized as a group of highly experienced people within the field of risk management (see section 5.3.1), this suggests that the assumption that members of the professional association have expertise in managing risk is valid. As such, survey findings are a valuable source of information for the purpose of model validation. These findings are discussed in the next two subsections.

5.3.3 Validation of previously identified factors

As mentioned in section 5.2.3, respondents were asked in the second part of the survey to indicate, for each of the 21 factors in the initial list of influencing factors, whether or not the factor is indeed relevant with respect to organizational early warning signal detection. Table 5.5 gives an overview of the factors and the number of respondents that marked the factor as being relevant.
Table 5.5: Number of survey respondents (total n=34) that indicated that the described influencing factor is relevant with respect to organizational early warning signal detection

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>32</td>
</tr>
<tr>
<td>Experience</td>
<td>33</td>
</tr>
<tr>
<td>Cognitive Bias</td>
<td>33</td>
</tr>
<tr>
<td>Personal Characteristics</td>
<td>33</td>
</tr>
<tr>
<td>System Architecture</td>
<td>28</td>
</tr>
<tr>
<td>System User Interaction</td>
<td>31</td>
</tr>
<tr>
<td>Procedures</td>
<td>34</td>
</tr>
<tr>
<td>Compliance</td>
<td>34</td>
</tr>
<tr>
<td>Communication</td>
<td>33</td>
</tr>
<tr>
<td>Responsibility &amp; Authority</td>
<td>33</td>
</tr>
<tr>
<td>Training</td>
<td>31</td>
</tr>
<tr>
<td>Internal Stakeholder Engagement</td>
<td>33</td>
</tr>
<tr>
<td>Organizational Risk Attitude</td>
<td>33</td>
</tr>
<tr>
<td>Organizational Learning</td>
<td>33</td>
</tr>
<tr>
<td>Leadership</td>
<td>31</td>
</tr>
<tr>
<td>Group Behavior</td>
<td>32</td>
</tr>
<tr>
<td>Empowerment</td>
<td>30</td>
</tr>
<tr>
<td>Management Commitment</td>
<td>34</td>
</tr>
<tr>
<td>Vision</td>
<td>33</td>
</tr>
<tr>
<td>External Stakeholder Engagement</td>
<td>32</td>
</tr>
<tr>
<td>External Communication</td>
<td>32</td>
</tr>
</tbody>
</table>

For a factor to be considered irrelevant, one would expect to see a low number of respondents indicating the factor as being relevant. As is apparent from table 5.5, there is no influencing factor for which a low number of respondents indicated that the factor is relevant. The factor for which the lowest number of respondents indicated factor relevance is the factor System Architecture, for which still 28 out of 34 respondents agreed that it is a relevant factor.

To ascertain the overall level of agreement of respondents with the influencing factors identified during the model development step, a measure of reliability proposed by Miles & Huberman (1994) was calculated, i.e. Reliability ($R_e$) = $N_a/(N_a+N_d)$, where $N_a$ equals the number of agreements and $N_d$ equals the number of disagreements.

For the factor with the highest number of disagreements (System Architecture), reliability was calculated, i.e. 0.82. Whereas a measure of 0.8 or above can be considered satisfactory (Miles & Huberman, 1994), even the factor with the highest number of disagreements is sufficiently reliable. Firstly, this indicates overall agreement among the respondents with regard to marking System Architecture as an influencing factor of organizational early warning signal detection. Secondly, it confirms overall agreement on all other factors in table 5.5, since a lower number of respondents disagree with their relevance compared to System Architecture.

As a result, it can be concluded that overall, none of the factors in the initial list of influencing factors were deemed irrelevant. More importantly, these findings suggest that overall, respondents agree on the relevance of the factors mentioned in the survey, thereby validating the factors enlisted in table 5.5.
5.3.4 Further insights into influencing factors

In part 3 of the survey, respondents had the opportunity to indicate whether any relevant factors were missing in the overview provided and if so, which factor(s) needed to be included. Most respondents took the opportunity to provide comments on the factors identified in each of the main factor categories (Human factors, Internal environment, External environment), and gave suggestions for factors to be included.

The comments provided by respondents in the third part of the survey were jointly reviewed by three researchers, all knowledgeable on organizational early warning signal detection and familiar with the research described in this thesis. Since suggestions for factors to include were by and large rich in description, sufficient information was available for the researchers to be able to interpret the meaning of the suggested factor, and to assess whether the suggestion would result in an adjustment of the initial list of influencing factors. Based on this review process, some minor modifications were made, which are discussed next.

Human factors
For the category Human factors, the factors Cognitive Bias and Personal Characteristics raised some questions. One respondent suggested that Cognitive Bias is a phenomenon caused by a combination of experience, education and personal characteristics, thus opting to exclude Cognitive Bias from the list of influencing factors. Although the researchers agreed that Cognitive Bias is affected by these factors, other influences such as social impact can be distinguished as well. Consequently, it was decided to keep Cognitive Bias as a separate factor. The claim that Cognitive Bias is an influencing factor in itself and not just a combination of other factors, is further supported by the fact that Cognitive Bias was mentioned numerous times as an influencing effect on organizational early warning signal detection in literature (see appendix 4.1) and was also confirmed as a separate factor in the focus group (see section 4.3.2).

More than one respondent indicated that Personal Characteristics as a factor might be split up. Respondents confirmed the relevance of a person’s character and physical traits, (e.g. immunity to stress, attitude towards risk, systems thinking), but at the same time stressed the effect of personal circumstances on an individual’s ability to detect early warning signals within an organizational context. As a result, a person’s (unique) situation both within and outside the organization, such as workload or an employee’s private situation, was captured in a separate new factor called Personal Circumstances.

Internal environment
A minor modification was made in the Internal environment category with regard to the influencing factor Compliance. The factor Compliance was identified during the focus group (see section 4.3.2), after a discussion on the effect of Procedures on signal detection. As a result, Compliance was originally placed in the same subcategory as Procedures, i.e. the subcategory Structure. However, as indicated by survey respondents, compliance with procedures is typically an aspect of the culture within an organization and might even be considered an aspect of the broader (national) culture to which an organization belongs. As a result, Compliance was placed in the Culture subcategory instead.

Some respondents indicated that available time and means to perform proactive risk management should be included as an influencing factor. However, time and means available to perform risk management is determined in various ways within an organization.
Firstly, top management’s strategic commitment to risk management partly determines the amount of resources (time, budget) assigned to proactive risk management within the organization. The effect of time and budget assigned to risk management at a strategic level is included in the influencing factor Management Commitment (see factor group #19 in appendix 4.2). Secondly, time and means available for people to proactively manage risk at all levels within an organization is also determined by the assigned responsibility and authority for managing risk, which is captured under the influencing factor Responsibility & Authority. Consequently, it was decided not to include time and means to perform risk management as a separate factor, since it concerns a particular circumstance that may affect signal detection, to which influencing factors such as Management Commitment and Responsibility & Authority contribute.

**External environment**

No modifications were made to the External environment category based on the comments of the respondents. Various suggestions for factors to be included in this category were given, but these related to influencing factors originating from an organization’s external environment, such as dynamics and complexity of the technological environment, society’s perception of risk, and legislation. As explained in section 3.2.4, such factors belong to the Exogenous category however, since regardless of their potential influencing effect on organizational early warning signal detection, they are largely outside of an organization’s range of influence, and were hence considered outside the scope of this thesis. As a result, the potential effect of the suggested factors on signal detection was acknowledged by the researchers, but no adjustment to the initial list of influencing factors was made.

### 5.3.5 Conclusions and discussion

Based on the analysis of the survey results described in the previous subsections, the following conclusions with regard to the initial list of influencing factors of organizational early warning signal detection were drawn.

Firstly, findings on part 2 of the survey (factor relevance) indicated that overall, respondents agreed on the relevance of these factors on organizational early warning signal detection, and that overall no influencing factors were deemed irrelevant. Hence, no influencing factors were removed from the initial list of influencing factors.

Secondly, findings on part 3 of the survey (extension of the initial list of influencing factors) led to minor modifications to the initial list of influencing factors. The factor Personal Characteristics was split in two, since respondents indicated that not only a person’s character and physical traits will affect signal detection, but that personal circumstances (i.e. a person’s (unique) situation both within and outside the organization) will play a role as well. Hence, Personal Circumstances was added as a factor in the Human factors category. The factor Compliance was moved from the Internal environment subcategory Structure to the subcategory Culture. Also, the importance of some of the earlier identified factors and Exogenous factors (e.g. complexity of the environment) was confirmed in part 3.

Consequently, based on survey findings, only minor modifications were made to the initial list of influencing factors, resulting in an updated list of factors, which is shown in table 5.6. The fact that survey results are by and large in accordance with earlier results obtained in the model development phase suggests that survey responses are applicable to the context of organizational early warning signal detection as was intended.
Table 5.6: Updated list of influencing factors based on survey findings

<table>
<thead>
<tr>
<th>Factor category</th>
<th>Factors found in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Factors</td>
<td>Education, Experience, Cognitive Bias, Personal Characteristics, Personal Circumstances</td>
</tr>
<tr>
<td>Internal Environment</td>
<td>Technology (System Architecture, System User Interaction)</td>
</tr>
<tr>
<td></td>
<td>Structure (Procedures, Communication, Responsibility &amp; Authority, Training)</td>
</tr>
<tr>
<td></td>
<td>Culture (Internal Stakeholder Engagement, Organizational Risk Attitude, Organizational Learning, Leadership, Group behavior, Empowerment, Compliance)</td>
</tr>
<tr>
<td>Strategy</td>
<td>Management Commitment, Vision</td>
</tr>
<tr>
<td>External Environment</td>
<td>External Stakeholder Engagement, External Communication</td>
</tr>
<tr>
<td>Exogenous</td>
<td></td>
</tr>
</tbody>
</table>

Hence, any potential misinterpretation of the survey’s focus due to the use of the term ‘proactive risk management’ instead of ‘organizational early warning signal detection’, for which various measures were taken (see section 5.2.3), appears to be limited.

**Validity of survey findings**
Various measures were taken to ensure survey quality, i.e. that the survey would yield valuable insights for the purpose of (potentially) updating the initial list of influencing factors, thereby contributing to the validity of survey findings.

Firstly, the survey was directed to risk management experts. Through their expertise in managing risk, these people are considered a rich source of information for validation of the initial list of influencing factors. As was discussed in sections 5.3.1 and 5.3.2, respondent characteristics such as number of years of experience with managing risk and subjective knowledge of risk management suggested that the assumption that respondents from the survey sample (i.e. members of a professional association for risk analysis and reliability) are indeed experts is justified.

Due to the reliance on risk management experts, the survey sample should however be considered biased. Measures were taken against expert bias, e.g. by targeting experts active in various industries, in various disciplines, and at various organizational levels (strategic, tactical, operational). Nevertheless, restrictions with regard to external validity of survey findings remain.
Secondly, quality of the survey instrument was tested. Two pretest groups (n=5 and n=3) assessed the survey, which led to minor modifications in terms of appearance, layout and wording (see section 5.2.5). With regard to whether the survey was adequate for its purpose, people from the second pretest group, who shared many characteristics with the target population, did not express any concerns and confirmed suitability of the survey instrument to reach its intended goal. Further support for (content) validity of the survey instrument comes from the fact that input to the survey, including the factors and their descriptions, resulted from earlier research, including an extensive literature study and focus group.

Thirdly, modifications were made to the initial list of influencing factors based on comments provided by respondents, which were jointly reviewed by three researchers. These comments were rich in description, thereby facilitating interpretation of the suggested factors. Both aspects are considered to further add to the validity of the survey findings.

Lastly, survey findings confirmed the results of earlier research into influencing factors performed in this thesis, in the sense that respondents overall agreed that factors previously identified are indeed relevant for organizational early warning signal detection. Given this consistency, taken into account the measures employed to ensure survey quality described above, it is concluded that the survey findings overall can be considered valid for the purpose of (potentially) updating the initial list of influencing factors.

5.4 Analysis of case studies: selected cases and protocol

Since the survey among risk management experts yielded some minor modifications to the initial list of influencing factors as presented at the end of chapter 4, it was decided to perform another iteration as part of the mixed methods approach to model validation (see section 5.1). For several reasons, the main source of evidence employed for further validation of the post-survey list of factors constituted case studies (i.e. mainly major industrial accidents, in which early warning signals were present and largely remained undetected).

As was explained in section 4.1, most major industrial accidents are well documented and investigated, including the sequence of events leading to the catastrophic event. Consequently, such case studies generally have the required level of detail (both descriptive and analytical) to allow for analysis with respect to early warning signals and their detection, and related influencing factors. As such, case studies are a source of empirical evidence for model validation. Secondly, data triangulation and methodological triangulation are two important characteristics of the employed approach to factor identification. Hence, a source other than literature on crisis management and resilience engineering, and risk management experts was employed, which requires a different means of analysis.

Hence, it was decided to analyze various case studies to further validate the post-survey list of influencing factors. In this section, the approach to case study analysis is discussed. The criteria used for case selection and the resulting overview of case studies to be analyzed are presented in section 5.4.1. Next, the protocol for analysis is discussed in section 5.4.2. Lastly, section 5.4.3 discusses the outcome of a workshop prior to protocol execution.
5.4.1 Case study selection

In selecting the case studies to be analyzed, several criteria were taken into account:

- Case studies are analyzed with respect to early warning signals and the factors that either positively, but in most case negatively contributed to signal detection. To allow this type of analysis, it is required that cases are well documented and that the sequence of events leading to the catastrophic accident has been formally investigated. A review of several accident databases (e.g. the FACTS database (Facts, 2011)) demonstrated that the description and analysis of accidents included in these databases in general do not have the required level of detail. In comparison, given their impact on society and industry, most major industrial accidents are well analyzed and investigated. Consequently, major industrial accidents were considered for analysis.

- Only case studies in which early warning signals were present (either explicitly mentioned in the case study material as being a warning signal, or implicitly when the phenomenon being described in the material indicated an early warning signal, but was not labeled as such) were considered for analysis.

- Selected case studies should represent a variety of industries and should not be limited to e.g. accidents in the chemical industry, since this thesis focuses on early warning signal detection in industrial organizations in general.

- Selected case studies should not be limited to a specific era, but should include examples of both recent history (2000s) as well as earlier examples of industrial accidents.

- Where possible, “success stories” of early warning signal detection should be included, as was already discussed in section 4.1.1. In literature, only limited examples of success stories can be found though, i.e. inherent to the field of reliability engineering and risk.

Multiple case studies from different industries satisfying these criteria were obtained from literature, and through suggestions made by academic and industrial experts in risk management during an expert meeting, which is further discussed in section 5.4.3. This resulted in a long list of case studies suitable for analysis. For practical reasons, such as the involvement of a second researcher in the analysis process (see section 5.4.2), the list needed to be narrowed down to a manageable set of case studies, which was arbitrarily limited to a maximum of ten case studies.

In this process, it was ensured that selected case studies represented a wide variety of industries and spanned a relatively long time period, preferably including a large number of recent (period 2000-2011) accidents. For that purpose, it was decided to include no more than two case studies from the same industry, and to select recent case studies with priority. Furthermore, because “success stories” of organizational early warning signal detection are limited in literature, any successful examples of signal detection found were automatically included. Lastly, case studies suggested by the academic and industrial experts during the expert meeting were also automatically added to the list of cases to be analyzed.

This resulted in the selection of the eight case studies as indicated in table 5.7, in which a short description of each case study and the consulted case material is presented.
Table 5.7: Overview of selected case studies

<table>
<thead>
<tr>
<th>Case</th>
<th>Year</th>
<th>Industry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhopal</td>
<td>1984</td>
<td>Chemical</td>
<td>Major release of toxic methyl isocyanate (MIC) gases at the Union Carbide pesticide plant in Bhopal, India, exposing over 500,000 people and killing 1000s in the Bhopal area. Things were set in motion when water contaminated a MIC storage tank causing a runaway reaction. (Kletz, 2001: chapter 10) (Shrivastava, 1987)</td>
</tr>
<tr>
<td>Davis-Besse</td>
<td>2002</td>
<td>Nuclear</td>
<td>During a refueling outage in February 2002, serious degradation of the reactor pressure vessel head was found which could have potentially led to a substantial loss of reactor coolant accident. (Axial) cracking of several nozzles allowed boric acid leakage onto the reactor pressure vessel head. These conditions had existed for several years at Davis-Besse Nuclear Power Station before discovery. (United States Nuclear Regulatory Commission, 2008) (Advisory Committee on Reactor Safeguard, 2003) (FirstEnergy, Davis-Besse Nuclear Power Station, 2002) (Ghosh &amp; Apostolakis, 2005)</td>
</tr>
<tr>
<td>Deepwater Horizon¹</td>
<td>2010</td>
<td>Offshore Oil</td>
<td>On April 20, 2010, high pressure methane gas escaped from a subsa well, leading to several explosions on the Deepwater Horizon oil rig, killing 11 crew members and injuring many more. On April 22, 2010, the oil rig consequently sank, destroying it and causing one of the largest oil spill in the Gulf of Mexico to date. (Bea, 2010) (60 Minutes, 2010) (McQuaid, 2010)</td>
</tr>
<tr>
<td>Fire semiconductor plant Philips (Nokia vs. Ericsson)</td>
<td>2000</td>
<td>Consumer Electronics</td>
<td>Lightning struck an electric line in New Mexico leading to power fluctuations, which resulted in a small fire in a Philips semiconductor plant. Even though the initial effect of the fire appeared to be relatively small (some thousands of chips were directly damaged by the fire), smoke and water damage affected millions of chips and major supply disruptions to Philips' two major customers, i.e. mobile telephone manufacturers Nokia and Ericsson, lasted for several months. (Latour, 2001) (Norrman &amp; Jansson, 2004)</td>
</tr>
<tr>
<td>Flixborough</td>
<td>1974</td>
<td>Chemical</td>
<td>Leaking cyclohexane in the Nypro chemical plant in Flixborough, UK, formed a vapor cloud which ignited. 28 people were killed and many more were injured. The chemical plant itself was destroyed and numerous buildings within a mile radius were damaged. (Kletz, 2001: chapter 8) (Lees, 1995: appendix 2)</td>
</tr>
</tbody>
</table>

¹ At the time when the analysis of case studies was performed (July 2010), investigation of the Deepwater Horizon accident was still ongoing, and no formal investigation report by the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling was available. Analysis was consequently conducted based on preliminary research findings, such as reported by Bea (2010).
Table 5.7: Overview of selected case studies (cont.)

<table>
<thead>
<tr>
<th>Case</th>
<th>Year</th>
<th>Industry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperial Sugar</td>
<td>2008</td>
<td>Food</td>
<td>Massive dust explosion at a sugar refinery plant killed 14 and injured 36. A first dust explosion initiated in an enclosed steel belt conveyor. Secondary explosions throughout the packing buildings and other areas of the plant were fuelled by massive accumulations of combustible sugar dust. (U.S. Chemical Safety and Hazard Investigation Board, 2009)</td>
</tr>
<tr>
<td>Texas City BP</td>
<td>2005</td>
<td>Oil</td>
<td>On March 23rd 2005, BP Texas City Refinery suffered one of the worst industrial accidents in recent U.S. history with an explosion during the Isomerization unit startup, caused by heavier-than-air hydrocarbon vapours combusting after coming into contact with an ignition source, killing 15 and injuring 180. The hydrocarbons originated from liquid overflow from the Blowdown Stack following the operation of the Raffinate Splitter overpressure protection system caused by overfilling and overheating of the tower contents. (U.S. Chemical Safety and Hazard Investigation Board, 2007) (Baker et al., 2007) (Broadribb, 2006)</td>
</tr>
<tr>
<td>Three Mile Island</td>
<td>1979</td>
<td>Nuclear</td>
<td>On 28 March 1979, the nuclear power station at Three Mile Island in Pennsylvania overheated and a small amount of radioactivity escaped to the atmosphere. Although effects on public health appeared to be limited, public confidence in the nuclear energy was shattered. Particularly people-related problems (e.g. misinterpreting the position of the pilot-operated relief valve (PORV)) caused an initially minor incident to lead to a partial core meltdown. (Kletz, 2001: chapter 11) (Lees, 1995: appendix 21) (U.S. President’s Commission on the accident at Three Mile Island, 1979)</td>
</tr>
</tbody>
</table>

As much as possible, formal investigation reports were consulted as well as scientific accounts of the accidents (e.g. Kletz (2001), Lees (1995) and Shrivastava (1987)), instead of popular accounts of the cases studies. Almost all cases represent the inability to successfully detect early warning signals, but in some cases (including Davis-Besse and the fire at the Philips semiconductor plant), successful early warning signal detection is described.

5.4.2 Protocol for analysis

Case study analysis by means of reviewing case material can be executed in various ways. One option is to perform an extensive qualitative content analysis (Krippendorff, 2004). Based on qualitative content analysis, the reviewer is able to label and distill terms used in the case material, known as labeling and tallying. Going through this rigorous process can act as input for a theoretical model, and as such is particularly useful for theory construction. Since the main purpose of case study analysis in this thesis is not to build a theoretical model but to further validate an existing model of influencing factors, qualitative content analysis to the degree described by Krippendorff (2004) was not deemed necessary. Instead, case material was qualitatively analyzed by means of the existing post-survey list of influencing factors. The content analysis protocol followed is presented in figure 5.2.
**Step 1:** Collect relevant case material for each case study. Of particular interest are (scientific) studies that capture not only direct (technical) causes of the accident, but take into account contributing factors at all levels.

**Step 2:** Identify early warning signals described in the case material (either explicitly mentioned in the case study material as being a warning signal, or implicitly when the phenomenon being described indicated an early warning signal, but was not labeled as such).

**Step 3:** For each identified early warning signal, identify the related factors affecting the signal and its detection in the particular case study.

**Step 4:** For each identified early warning signal, compare the identified influencing factors with the existing post-survey model. If the identified factor corresponds to one of the earlier identified influencing factors, this is indicated by checking the corresponding box in the answering form. A short description is provided as well, as a means to allow for a check whether the identified factor indeed belongs to the existing category. If the identified factor cannot be directly placed into one of the existing categories, it is mentioned separately and reviewed in the next step.

*(Steps 2-4 are performed separately by two researchers, both familiar with the post-survey model)*

**Step 5:** Both researchers present the results of the performed case study analysis to each other. Through deliberation, agreement is reached on the identified early warning signals and the related influencing factors. Identified factors which could not be directly placed into one of the existing categories are discussed separately. If after deliberation it is decided that indeed the identified factor cannot be placed in the existing model, a recommendation is made to further investigate if and how the existing model should be adjusted.

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**Fig. 5.2: Protocol utilized for case study analysis**

### 5.4.3 Workshop prior to protocol execution

Prior to protocol execution, it was ascertained whether case study analysis performed by others than the two researchers intended would yield non-comparable results, and consequently, whether it would be necessary to include any other reviewers for case study analysis.

For this purpose, a small group (n=4) of industrial and academic experts in the field of risk management who were not familiar with the post-survey model of influencing factors were asked to analyze one particular case study (i.e. the Bhopal accident) for early warning signals and the factors that contributed to their non-detection. In a workshop style session, these experts were shortly introduced to the concept of organizational early warning signal detection as regarded in this thesis, without presenting them with the existing model of influencing factors. Instead, only the main factor categories Human factors, Internal environment, External environment and Exogenous were introduced.
Afterwards, they were presented with the same Bhopal case material which one of the researchers had used prior to the workshop as input for the analysis of the Bhopal case. Analysis of the Bhopal case by the researcher was performed prior to the workshop, in order to prevent any potential influencing effect by the outcome of the workshop. Workshop participants were asked to review the case material by themselves, after which a group discussion took place. A comparison of the participants’ individual results, deliberation results and researchers’ Bhopal analysis results (discussed in the next section) led to several observations.

Most importantly, it was found that signals and factors identified by workshop participants were a subset of the signals and factors identified by the researchers. Workshop participants identified a smaller set of signals and factors compared to the researchers, which might be attributed to workshop time constraints. Whereas case study analysis performed by workshop participants thus yielded comparable results to the analysis performed by the researchers, although less comprehensive, it was not considered necessary to adapt the protocol by involving other reviewers than the two researchers.

Some other observations were made as well. Firstly, all factors identified by the workshop participants could be mapped to the existing model. Hence, no additional influencing factors to the post-survey list of factors were identified during the workshop. Secondly, it was observed that participants had difficulty in distinguishing between the main factor categories, as well as between causes, signals, and factors, which was expected to be due to limited time available for introduction to the concept of organizational early warning signal detection.

5.5 Analysis of case studies: results

The tables in appendix 5.3 give an overview of the results of the analysis of case studies. Table rows correspond to the early warning signals which were distilled from the case material, either explicitly or implicitly (i.e. when a phenomenon being described in the case material indicated an early warning signal, but was not labeled as such). Table columns indicate which factors contributed either positively, but mainly negatively, to the signal and its detection.

In total, eight cases were analyzed by two independent researchers, whose results after deliberation are represented in appendix 5.3. It should be noted that every table entry can be directly linked to the case material. In other words, the researchers restricted their analysis to what could be extracted from the case material and refrained from coming up with own arguments which could explain (non) detection of the identified early warning signals beyond the case material. The arguments found in the case material in support of the identified early warning signals and the related factors are captured as comments in the Excel sheets on which the tables of appendix 5.3 are based. For the purpose of readability and conciseness, these arguments are only explicitly mentioned in tables A5.4 and A5.5 in appendix 5.3 (Davis-Besse case), but are available for all other cases as well.

To illustrate how case study analysis results were obtained and how to interpret them, the Bhopal case study analysis will be discussed in detail. All cases have gone through the same process of analysis and any other case could thus serve as an equally illustrative example. An overview of the results of the analysis of the Bhopal accident can be found in appendix 5.3, table A5.2.
5.5.1 Analysis of the Bhopal accident

In 1984, a release of toxic methyl isocyanate (MIC) gases at the Union Carbide pesticide plant in Bhopal, India, exposed over 500,000 people and killed 1000s in the Bhopal area. Things were set in motion when water contaminated a MIC storage tank causing a runaway reaction. Temperature and pressure rose, the relief valve lifted and MIC vapor was discharged into the atmosphere. Protective equipment designed to prevent or minimize (the effect of) the discharge was out of action or not in full working order (Kletz, 2001).

The Bhopal accident is considered to be the worst accident in the history of the chemical industry and has been the subject of many investigations, by Union Carbide, the Indian government and other parties. The case material used for analysis is by Kletz (Kletz, 2001: chapter 10) and Shrivastava (Shrivastava, 1987). These studies do not only go into the technical details of the accident such as the technical design and malfunctioning protective equipment, but consider the human and organizational aspects of the Bhopal accident as well, which are essential elements of early warning signal detection. Moreover, these studies are more suitable for case analysis since they were not directly ordered by one of the involved parties (Union Carbide, Indian government) and are expected to give a more unfiltered account of the events leading up to the Bhopal accident.

Following the earlier described protocol, researcher 1 and researcher 2 were able to extract early warnings signals connected to the Bhopal accident, and related influencing factors:

1. The first reaction of the Bhopal works manager after the accident was “The gas leak can’t be from my plant (…) Our technology just can’t go wrong, we just can’t have such leaks” (Kletz, 2001). This suggests a certain attitude of overconfidence among Bhopal workers, which would have been apparent prior to the accident.

   Related factor: Cognitive Bias. The reaction of the works manager is a clear indication of cognitive bias on an individual level and most likely within the organization as a whole. Since the case material does not go into this specific issue beyond stating the fact, it is not possible to deduce what might have caused this attitude. Therefore, only Cognitive Bias is indicated as the related factor.

2. The Bhopal accident occurred several years after the Flixborough accident. A contributing factor to both accidents was the large storage of hazardous materials. The need to reduce or eliminate inventories of hazardous materials was reported in numerous papers written post-Flixborough, but these ‘lessons learned’ from the past were not taken into account in many companies, including Union Carbide.

   Related factors: Organizational Learning, External Stakeholder Engagement. Not taking into consideration earlier reports on ‘lessons learned’ amongst other things points to an organizational culture which is insufficiently directed towards learning from past experiences, beyond organizational boundaries.

3. Employee morale was low for several reasons, such as the plant losing money and being considered for divestment. Low employee morale, combined with ongoing labor-management conflicts, contributed to carelessness in operations and negligence to be tolerated.
Related factor: Personal Circumstances. On an individual basis, employee morale was low. Personal circumstances such as an unstable working environment and the fear of losing their job in the near future (the plant was for sale at the time of the accident) contributed negatively to Union Carbide employees’ working morale and motivation.

4. In the past, there had been many minor accidents, fires, and MIC leakages. One worker had died and others were injured as they were physically inspecting the systems.

Related factors: Education, Experience, Organizational Risk Attitude, Organizational Learning, Management Commitment. As stated in the case material, many of the operators lacked a sufficient understanding of safe operating procedures. This can be attributed to a lack of knowledge, either in education and/or experience. At the same time, it is an indication of an organizational culture in which risks are structurally downplayed and lessons from the past are disregarded.

5. On a large scale, safety and operating procedures were ignored or not carried out correctly.

Related factors: Education, Experience, Personal Circumstances, Training, Compliance, Organizational Risk Attitude, Management Commitment. This early warning signal is related to some of the signals discussed earlier. For example, procedures were not followed due to low morale. Also, employee knowledge has played a role since safety and operating manuals were in English, not easily readable by operators. Of particular interest are the factors Training, Compliance and Management Commitment. Firstly, inadequate safety training is explicitly mentioned in the case material; the use of safety equipment such as helmets, gas masks and protective clothing was erratic. Secondly, the fact that safety procedures were ignored indicates a non-compliance issue. Thirdly, procedures, including testing and maintenance procedures, were subject to corrosion in the sense that management quickly lost interest. Non-compliance by employees was not addressed by management. Moreover, (management) decisions to disconnect the flare system and shut down the refrigeration system show a lack of understanding and/or commitment.

6. Water was allowed near the MIC storage tank, despite the fact that it was well known that water violently reacts with MIC; no hazard and operability study (HAZOP) was performed.

Related factors: Education, Experience, Procedures. Employees were insufficiently aware of the potential risk of water coming in contact with MIC (due to little experience in MIC technology and little knowledge of the hazards). Also, a method such as HAZOP would have identified the need to keep water clearly away from the MIC storage tank area, which does not appear to have been carried out on the design.
7. Months before the Bhopal accident, safety systems were not in full working order. For example, the storage tank was fitted with a refrigeration system but it was not in use (actually, coolant was drained for use in another part of the plant, making it impossible to switch on the refrigeration system during an emergency). Another example concerns the scrubber system which should have absorbed the MIC discharged through the relief valve, but which was not in full working order.

*Related factors: Education, Experience, Procedures, Compliance, Management Commitment. Among other things, a combination of insufficient understanding by plant employees, no continuous auditing effort, non-compliance, and management ignoring plant safety on a large scale caused safety systems not to be in full working order.*

8. High temperature and pressure on the MIC tank were at first ignored, as the instruments were poorly maintained and known to be unreliable.

*Related factors: Education, Experience, System Architecture, Procedures, Training, Compliance, Management Commitment. This signal is an example of how procedures were ignored and how control systems were not in full working order. Specific attention is paid to the effect that System Architecture can have on disregarding warning signals (e.g. the system being unreliable), although in this particular instance poor maintenance is more apparent.*

9. The Bhopal plant was half-owned by Union Carbide and half owned locally. The Indian government had a special interest in keeping the Bhopal plant running (attractive employer for former government officials, stimulus of local economy), which led central and state government authorities to overrule Bhopal city’s objections and grant an industrial license to manufacture, rather than simply formulate, pesticides. Given the shanty towns in close proximity of the site, such an industrial license should not have been granted.

*Related factors: Management Commitment, External Stakeholder Engagement, Exogenous. In a joint venture, the technically more sophisticated partner has a special responsibility to make sure that the operating partner has the knowledge, commitment and resources necessary for safe operation. Union Carbide did not take sufficient responsibility for this issue. Secondly, the more or less dependent nature of the relation between the Indian government and Union Carbide caused safety issues to be disregarded and warning signals such as a hazardous plant located in close proximity of a densely populated area to be ignored. Lastly, exogenous factors such as little supervision (no community watchdogs) played a role.*

10. Over the previous fifteen years, the plant had been run by eight different managers. Many of them did not have a chemical background and had little or no experience dealing with hazardous technologies.

*Related factors: Education, Experience. Managers with little or no experience in dealing with hazardous technologies indicates lacking education and/or experience on an individual basis. Also, personnel discontinuity indicates a discontinuity in process knowledge.*

11. Because of its relative unimportance as a business unit in Union Carbide’s corporate portfolio, the Bhopal plant did not receive top-management attention and support.
Related factors: Management Commitment, Vision, Exogenous. There was no long term or short term commitment to the Bhopal plant. Consequently, commitment to operating the plant in a safe manner, with long term commitment to safety and risk management was non-existent. Mounting competitive pressures and a declining market for pesticides contributed to the limited attention and support.

12. Technical preconditions for a major accident were embedded in the design of the Bhopal plant, such as the bulk storage of MIC in large underground tanks in a production environment that used manual non computerized control systems. Also, water sprays did not reach the desired height.

Related factors: System Architecture, System-User Interaction, Procedures. Poor technical design, more dangerous than alternative designs available, contributed to the accident. At the same time, unreliable instruments and gauges made the interpretation of signals more difficult. Also, as mentioned previously, it appears that no HAZOP was performed on the design.

Based on the analysis of the Bhopal case study, the following conclusions can be drawn.

Firstly, a wide variety of signals were identified. For the Bhopal case, it can hence be concluded that numerous signals long before the Bhopal accident were present. These signals overall could have been detected and consequently might have led to the prevention of the Bhopal accident or a mitigation of its consequences. However, this was not the case. The fact that this concerned not a single isolated signal, but a combination of multiple signals over a long time span to be left undetected or ignored indicates structural and organization-wide flawed signal detection.

Other signals than the early warning signals indicated above were identified as well, such as the growth of shanty towns in close proximity of the plant. However, a distinction had to be made between signals related to the occurrence of the accident, and signals related to the consequence of the accident. Shanty town growth makes it more likely that when a major accident occurs, more people will be affected (due to their proximity to the plant). However, it did not affect the occurrence of the accident. The fact that it was possible for the shanty towns to grow is an indication of a disregard of safety issues by both Union Carbide and the Indian government. This disregard of safety issues is a warning signal in itself, as is apparent from the analysis.

Secondly, no influencing factors outside the post-survey model were identified. Both researcher 1 and researcher 2 were able to ascribe influencing effects found in the case material relating to the poor detection of early warning signals to factors in the post-survey list of influencing factors. A certain level of interpretation by the researchers was required here, since phrasing of the effect found in the case material and factor naming differed in most cases. Factor descriptions (see table 4.4 in chapter 4) proved to be helpful in this process, allowing the researchers to determine which (if any) factor(s) best captured the effect found in the case material.
Thirdly, a wide variety of influencing factors could be identified, where all major factor categories (Human factors, Internal environment, External environment, and Exogenous) and subcategories (Technology, Structure, Culture, and Strategy) were represented. This indicates that a combination of factors jointly contributed to poor detection of early warnings signals prior to the accident, and that these factors are not limited to a particular category, suggesting no particular dominant effect of human factors, organizational aspects or Union Carbide’s external environment on signal detection.

5.5.2 Conclusions and discussion

Besides Bhopal, seven other case studies were analyzed in the same manner. Appendix 5.3 presents the results of each case study analysis. Table 5.8 on the next page gives a summary of these results. Based on these results, several conclusions can be drawn. Firstly, conclusions with regard to validation of the (initial) list of influencing factors are presented. Next, validity of the case study analysis findings is discussed, after which additional insights gained by case study analysis beyond the main purpose of model validation are described.

Model validation

Most importantly, as is apparent from table 5.8, analysis of these case studies did not result in the identification of factors outside the post-survey list of influencing factors. Both researcher 1 and researcher 2 were able to ascribe influencing effects on organizational early warning signal detection found in the case material to the existing list of factors. In this process, a high level of consistency between the analyses performed by both researchers was observed. Nevertheless, some effects identified in the case material required further deliberation. This did not concern deliberation on whether to include the particular identified effect as a separate additional factor to the existing model though. Rather, it concerned discussions on which of the factors in the post-survey list of influencing factors, out of a selection of potential candidates, best captured the particular influencing effect found in the case material. Also, deliberation took place on which particular factor(s) played a role in the (non-) detection of specific early warning signals identified.

Whereas analysis of case studies did not result in the identification of additional influencing factors, no adjustments were made to the existing list of influencing factors. As a result, it was decided not to proceed with another iteration as part of the model validation step of the factor identification approach, and to accept the post-survey model as a validated list of influencing factors of organizational early warning signal detection. The validated list of factors obtained by employment of the proposed approach to factor identification is shown in table 5.9.

With regard to its validity, two remarks are in order. Firstly, the obtained overview of factors can only be considered valid for its intended purpose, i.e. to give an overview of the various ways in which early warning signal detection is affected in industrial organizations in general. On the level of any one specific industry or organization though, despite the high level of agreement across industries and organizations on factors of influence that was observed throughout the factor identification process, the overview might be non-valid. Non-validity in this sense refers to the fact that not all factors may be applicable to the specific context in which the industry and/or organization under consideration operates, and the fact that other factors beyond those identified may be of interest.
### Table 5.8: Results of the analysis of case studies, as described in appendix 5.4

<table>
<thead>
<tr>
<th></th>
<th>Human Factors</th>
<th>Internal Environment</th>
<th>External Environment</th>
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<tbody>
<tr>
<td></td>
<td>Education</td>
<td>Technology</td>
<td>Strategy</td>
</tr>
<tr>
<td></td>
<td>Experience</td>
<td>Structure</td>
<td>Management Commitment</td>
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<tr>
<td></td>
<td>Cognitive Bias</td>
<td>Culture</td>
<td>Vision</td>
</tr>
<tr>
<td></td>
<td>Personal Characteristics</td>
<td>Schmalz (2008)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Personal Circumstances</td>
<td>Schmalz (2008)</td>
<td></td>
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<tr>
<td></td>
<td>System Architecture</td>
<td>Schmalz (2008)</td>
<td></td>
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<tr>
<td></td>
<td>System-User Interaction</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Procedures</td>
<td>Schmalz (2008)</td>
<td></td>
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<tr>
<td></td>
<td>Communication</td>
<td>Schmalz (2008)</td>
<td></td>
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<tr>
<td></td>
<td>Responsibility &amp; Authority</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Training</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Compliance</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Internal Stakeholder Engagement</td>
<td>Schmalz (2008)</td>
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<td>Organizational Risk Attitude</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Organizational Learning</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Group Behavior</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Empowerment</td>
<td>Schmalz (2008)</td>
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<td></td>
<td>Management Commitment</td>
<td>Schmalz (2008)</td>
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<tr>
<td></td>
<td>External Stakeholder Engagement</td>
<td>Schmalz (2008)</td>
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<tr>
<td></td>
<td>External Communication</td>
<td>Schmalz (2008)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exogenous</td>
<td>Schmalz (2008)</td>
<td></td>
</tr>
</tbody>
</table>

- **Bhopal (1984)**
  - Education: ●●●
  - Experience: ●●●
  - Cognitive Bias: ●●●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●
  - Vision: ●
  - External Stakeholder Engagement: ●
  - External Communication: ●
  - Exogenous: ●

- **Davis-Besse (2002)**
  - Education: ●
  - Experience: ●
  - Cognitive Bias: ●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●●
  - Vision: ●●
  - External Stakeholder Engagement: ●●
  - External Communication: ●●
  - Exogenous: ●

- **Deepwater Horizon (2010)**
  - Education: ●
  - Experience: ●
  - Cognitive Bias: ●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●●
  - Vision: ●●
  - External Stakeholder Engagement: ●●
  - External Communication: ●●
  - Exogenous: ●

- **Fire semiconductor plant (Nokia vs. Ericsson) (2000)**
  - Education: ●●●
  - Experience: ●●●
  - Cognitive Bias: ●●●
  - Personal Characteristics: ●●●
  - Personal Circumstances: ●●●
  - System Architecture: ●●●
  - System-User Interaction: ●●●
  - Procedures: ●●●
  - Communication: ●●●
  - Responsibility & Authority: ●●●
  - Training: ●●●
  - Compliance: ●●●
  - Internal Stakeholder Engagement: ●●●
  - Organizational Risk Attitude: ●●●
  - Organizational Learning: ●●●
  - Group Behavior: ●●●
  - Empowerment: ●●●
  - Management Commitment: ●●●
  - Vision: ●●●
  - External Stakeholder Engagement: ●●●
  - External Communication: ●●●
  - Exogenous: ●●●

- **Flixborough (1974)**
  - Education: ●●
  - Experience: ●●
  - Cognitive Bias: ●●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●●
  - Vision: ●●
  - External Stakeholder Engagement: ●●
  - External Communication: ●●
  - Exogenous: ●●

- **Imperial Sugar (2008)**
  - Education: ●●
  - Experience: ●●
  - Cognitive Bias: ●●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●●
  - Vision: ●●
  - External Stakeholder Engagement: ●●
  - External Communication: ●●
  - Exogenous: ●●

- **Texas City BP (2005)**
  - Education: ●●
  - Experience: ●●
  - Cognitive Bias: ●●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●●
  - Vision: ●●
  - External Stakeholder Engagement: ●●
  - External Communication: ●●
  - Exogenous: ●●

- **Three Mile Island (1979)**
  - Education: ●●
  - Experience: ●●
  - Cognitive Bias: ●●
  - Personal Characteristics: ●●
  - Personal Circumstances: ●●
  - System Architecture: ●●
  - System-User Interaction: ●●
  - Procedures: ●●
  - Communication: ●●
  - Responsibility & Authority: ●●
  - Training: ●●
  - Compliance: ●●
  - Internal Stakeholder Engagement: ●●
  - Organizational Risk Attitude: ●●
  - Organizational Learning: ●●
  - Group Behavior: ●●
  - Empowerment: ●●
  - Management Commitment: ●●
  - Vision: ●●
  - External Stakeholder Engagement: ●●
  - External Communication: ●●
  - Exogenous: ●●
Moreover, the obtained overview of influencing factors given in table 5.9 can only be considered valid at the time at which the overview was obtained, given its dynamic nature. As is apparent from the trends described in chapter 1 (e.g., increasing complexity in (business) processes and business chains), organizations operate in a highly dynamic environment, to which they ideally adapt, for instance by learning from some of the external (early warning) signals they receive. Since both organizations and their environment change over time, other factors may hence become relevant for organizational early warning signal detection.

As a result, prior to utilizing insight into influencing factors for the purpose of signal detection improvement in a particular industrial or organizational setting, validity of the (current) overview of factors needs to be checked. This is further discussed in section 5.6.2.

Within this context, the fact that interactions between (some of) the factors in the overview are expected should be stressed. Utilization of this additional insight into influencing factors could namely further contribute to signal detection improvement in practice, since amongst other things it can help prevent that an organization takes suboptimal measures to improve detection (in terms of targeting one specific factor in isolation for improvement without considering related factors in the process). Such interactions are apparent between influencing factors in the Internal environment category for instance, since these influencing factors relate to an organization’s main subsystems (technology, structure, culture, strategy), which depend on each other and are interrelated (see section 3.2.3).
Furthermore, in the model development phase as well as in the model validation phase of the employed factor identification approach, the existence of certain parameters or circumstances that can simultaneously affect multiple factors was confirmed. For example, an organization that is under high (economic) pressure might experience the effect of this pressure on early warning signal detection both on an individual level (e.g. people’s ability to detect early warning signals in high pressure circumstances) and on an organizational level (e.g. shifting management focus, tendency to take procedural shortcuts to save time).

While acknowledging both the existence of factor interactions and the added value of utilizing such insight for the purpose of improving organizational early warning signal detection in practice, further (analytic) research into factor interactions was outside the (exploratory) scope of this thesis for practical reasons.

Validity of the case study analysis findings
Various measures were taken to ensure validity of the case study analysis findings for the purpose of (potentially) updating the post-survey list of influencing factors. Firstly, case studies to be analyzed were selected by taking into consideration the representativeness of the selected sample. Amongst other things, this implied that case studies from a variety of industries were analyzed, spanning a relatively long time period, and that “success stories” of organizational early warning signal detection found in literature were included as well. Secondly, for the analysis of the case studies, formal investigation reports as well as scientific accounts were consulted as much as possible, which were expected to give a more unfiltered account of events compared to popular accounts of the events or reports ordered by the companies in question. Thirdly, review of the case material was independently performed by two researchers, both familiar with the post-survey model, by means of the protocol presented in figure 5.2. These measures combined contributed to an overall acceptable validity level of the case study findings.

Next to these three measures, deliberation on the individual findings of these researchers indicated agreement among the researchers with regard to the validity of the post-survey model, since both researchers individually did not identify factors outside the post-survey list of influencing factors. This agreement confirms the overall acceptable validity level of the case study findings.

Nevertheless, two potential threats to the validity of the case study analysis findings should be noted. For one thing, whereas both researchers were familiar with the post-survey model, bias in the identification of factors within this model cannot be ruled out. Any potential bias is not expected to have had a major effect on the outcome however. This is suggested by the outcome of a workshop organized prior to analysis, in which it was found that the two researchers were able to reach case study analysis results comparable to the results of a small group of academic and industrial risk management experts. The second threat to validity concerns the fact that only a limited number of case studies were analyzed. Although great care was taken in their selection, the fact that only eight case studies were performed indicates that no strong claim can be made with regard to model validation based on the analysis of case studies in itself. However, for the purpose of this research, in which the case study findings can be considered a confirmative iteration of the earlier performed survey research which yielded very limited new insight compared to the initial list of influencing factors, case study analysis findings offer a valid confirmation of earlier research findings.
Other insights into organizational early warning signal detection

Although primarily intended for the purpose of model validation, case study analysis also yielded other insights into organizational early warning signal detection which are worth mentioning.

Firstly, in all case studies, multiple early warning signals were present prior to the respective adverse event. (Non-) detection of these signals could in most cases be attributed to a combination of influencing factors from all major factor categories (Human factors, Internal environment, External environment, Exogenous). In other words, the interaction of human factors, organizational aspects, and the organization’s external environment influenced early warning signal detection in these case studies.

Whereas any one particular category hence does not appear to have a dominant effect on organizational early warning signal detection in general, this suggests that influencing factors from all categories should be taken into account when trying to learn how signal detection might be improved, instead of solely focusing on e.g. human factors.

Secondly, analysis of the case studies showed that commonalities between early warning signals identified in the eight cases exist. One example of such a common signal is the availability of lessons learned from the past, either locally (within the organization) or on an industry level. Also, for most cases, similar accidents to the one described in the case material occurred, to a lesser degree, either within the own organization or in comparable organizations.

Another example of a common signal is non-compliance with (safety) procedures, which results e.g. in poor maintenance. The case studies at the same time showed that although commonalities between signals exist, factors influencing the detection of these signals will not necessarily be the same for each case. Although not the main purpose of the analysis of case studies, this finding suggests that categorization of early warning signals might be feasible and further research effort to explore other commonalities might be worthwhile.

5.6 Discussion on the proposed approach to factor identification

As was explained in chapter 3, insight into underlying factors of organizational early warning signal detection in the main factor categories Human factors, Internal environment, and External environment is needed, as part of the effort to try to improve (industrial) organizations’ ability to detect early warning signals. For that purpose, a general approach to factor identification was proposed at the beginning of chapter 4, the application of which was discussed in chapters 4 and 5. Section 5.6.1 discusses the effectiveness of the proposed approach in factor identification. Next, industry and/or organization specific application of insight gained into influencing factors for the purpose of signal detection improvement is elaborated upon in section 5.6.2, after which a main conclusion is given in section 5.6.3.

5.6.1 Effectiveness of the proposed approach

Based on its application, it is concluded that the proposed approach was effective with regard to its intended goal, i.e. identification of underlying factors that affect early warning signal detection by industrial organizations. Moreover, the overview of factors in table 5.9 can be considered a valid list of influencing factors of organizational early warning signal detection.
Firstly, application of the approach required that factor identification was based on insights non-specific to any one particular organization, and that sources of information across industries were utilized. Through the utilization of literature on crisis management and resilience engineering, consultation of risk management experts assembled in an expertise network transcending industries, and analysis of major industrial accidents from various industries, this criterion was met. Because of the use of multiple sources of evidence for factor identification, converging lines of inquiry were developed (Yin, 1994), adding to the validity of the research findings.

In particular, consultation of risk management experts in an expertise network was found to be a rich source of information for factor identification. Most importantly, because experts in these networks share their practical experience with managing risk with fellow experts and at the same time learn from others’ insights, expertise networks present a platform for consolidating knowledge of risk management across industries. As a result, experts in such networks are expected to have insight into managing risk beyond the particular organization or even industry in which they are active.

Secondly, characteristic for the proposed approach is the employment of a structured two step process for factor identification, in which first an initial model of influencing factors is constructed, which is later validated. In both of these steps, multiple research methods are to be utilized, concurrently for model development and iteratively for model validation. Application of the approach in this thesis has shown the added value of such a structured process, including the utilization of multiple research methods in each step of the process, to arrive at a validated list of influencing factors.

For one thing, research methods employed for model development (i.e. a literature study and focus group) yielded comparable results, but differences in factors identified nevertheless existed. Consequently, it can be concluded that neither of these methods in itself would have resulted in a valid list of influencing factors, and that further model validation is in order.

Given the iterative nature of the model validation step of the approach, it is furthermore ensured that (iterative) validation continues until very little or no new insights into influencing factors are gained. As a result, a strong claim can be made with regard to the validity of the obtained overview of influencing factors by application of the approach, since it reasonable to assume that subsequent research (i.e. research performed after the last iteration) will not result in any major modifications. Since analysis of case studies performed in this thesis as part of model validation did not yield any new insight into the overview of influencing factors identified earlier, the overview of factors in table 5.9 is therefore considered valid.

Validity of the influencing factors identified nevertheless strongly depends on the particular research methods employed for model development and model validation. For the research methods employed in this thesis, validity of the method and consequently, validity of the related findings, was assessed as part of the discussion on the results of each applied method. These assessments overall showed an acceptable level of validity of the research methods employed, but also raised some concerns (such as having to rely on a single focus group meeting for model development instead of multiple focus group meetings, rendering the option to ascertain whether additional meetings would have led to new insights impracticable). This confirms the conclusion drawn earlier, i.e. that none of the methods in itself would have resulted in a valid list of factors. As such, the fact that these research
methods were employed as part of a structured framework for factor identification, built on the principles of data triangulation and methodological triangulation, ensured that a valid list of influencing factors could be obtained despite the inherent shortcomings in the application of each method separately.

5.6.2 Industry and/or organization specific application

As was explained in section 5.5.2, the list of influencing factors obtained by means of the proposed factor identification approach can only be considered valid for its intended purpose, i.e. to give an overview of the various ways in which early warning signal detection is affected in industrial organizations in general. Furthermore, the overview is dynamic, since organizations and their environment change over time.

Consequently, before members of any organization can start to think about how to purposely target influencing factors in order to try to improve the organization’s ability to detect early warning signals, the extent to which factors found are applicable to the organization (and/or industry) in question should be ascertained. Whereas chapter 6 focuses on the ‘how’ of utilizing insight into organizational early warning signal detection gained, this subsection addresses the precondition of industry and/or organization specificity. Although there are various ways in which this precondition might be met, this thesis explores one particularly practical means of doing so as provided by a diagnostic evaluation tool for accident prevention already briefly discussed in section 2.3.3 called Tripod-Delta.

Tripod-Delta

Tripod-Delta is a proactive approach to enhance safety complementary with an organization’s existing safety management systems, designed to help identify indications of potential causes of future accidents (i.e. latent failures) within an organization before these latent failures generate active failures (Hudson et al., 1994). Instead of targeting the unsafe acts or local triggering conditions directly related to accident occurrence, Tripod-Delta addresses the mainly organizational and human factors behind them for safety improvement, in terms of General Failure Types (GFTs). Tripod-Delta distinguishes between eleven GFTs, which were identified in field studies and from analyses of major accidents (Hudson et al., 1994). Table 5.10 provides definitions for some of these GFTs, taken from Akerboom & Maes (2006).

<table>
<thead>
<tr>
<th>General Failure Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Ergonomic design of workplace and equipment</td>
</tr>
<tr>
<td>Hardware</td>
<td>Quality, condition, suitability or availability of materials</td>
</tr>
<tr>
<td>Procedures</td>
<td>Usefulness and availability of procedures and instructions</td>
</tr>
<tr>
<td>Communication</td>
<td>Quality and effectiveness of communications between individuals, groups, or departments of a company</td>
</tr>
<tr>
<td>Training</td>
<td>Quality of job related training and competence or experience among employees</td>
</tr>
<tr>
<td>Incompatible goals</td>
<td>Way safety is managed against a variety of other goals</td>
</tr>
<tr>
<td>Organization</td>
<td>Effectiveness of the organization’s structure and processes, and management strategies</td>
</tr>
</tbody>
</table>
Similarities between the GFTs indicated in table 5.10 and the influencing factors of organizational early warning signal detection as identified in this thesis are apparent. Both GFTs and influencing factors are defined in general terms, and suggest directions in which (safety) risk might be managed more effectively in a proactive manner. Moreover, given the same focus on mainly organizational and human factors of influence, a shared perspective is observed. On the level of individual factors, GFTs such as Procedures, Communication and Training can be directly linked to influencing factors identified, although differences in definition exist.

For example, whereas the influencing factor Communication relates to the degree to which the exchange of information is formally organized, the GFT Communication takes into account other aspects of communication as well, such as the informal exchange of information at various levels (individuals, groups, departments) within an organization. In contrast, the latter is captured under the influencing factor Internal Stakeholder Engagement in this thesis. Based on their definitions, some of the other GFTs furthermore can be linked to influencing factors of organizational early warning signal detection as well, e.g. the GFT Incompatible Goals versus the influencing factor Management Commitment.

Given this degree of overlap, the process by which GFTs are employed for safety assessment of an organization or organizational unit as part of the effort to proactively enhance safety can provide valuable insights on how influencing factors might be utilized for the potential improvement of a specific organization’s or organization unit’s ability to detect early warning signals. Since such a safety assessment is essentially derived from checklists based upon specific indicators of the presence and degree of each GFT (Reason, 1997), two main elements of this process involve identification of indicator items and checklist construction, which are discussed next.

**Identification of indicator items and checklist construction**

In its assessment of safety, Tripod-Delta intends to provide information about where problems might be found in an organization or organizational unit, and their relative importance, framed in terms of the different GFTs (Hudson et al., 1994). For that purpose, instead of measuring GFTs directly, indicator items firstly are established for each of the GFTs. These indicator items are tangible and relatively small items (in terms of being sufficiently trivial to be below the threshold of immediate action) agreed to be relevant, both for the specific activities of an organizational unit or organization, and for (one of) the eleven GFTs (Hudson et al., 1994). As such, indicator items are merely symptoms of the potentially underlying reasons of concern. Examples of indicator items for the GFTs Communication and Training are given in table 5.11, derived from Akerboom & Maes (2006).

Indicator items are usually created in a small group of specialists, known as a syndicate, led by a (trained) syndicate leader (Hudson et al., 1994). This syndicate consists of people that have experience with and are involved in the day-to-day management and operation of the particular organization or organizational unit’s activities, and might include e.g. front-line supervisors, operators, etc. As such, it is ensured that indicators specific and relevant to the organization in question are identified. Moreover, by directly involving members of the organization in the process, the instrument for assessment is built and owned by the organization itself, ensuring that information provided in the assessment is perceived as relevant by employees and management (Reason, 1997).
Table 5.11: Examples of indicator items for GFTs Training and Communication (taken from Akerboom & Maes (2006))

<table>
<thead>
<tr>
<th>General Failure Type</th>
<th>Related indicator items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td></td>
</tr>
<tr>
<td>Accessibility personnel department</td>
<td></td>
</tr>
<tr>
<td>Receiving information too late or not at all</td>
<td></td>
</tr>
<tr>
<td>Information relevant for work provided in a timely way</td>
<td></td>
</tr>
<tr>
<td>Receiving incomplete and/or incorrect information</td>
<td></td>
</tr>
<tr>
<td>Getting an answer to a request too late or not at all</td>
<td></td>
</tr>
<tr>
<td>Problems in getting hold of information</td>
<td></td>
</tr>
<tr>
<td>Failure to write down rules/procedures/agreements</td>
<td></td>
</tr>
<tr>
<td>Management does not keep agreements</td>
<td></td>
</tr>
<tr>
<td>Receiving permission too late or not at all</td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
</tr>
<tr>
<td>Encouraging continued training</td>
<td></td>
</tr>
<tr>
<td>Access to continued training and education</td>
<td></td>
</tr>
<tr>
<td>Training opportunities to increase career opportunities</td>
<td></td>
</tr>
<tr>
<td>Relevance of attended courses/training for daily work</td>
<td></td>
</tr>
<tr>
<td>Evaluating quality of attended courses/training</td>
<td></td>
</tr>
<tr>
<td>Organization keeps employees informed about work-related developments</td>
<td></td>
</tr>
<tr>
<td>Training aimed at specific problems in the care sector</td>
<td></td>
</tr>
<tr>
<td>Receiving information on work-relevant courses</td>
<td></td>
</tr>
</tbody>
</table>

The main goal of the syndicate is to generate a list of indicator items for each of the eleven GFTs, which together form a local database of indicator items for the organization or organizational unit under consideration. Typically, such a database consists of about 150 to 200 items per GFT. To support the generation of indicator items by syndicate specialists, generic Tripod-Delta databases of indicator items can serve to either prime the process, or as a (major) source of items for the syndicate (Hudson et al., 1994). These generic databases are constructed through earlier research and application of the approach in a variety of industries and organizations. Practices extend from the initial fields of onshore and offshore construction, and marine operations, to the use of Tripod-Delta in e.g. refineries and chemical plants, as well as in non-industrial organizations.

After a local database of indicator items has been established, the next step in the assessment process is to construct checklists which will act as the measuring instrument, by sampling a number of indicator items (usually 20 to 25) from each of the eleven GFTs. This results in a 200+ item checklist, to be completed by members of the organization or organizational unit in question. Members complete the checklist by providing a simple yes/no response to each of the indicator items (Reason, 1997). For example, for the indicator item ‘Encouraging continued training’ mentioned in table 5.11, a ‘yes’ response indicates that the person completing the checklist believes continued training is encouraged in their organization or organizational unit, whereas a ‘no’ response would suggest the opposite.

Once completed, Tripod-Delta software (which is also used to automatically construct the checklist) analyzes the response data to generate a bar chart known as a Failure State Profile, showing the relative cause of concern for each of the GFTs (Reason, 1997). In this way, those GFTs most in need of immediate action are identified. This information can then act as input to define remedial actions, in the form of specific tasks and targets to be achieved.

The resulting ‘safety check’ performed by means of the Tripod-Delta approach might be repeated after these remedial actions are taken to assess the level of safety improvement, with newly sampled checklists and if needed, with revalidated indicators items as input.
Meeting the precondition of industry and/or organization specificity

The discussion above on how safety assessments are performed in Tripod-Delta has shown that the approach takes into account the specific nature of the organization or organizational unit under investigation. It does so by establishing indicator items for each General Failure Type, both relevant and specific for the particular organization in question. This is ensured by relying on a syndicate of specialists for indicator item identification, which consists of people that have experience with and are involved in the day-to-day management and operation of the organization or organizational unit’s activities. These indicator items form the basis of the assessment’s main measuring instrument, i.e. a checklist combining indicator items for all GFTs.

Given the similarities between GFTs and influencing factors of organizational early warning signal detection as was explained earlier, identification of indicator items for each of the influencing factors indicated in table 5.9 by a syndicate of specialists therefore might provide a practical means to ascertain the extent to which factors found are specific to any one particular organizational unit, organization, or even industry. Moreover, this approach allows corrective action to be taken if needed, in terms of ensuring factors both relevant for and specific to the given context are taken into account.

For example, a syndicate might find it difficult to identify indicators for one of the 22 influencing factors given in table 5.9. Although this might suggest that this is simply a rather complex factor to capture in terms of more tangible and relatively small items, it may also be an indication that the particular influencing factor is perceived as being less applicable to the industrial or organizational context considered. On the other hand, the opposite might occur as well, in the sense that a syndicate might generate indicator items which they consider to be relevant for the specific organization or industry, which cannot be captured under any of the influencing factors in the current list. Given the dynamic nature of the obtained overview of influencing factors shown in table 5.9 (due to the fact that both organizations and their environment change over time, as was explained in section 5.5.2), such a situation is certainly possible. In this case, indicator items identified might already suggest which influencing factor(s) to add. Also, reappraisal of (part of) the factor identification approach described in the previous chapters with the current overview of factors as input might be appropriate. If executed, syndicate specialists should act as a major source of information for factor identification and validation, if needed complemented with other specialists.

Although Tripod-Delta is mostly executed to perform safety assessments for organizational units or organizations as a whole, it is important to emphasize that the approach also appears to be applicable at an industrial level. This can be accomplished by selecting a syndicate of specialists capable of generating indicator items both relevant and specific for the industry in question, and for the influencing factors. Either industry specific expertise networks or networks that transcend industries, like the one utilized as part of the factor identification process described in the previous chapters, might prove of value to establish such a syndicate.

Lastly, to assist syndicate specialists in the generation of indicator items in practice, Tripod-Delta provides a detailed account of which activities to perform and how, which can act as an excellent point of reference (for additional information, the reader is referred to the paper by Hudson et al. (1994)). In further support of the generation process, it is also suggested to investigate the potential use of (generic) Tripod-Delta databases constructed through earlier assessments in similar industries or organizations to either prime the process, or act as a major source of items for the syndicate.
Once the generation process has finished, indicator items identified can set the stage for utilizing influencing factors as part of a diagnostic tool to enhance organizations’ ability to detect early warning signals. This topic is discussed in further detail in the next chapter, section 6.3.1.

5.6.3 Main conclusion

To summarize, application of the factor identification approach has shown its effectiveness in identifying factors, and its ability to arrive at a valid list of influencing factors of organizational early warning signal detection. The main contribution of the approach lies in the provision of a structured framework which enables the utilization and integration of a variety of research methods (which are not limited to a single source of evidence) to arrive at a validated list of factors. In this way, not the approach itself, but the application of the approach is specific to the particular context, given the type of data available for factor identification and consequently, the type of research methods that might be employed in the approach. Given this flexibility, the approach consequently appears to be adaptable to the particular circumstances (e.g. data availability and data access) under which research into influencing factors is performed, and might be utilized beyond the context of this thesis.

With regard to the validity of the overview of factors obtained, it is important to realize that this will strongly depend on the validity of the particular research methods employed, as well as the richness of the information available for the purpose of factor identification. Consultation of experts assembled in an expertise network transcending industries was found to be one such potential rich source of information.

Furthermore, the overview obtained can only be considered valid for its intended purpose, i.e. to give an overview of the various ways in which early warning signal detection is affected in industrial organizations in general. On the level of any one particular industry or organization however, the overview might be non-valid. Also, it should be realized that the list of factors identified is dynamic, since organizations and their environment change over time. Consequently, prior to utilizing insight into influencing factors to potentially improve signal detection in practice, the precondition of industry and/or organization applicability should be met. One means to do so is provided by the Tripod-Delta approach, in the way it employs General Failure Types for safety assessment of an organization (or organizational unit) as part of the effort to proactively enhance safety. More specifically, this is accomplished by establishing both relevant and specific indicator items for each General Failure Type by a syndicate of specialists (i.e. people experienced with and involved in the management and operation of the organization’s activities). A similar approach appears to be applicable in the context of organizational early warning signal detection as well, by generating indicator items for influencing factors in a syndicate, consisting of specialists on an industry level, or on the level of a particular organization or organizational unit (depending on the given context).

5.7 Summary and conclusions

As part of the effort to demonstrate the effectiveness of the approach to factor identification proposed in chapter 4, and to try to obtain an overview of influencing factors of organizational early warning signal detection, this chapter discussed application of the second step of the approach, i.e. model validation. The main purpose of this step is to further validate the initial list of factors obtained in the model development step, presented at the end of chapter 4.
Consultation of experts was employed first for the purpose of model validation. An internet based survey was spread among risk management experts assembled in an expertise network transcending industries. Based on survey findings, some modifications were made to the initial list of influencing factors. The factor Personal Characteristics was split in two, which led to the addition of the factor Personal Circumstances to the Human factors category. Also, the factor Compliance was moved from the Internal environment subcategory Structure to the subcategory Culture.

Since the survey yielded some modifications (albeit minor) to the initial list of influencing factors, it was decided to perform another iteration as part of the mixed methods approach to model validation. For that purpose, case studies, mainly concerning major industrial accidents, from various industries were jointly analyzed by two researchers. Analysis of these case studies did not result in the identification of factors outside the post-survey list of influencing factors. Consequently, it was decided to accept the post-survey model as a validated list of influencing factors of organizational early warning signal detection.

Based on its overall application, it was concluded that the proposed approach is effective with regard to its intended purpose, i.e. factor identification, and is able to arrive at a valid list of influencing factors. Amongst other things, this is realized by offering a structured two-step framework to factor identification built on the principles of data triangulation and methodological triangulation, and by the iterative nature of the model validation step.

Nevertheless, the approach’s success in factor identification will largely depend on the particular data sources and research methods employed for model development and model validation, which are not prescribed by the approach. Care should thus be taken to ensure both acceptable validity of the methods utilized and availability of rich sources of information when applying the approach. Consultation of experts assembled in an expertise network transcending industries was found to be one such potential rich source of information.

How insight into influencing factors, such as gained by application of the proposed approach, might potentially contribute to the improvement of an organization’s ability to detect early warning signals, is the topic of interest of the next chapter. Prior to utilizing this insight in practice however, the precondition of industry and/or organization specificity should be met. One particular means of doing so was presented in this chapter, i.e. the identification of indicator items for each influencing factor by a syndicate of specialists from the industry and/or organization under consideration.
6 Utilization of insight into influencing factors

This chapter examines the way in which insight gained into influencing factors of organizational early warning signal detection might be used to potentially improve (industrial) organizations’ ability to detect early warning signals. Firstly, utilization of exploratory insight into influencing factors, gained by application of the proposed approach to factor identification, is discussed. Next, this chapter explores how insights gained from descriptive research into influencing factors (i.e. research into factor characteristics) might be utilized. More specifically, research findings on factor relevance, obtained by means of an internet based survey, are presented. Lastly, more practical means of utilizing insight into factors and their relevance are explored, amongst other things in the form of a diagnostic evaluation tool for organizational early warning signal detection.

6.1 Towards improving organizational early warning signal detection

As was explained in section 2.6, the research described in this thesis can be classified as applied research. Contrary to basic research, the purpose of applied research is to gain knowledge of a particular problem at hand, with the intent to use this knowledge to contribute to the solution of that problem (Bickman & Rog, 1998). In light of the topic of interest of this thesis, i.e. proactive risk management and more specifically, organizational early warning signal detection, research should thus not be limited to gaining knowledge of how organizations detect such signals, but should also indicate how this knowledge can contribute to signal detection improvement. The fact that this concerns a contribution to a topical problem at hand is apparent from the need for, and difficulty in, managing risk proactively in today’s society, as put forward in chapter 1.

As a starting point to indicating how insight into influencing factors of organizational early warning signal detection can contribute to signal detection improvement, section 6.1.1 addresses the question how exploratory insight gained by application of the proposed approach to factor identification might be utilized. For one thing, as will be explained in this subsection, a validated list of influencing factors can act as input to further research into these influencing factors. This is discussed in more detail in section 6.1.2.

6.1.1 Utilization of exploratory insight into influencing factors

Next to establishing the four factor categories as discussed in chapter 3, exploratory insight into influencing factors was mainly gained by application of the proposed approach to factor identification, resulting in a validated list of influencing factors presented at the end of the previous chapter. In total, 22 influencing factors were identified in 3 main categories (Human factors, Internal environment, External environment). Also, the existence of influencing factors originating from an organization’s external environment was confirmed, which were captured in the fourth factor category Exogenous.

In various respects, this exploratory insight contributes to signal detection improvement:

- *Raises awareness about the extent to which an organization can exert influence on signal detection.* Exploratory insight into influencing factors, by means of a validated list of influencing factors, explicitly indicates the various ways in which signal detection might be affected.
At a basic level, such an explicit overview of factors helps to demonstrate that indeed organizational early warning signal detection can be (positively) affected, and does this much more convincingly than simply stating the fact. Moreover, as is apparent from the overview of influencing factors presented at the end of chapter 5, to a large extent these factors are within an organization’s range of control. Hence, exploratory insight into influencing factors helps raise awareness about the extent to which an organization can exert influence on signal detection as regarded in this thesis, i.e. detection of early warning signals by people within an organization. With respect to improving signal detection, this awareness is valuable as it helps both organizations and regulators realize that responsibility for successful organizational early warning signal detection at least partly lies with the organization(s) in question.

- **Indicates that non-detection can not necessarily be attributed to human failure.** Although organizational early warning signal detection as regarded in this thesis concerns detection of signals by people within an organization, exploratory insight into influencing factors indicates that poor signal detection can not necessarily be attributed to human failure in detection. Rather, as was found in the analysis of the case studies discussed in the previous chapter, non-detection of signals in most cases can be attributed to a combination of influencing factors from all main factor categories (Human factors, Internal environment, External environment, Exogenous). Hence, in order to improve organizational early warning signal detection, influencing factors from all categories should be taken into account, instead of focusing on one particular category (e.g. Human factors).

- **Acts as input to further research into influencing factors.** Although the previous arguments show that a validated list of influencing factors in itself can be considered valuable, and at a basic level contributes to signal detection improvement (e.g. by creating awareness), exploratory insight into influencing factors insufficiently indicates how signal detection improvement in practice might be realized. However, such exploratory insight can act as input to further research into influencing factors, in which additional insight into influencing factors is obtained for the purpose of signal detection improvement.

To illustrate this, consider a major industrial accident, in which early warning signals prior to the accident were not detected. When analyzing such an accident, a validated list of influencing factors can act as a checklist to assess which factor(s) contributed to non-detection of these signals. However, in order to determine which action(s) should be taken to improve signal detection in the future, additional information is required, such as which factor(s) to address with priority and how to do so. Since the information to be obtained relates to factors already identified, the point of departure for this process of inquiry is the validated list of influencing factors.

The extent to which further research into influencing factors, building on exploratory insights gained, can contribute to the improvement of organizational early warning signal detection is the topic of interest of the remainder of this chapter. Firstly however, the next subsection discusses the type of research to be performed.
6.1.2 Further research into influencing factors

Henry (1998) classifies research as exploratory, descriptive or analytic, depending on the nature of the research. This classification is in line with the three main purposes of research put forward by Babbie (2007), i.e. exploration, description, and explanation. Exploratory research is generally conducted to provide an orientation or familiarization with the topic of interest, such as to learn which variables are of importance for the study. Whereas the identification of influencing factors is performed to learn which factors are of importance for organizational early warning signal detection, factor identification can be considered exploratory research, as was explained in section 2.6. Often, this type of research acts as a preliminary activity to more rigorous descriptive or analytic research (Henry, 1998). Building on the exploratory insight into influencing factors, descriptive research into influencing factors aims to describe factor characteristics or attributes. On the other hand, analytic research into influencing factors examines relationships between influencing factors, such as factor dependencies. In order to learn how organizational early warning signal detection might be improved beyond the basic contribution of exploratory insight into influencing factors (e.g. by raising awareness), descriptive and analytic insight into influencing factors is thus valuable.

From an organization’s perspective, the main usage of such additional insight is to learn how signal detection might be influenced, or more specifically, which measures could best be taken to move towards the desired situation (i.e. signal detection improvement in this thesis). As a starting point, this requires information on which factors to address with priority, since in most cases multiple factors simultaneously will affect signal detection. In these cases, prioritization of influencing factors can help to determine how an organization’s usually limited resources are best to be allocated in order to try to improve signal detection. This applies both to organizations that want to take appropriate measures to improve their proactive management of risk in the aftermath of a major accident, and to organizations that wish to prevent such an accident from occurring by investing upfront in proactive risk management. Prioritization of influencing factors may serve other purposes as well. For example, it can help focus future research efforts to those factors with the highest priority for improving organizational early warning signal detection.

This chapter firstly investigates one particular means of prioritization of influencing factors, i.e. prioritization according to the degree of influence of a factor on signal detection, referred to as factor relevance. For one thing, prioritization according to factor relevance can help an organization to allocate their resources to those factors which are expected to have the greatest potential for signal detection improvement. Research findings on factor relevance are presented in section 6.2. Given the focus on factor relevance, the additional insight gained into influencing factors in this chapter is thus descriptive in nature. While acknowledging the importance of analytic insight for the purpose of improving signal detection (as mentioned in section 5.5.2), for practical reasons this thesis does not further explore such insights.

Next, the way in which prioritization of influencing factors can contribute to the improvement of signal detection, as well as other practical means of utilizing insight into influencing factors and their relevance for the same purpose, are explored in sections 6.3 and 6.4. Lastly, the summary and conclusions of this chapter are presented in section 6.5.
6.2 Factor relevance

To learn how influencing factors might be prioritized, research into factor relevance was performed. First and foremost, the goal of the research into factor relevance was to determine whether indeed differences in relevance exist. Intuitively, one would expect some factors to be more relevant than other factors with regard to organizational early warning signal detection, but this hypothesis needs to be tested. If the question whether differences in factor relevance exist can be positively answered, it should then be investigated which factors dominantly affect signal detection, since these factors are expected to have the greatest potential for signal detection improvement.

Section 6.2.1 describes how data about factor relevance was obtained, i.e. by means of an internet based survey. Next, hypotheses about factor relevance to be tested are presented in section 6.2.2, which includes amongst others the hypothesis that all influencing factors are equally relevant with respect to organizational early warning signal detection. Section 6.2.3 presents the survey results on factor relevance, together with the outcome of the hypotheses testing. A discussion of the overall research findings is included in section 6.2.4. Lastly, limitations of the conducted research on factor relevance are discussed in section 6.2.5.

6.2.1 Approach to data collection

For factor identification, three potential sources of evidence were used, namely literature, experts and case studies. Not all of these sources are equally useful for determining factor relevance though. Firstly, to the best of the author’s knowledge, relevance of influencing factors of organizational early warning signal detection is currently not addressed in literature. This claim is supported by the observation that a (comprehensive) overview of influencing factors is not provided in literature (as was discussed in chapter 2), since research into factor relevance would require such an overview as input.

Secondly, documentation on major industrial accidents in general does not have the degree of information richness required to determine factor relevance. As is shown in table 5.8 in chapter 5, it is possible to determine which factors contributed to non-detection in these cases and consequently, factor frequencies across case studies can be calculated. However, it cannot automatically be assumed that a factor that is frequently found across case studies will have a higher degree of influence on detection compared to factors that are less frequently found. In other words, factor frequency does not equal factor relevance.

Expert consultation on the other hand can be employed to investigate factor relevance. Based on their experience with managing risk in practice, risk management experts assembled in expertise networks transcending industries are able to indicate which factors, if any, they consider to be most relevant with respect to organizational early warning signal detection. Obviously, an assessment of factor relevance by experts will yield subjective results, so amongst other things, care should be taken to ensure a representative sample of experts. It is important to stress that the need to ensure a representative sample is not unique to expert consultation though, as the same criterion applies to the selection of case studies, had this been an appropriate source of evidence for research into factor relevance.
In order to obtain experts’ opinion on factor relevance, part of the internet based survey presented in chapter 5 was dedicated to factor relevance (i.e. part 2 of the survey). In section 5.2, both the rationale for performing a survey as a means of expert consultation, and survey design (e.g. selection of the sample for the survey) were explained in detail. Therefore, discussion on the survey’s design and setup in this subsection is limited to a discussion on part 2 of the survey; the reader is referred to section 5.2 for additional information on the design and setup of the complete survey.

**Part 2 of the survey: factor relevance**

The main goal of the survey was to validate the initial list of influencing factors obtained by application of the model development step of the proposed approach to factor identification; see chapter 4. For that purpose, respondents were both asked to give their opinion on the relevance of the earlier identified factors (in part 2 of the survey), and to indicate whether in their opinion any factors were missing in the presented overview (in part 3 of the survey). For an impression of the survey, see appendix 5.1 in which screenshots of the survey are presented.

In part 2 of the survey, for each influencing factor, respondents were asked to indicate whether or not they considered the particular factor as an influencing factor of proactive risk management\(^2\) or in other words, whether or not they considered the factor as being relevant for proactive risk management. If positively answered, respondents were then asked to indicate the perceived degree of relevance.

To illustrate the way in which respondents’ opinion on factor relevance was obtained, figure 6.1 gives an example of some completed survey questions on factor relevance. As is apparent from this figure, data on the degree of perceived relevance was collected in a two-phase process.

Firstly, respondents were presented with an overview of influencing factors and the accompanying factor descriptions (as described in table 4.4 in chapter 4), divided per major factor category (Human factors, Internal environment with its four subcategories, and External environment). For each of these influencing factors, respondents were first asked to answer the following question:

1. “Is the factor mentioned below relevant with respect to proactive risk management?"

Three response options to this question were available, namely ‘Yes’ (indicating that the respondent believes that the factor is relevant for signal detection), ‘No’ (indicating that the respondent does not believe that the factor is relevant), and ‘No opinion / Don’t know’ (in case the respondent is unable to answer the question with a yes or no answer).

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\(^2\) As was already explained in section 5.2.3, the term ‘proactive risk management’ was used in the survey instead of ‘organizational early warning signal detection’. For more information on the rationale behind this decision, the related potential drawback, and the measures taken to try to overcome this drawback, the reader is referred to this section.
Only when a respondent marked ‘Yes’ in response to the question above (as is the case for the influencing factor Education in the example presented in figure 6.1), a second question would appear, namely:

2. “To what extent is this factor relevant?”

To allow people to indicate the perceived degree of factor relevance, a Likert scale was presented, ranging from 1 (indicating a low degree of relevance) to 5 (indicating a high degree of relevance). This measurement scale was taken from Roth et al. (2008).

This two-phase process was repeated for each of the influencing factors in the initial list of factors that acted as input to the survey, resulting in 1) an overview of those factors a respondent considers relevant, and 2) insight into the perceived degree of relevance for those factors marked as being relevant. Whereas the former results are valuable for factor validation, as was discussed in chapter 5, the latter results are useful for investigating factor relevance. Most importantly, these results are used to test various hypotheses with regard to organizational early warning signal detection, which are discussed next.
6.2.2 Hypotheses with regard to factor relevance

In the introduction of this section, it was argued that insight into factor relevance is particularly valuable with respect to the potential improvement of signal detection, since such information can act as a means to set priorities among the factors of interest. However, the underlying assumption here is that differences in factor relevance exist. To ascertain whether this is a valid assumption, the main hypothesis to be tested based on the factor relevance findings obtained in the survey is:

Hypothesis H₁: All influencing factors are equally relevant with respect to organizational early warning signal detection.

It should be noted that for testing purposes, hypothesis H₁ is reversely phrased to what one would intuitively expect, namely that some factors are more relevant than other factors for organizational early warning signal detection. In this way, rejection of hypothesis H₁ will indicate non equality of factor relevance.

If hypothesis H₁ can be rejected, further research into how influencing factors might be prioritized should be performed. Firstly, on the level of factor categories, it is interesting to learn whether certain categories of factors (e.g. Human factors) will have a stronger degree of influence on organizational early warning signal detection than other categories. In other words, the extent to which prioritization based on factor category is possible should be investigated. Secondly, on the level of individual factors, research into which particular factors are deemed most relevant can be performed, e.g. by ranking factors based on their relevance scores. Results on factor ranking in this case should be carefully considered though, as factor relevance scores could only obtained for factors in the initial list of influencing factors, and not for the validated list of factors presented at the end of chapter 5.

As was explained in section 5.2.1, the survey was spread among a largely homogeneous group of potential respondents, namely people that are actively involved in managing risk as part of their position within an organization (and as such are assumed to have the level of expertise required for the survey). Viewpoints of experts from various industries (transport, energy, infrastructure, chemical industry, (semi) government) were sought though, motivated by this thesis’ objective (i.e. to gain insight into and potentially improve early warning signal detection within industrial organizations in general). In addition, to allow for further variation among respondents and further generalization of the outcomes, survey participation was not limited to risk managers. Instead, participation was open to anyone actively involved in managing risk as part of their position within an organization, either on a strategic, tactical, or operational level.

To investigate whether these sources of variation (industry, organizational level) might cause respondents to rate factor relevance differently, resulting e.g. in different factor rankings per industry or level, the following hypotheses are to be tested as well:

Hypothesis H₂: Respondents from different industries have the same opinion on the relevance of the influencing factors.

Hypothesis H₃: Respondents from different organizational levels have the same opinion on the relevance of the influencing factors.
6.2.3 Survey results on factor relevance

In total, 37 completed surveys were received, which is above the minimum absolute sample size set for the survey (i.e. 25, see section 5.2.1). For these responses, both time spent on completing the survey and associated IP addresses were logged, as was explained in section 5.2.2. Based on the logging results, it was decided to exclude three responses for further analysis, since these concerned responses that either took less than five minutes to complete (average time spent on completing the survey: 13 minutes), or concerned multiple entries from the same IP address. Consequently, 34 responses remained for analysis, for which respondent characteristics are shown in table 6.1. This table indicates that people from various industries participated in the survey, and that most people were active in civil engineering (32.3%).

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of respondents</td>
<td>34</td>
</tr>
<tr>
<td>Demographics: Industry</td>
<td>Transport: 8.8%</td>
</tr>
<tr>
<td></td>
<td>Infrastructure: 8.8%</td>
</tr>
<tr>
<td></td>
<td>(Semi) government: 8.8%</td>
</tr>
<tr>
<td></td>
<td>Energy: 5.9%</td>
</tr>
<tr>
<td></td>
<td>Chemical industry: 11.8%</td>
</tr>
<tr>
<td></td>
<td>Civil engineering: 32.3%</td>
</tr>
<tr>
<td></td>
<td>Other (Food, ICT, Defense,…): 23.5%</td>
</tr>
<tr>
<td>Demographics: Organizational Level</td>
<td>Strategic: 29.4%</td>
</tr>
<tr>
<td></td>
<td>Tactical: 44.1%</td>
</tr>
<tr>
<td></td>
<td>Operational: 26.5%</td>
</tr>
</tbody>
</table>

Table 6.2: Descriptive statistics for factor relevance

<table>
<thead>
<tr>
<th>Influencing factor</th>
<th>Median (1=low relevance, 5=high relevance)</th>
<th>Mode</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>4.0</td>
<td>4.0</td>
<td>2-5</td>
<td>32</td>
</tr>
<tr>
<td>Experience</td>
<td>4.0</td>
<td>5.0</td>
<td>2-5</td>
<td>33</td>
</tr>
<tr>
<td>Cognitive Bias</td>
<td>4.0</td>
<td>4.0</td>
<td>3-5</td>
<td>33</td>
</tr>
<tr>
<td>Personal Characteristics</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>33</td>
</tr>
<tr>
<td>System Architecture</td>
<td>4.0</td>
<td>4.0</td>
<td>2-5</td>
<td>33</td>
</tr>
<tr>
<td>System User Interaction</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>31</td>
</tr>
<tr>
<td>Procedures</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>34</td>
</tr>
<tr>
<td>Compliance</td>
<td>4.0</td>
<td>4.0</td>
<td>2-5</td>
<td>34</td>
</tr>
<tr>
<td>Communication</td>
<td>5.0</td>
<td>5.0</td>
<td>2-5</td>
<td>33</td>
</tr>
<tr>
<td>Responsibility &amp; Authority</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>33</td>
</tr>
<tr>
<td>Training</td>
<td>4.0</td>
<td>4.0</td>
<td>2-5</td>
<td>31</td>
</tr>
<tr>
<td>Internal Stakeholder Engagement</td>
<td>4.0</td>
<td>5.0</td>
<td>1-5</td>
<td>33</td>
</tr>
<tr>
<td>Organizational Risk Attitude</td>
<td>4.0</td>
<td>5.0</td>
<td>2-5</td>
<td>33</td>
</tr>
<tr>
<td>Organizational Learning</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>33</td>
</tr>
<tr>
<td>Leadership</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>31</td>
</tr>
<tr>
<td>Group Behavior</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>32</td>
</tr>
<tr>
<td>Empowerment</td>
<td>4.0</td>
<td>4.0</td>
<td>2-5</td>
<td>30</td>
</tr>
<tr>
<td>Management Commitment</td>
<td>5.0</td>
<td>5.0</td>
<td>2-5</td>
<td>34</td>
</tr>
<tr>
<td>Vision</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>33</td>
</tr>
<tr>
<td>External Stakeholder Engagement</td>
<td>4.0</td>
<td>5.0</td>
<td>1-5</td>
<td>32</td>
</tr>
<tr>
<td>External Communication</td>
<td>4.0</td>
<td>4.0</td>
<td>1-5</td>
<td>32</td>
</tr>
</tbody>
</table>
Furthermore, table 6.1 shows a rather balanced distribution of participants with regard to the organizational level on which they are actively involved in managing risk, with the tactical level being represented the most (44.1%). Table 6.2 on the previous page presents descriptive statistics for factor relevance. Based on these statistics, several observations can be made. Firstly, median scores on factor relevance indicate that all factors on average score on the high end of the relevance scale, with a median score of 4.0 for all factors except for Communication and Management Commitment. Median scores of 5.0 were observed for the latter two factors, indicating high relevance. Secondly, the factors Experience, Internal Stakeholder Engagement, and Organizational Risk Attitude are also worth mentioning separately given their mode scores. Although the median scores of these factors give a typical score of 4.0 corresponding to what was observed for most other factors, the fact that the most frequently observed response for these three factors is 5.0 suggests that relatively more respondents perceived these factors as highly relevant. Thirdly, range statistics show that for most factors, the complete scale from 1 to 5 was used to indicate the perceived degree of relevance, which suggests non-bias towards using only one end of the relevance scale. For distributions of the relevance scores on each influencing factor, see appendix 6.1.

**Hypothesis H1:** All influencing factors are equally relevant with respect to organizational early warning signal detection

To determine whether differences exist in factor relevance between the 21 influencing factors, one-way analysis of variance (ANOVA) can be used for testing, under the assumption of normality and homogeneity of variance. If one of these assumptions is not met however, non-parametric analysis of variance should be used instead.

Shapiro-Wilk tests and Kolmogorov-Smirnov tests were performed to test for normality of the observed distributions on factor relevance, which indicated non-normality (p<0.05) in all cases. Levene’s test on the homogeneity of variance resulted in a significance value of 0.193, indicating that homogeneity of variance could be assumed (p>>0.05).

Since normality could not be assumed, non-parametric analysis of variance was performed to test hypothesis H1. Since the number of influencing factors to be compared exceeds two, Kruskal-Wallis one-way ANOVA was performed. Kruskal-Wallis test results on hypothesis H1 are presented in table 6.3. Results of this test show significant differences in factor relevance between influencing factors (p<0.001). Hence, H1 can be rejected, and it can be concluded that influencing factors are not equally relevant with respect to organizational early warning signal detection.

**Table 6.3: Results on hypothesis H1 testing**

<table>
<thead>
<tr>
<th>Hypothesis H1</th>
<th>Method of testing</th>
<th>Test statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kruskal-Wallis</td>
<td>$\chi^2=56.609$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>df=20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Asymp. Significance= <strong>0.0000235</strong></td>
</tr>
</tbody>
</table>

**Result:** Reject H1
Rejection of $H_1$ is in line with what was intuitively expected, namely that some factors are more relevant than other factors for organizational early warning signal detection. Based on this conclusion, it is subsequently interesting to investigate which factors are deemed most relevant for signal detection. Such insight is considered particularly valuable with respect to the potential improvement of signal detection, as it can act as a means to set priorities among factors. More specifically, prioritization on the level of factor categories and prioritization on the level of individual factors are discussed.

Prioritization on the level of factor categories

It is possible to prioritize factors based on their category, if the assumption is valid that certain categories of factors (e.g. Human factors) will have a stronger degree of influence on organizational early warning signal detection than other categories. Hence, as a starting point to prioritization of factors based on factor category, the validity of this assumption needs to be established. This is done by testing the following hypothesis:

| Hypothesis $H_{1a}$: All factor categories are equally relevant with respect to organizational early warning signal detection. |

To test this hypothesis, firstly a new dataset in PASW® was created, in which factor relevance scores were aggregated per factor category. Similar to the testing of hypothesis $H_1$, either one-way ANOVA or non-parametric analysis of variance can be performed on this dataset to test hypothesis $H_{1a}$, which depends on whether normality and homogeneity of variance can be assumed.

Tests of normality (Shapiro-Wilk and Kolmogorov-Smirnov) were performed, which indicated non-normality ($p<0.05$) for each category. Since normality could not be assumed, it was decided to use non-parametric analysis of variance to test hypothesis $H_1$, without further testing for the homogeneity of variance.

Non-parametric analysis of variance was first performed to compare aggregated factor relevance scores for the three main factor categories (Human factors, Internal environment, External environment). Given the fact that the number of main factor categories exceeds 2, Kruskal-Wallis one-way ANOVA was performed. Secondly, since the factor category Internal environment consists of several subcategories (Technology, Structure, Culture, and Strategy), a second comparison was performed, in which aggregated factor relevance scores for each of these subcategories were used instead. Again, Kruskal-Wallis one-way ANOVA was performed.

Table 6.4 presents the results of both Kruskal-Wallis tests. These results show no significant differences between factor categories with regard to their relevance for signal detection (comparison 1: significance value of 0.368, $p>>0.05$; comparison 2: significance value of 0.287, $p>>0.05$).

Consequently, $H_{1a}$ cannot be rejected, leading to the conclusion that there is no reason to assume that certain factor categories will have a stronger degree of influence on organizational early warning signal detection than other categories. This indicates that prioritization based on the degree of influence on signal detection should not be sought on the level of factor categories, but on the level of individual factors instead.
Table 6.4: Results on hypothesis H1a testing

<table>
<thead>
<tr>
<th>Comparison 1</th>
<th>Method of testing</th>
<th>Test statistics</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kruskal-Wallis</td>
<td>( \chi^2=1.998 )</td>
<td>Do not reject H1a</td>
</tr>
<tr>
<td></td>
<td>df=2</td>
<td>Asymp. Significance= 0.368</td>
<td></td>
</tr>
</tbody>
</table>

** Comparison 2**

<table>
<thead>
<tr>
<th>Method of testing</th>
<th>Test statistics</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kruskal-Wallis</td>
<td>( \chi^2=6.205 )</td>
<td>Do not reject H1a</td>
</tr>
<tr>
<td>df=5</td>
<td>Asymp. Significance= 0.287</td>
<td></td>
</tr>
</tbody>
</table>

* Human factors, Internal environment, External environment

Prioritization on the level of individual factors

Based on the available survey data, factor ranking was performed to determine which factors are deemed most relevant for organizational early warning signal detection. Firstly, mean ranks obtained from the Kruskal-Wallis test on hypothesis H1 were used for ranking. A second ranking was performed as well by application of the relative weight method, which was used by Zhang & Pham (2000) and Jacobs & Van Moll (2007) for factor ranking in similar studies into the importance of influencing factors, carried out in a different research context.

In the relative weight method, each individual factor rating (i.e. a rating by one respondent on one factor) is normalized first to obtain (normalized) factor weights (see Zhang & Pham, 2000). Next, these weights are averaged over all respondents to get a final normalized weight for each influencing factor. Then, linear interpolation can be applied to transform the final normalized weights into final normalized ratings between 1 (equivalent to the lowest final normalized weight) and 5 (equivalent to the highest final normalized weight) for each influencing factor, similar to the 5-point scale used in the survey. For more information on the way in which final normalized ratings were calculated, see appendix 6.2.

By arranging these final normalized ratings from highest (i.e. 5) to lowest (i.e. 1), factor ranking is achieved. The rationale for using normalized ratings for ranking instead of the mean ratings provided in table 6.2 is to compensate for the potential inclination of some respondents to use only one end of the relevance scale, instead of using the full scale for rating.

Results of both approaches to factor ranking can be found in appendix 6.3, which show considerable overlap between rankings. Of particular interest for the purpose of prioritization are those factors that are ranked the highest, since these factors point to the most relevant influencing factors as perceived by survey respondents. Besides for reversed ranks for the two highest ranked factors, agreement is observed between both ranking approaches on the five highest ranked factors; see table 6.5.
Table 6.5: Highest ranked and lowest ranked influencing factors based on ranking results

<table>
<thead>
<tr>
<th>Highest ranked factors</th>
<th>Lowest ranked factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication (1*,2**)</td>
<td>Procedures (21,21)</td>
</tr>
<tr>
<td>Experience (2,1)</td>
<td>External Communication (20,20)</td>
</tr>
<tr>
<td>Internal Stakeholder Engagement (3,3)</td>
<td></td>
</tr>
<tr>
<td>Management Commitment (4,4)</td>
<td></td>
</tr>
<tr>
<td>Organizational Risk Attitude (5,5)</td>
<td></td>
</tr>
</tbody>
</table>

* Ranking number based on Kruskal-Wallis ranking
** Ranking number based on relative weight ranking

If these ranking results can be considered an accurate representation of the differences in factor relevance in general, an (industrial) organization that wishes to improve organizational early warning signal detection may want to target especially Communication and Experience with priority. On the other hand, Procedures and External Communication are factors that probably should be low on an organization’s priority list in this case, since both ranking approaches assign the lowest rankings to these factors, as is shown in table 6.5.

Factor ranking results require a careful interpretation though. For one thing, factor relevance scores could only be obtained for factors in the initial list of influencing factors, and not for the validated list of factors presented at the end of chapter 5. Consequently, the factor Personal Circumstances (which was included based on respondent’s suggestions to split up the Personal Characteristics factor, as was discussed in section 5.3.4) is not incorporated in the ranking, thereby affecting the overall ranking. It should be noted that the effect of including Personal Circumstances in the ranking is not expected to result in any major change in the highest ranked factors though, given the low ranking of Personal Characteristics based on the results of both ranking methods (rank #15, and #19, respectively).

Furthermore, as is apparent from the normalized ratings as shown in appendix 6.3, differences between perceived factor relevance are only marginal for some factors. For example, Empowerment, System User Interaction, and Personal Characteristics have normalized ratings of 1.44, 1.48, and 1.51, respectively. For these factors, prioritization based on factor ranking is less appropriate, given the marginal differences.

**Hypothesis H2: Respondents from different industries have the same opinion on the relevance of influencing factors**

To test hypothesis H2, either one-way ANOVA or non-parametric analysis of variance can be performed, depending on whether normality and homogeneity of variance can be assumed. Tests of normality (Shapiro-Wilk and Kolmogorov-Smirnov) indicated non-normality (p<0.05) of the distributions of factor relevance scores per industry. Hence, it was decided to use non-parametric analysis of variance to test hypothesis H2, without further testing for the homogeneity of variance.

Since the number of industries to be compared exceeds two, Kruskal-Wallis one-way ANOVA was performed. Kruskal-Wallis test results on hypothesis H2 are presented in table 6.6. Results of this test show significant differences in perceived factor relevance between industries (p<0.001). Hence, H2 can be rejected in favor of the alternative hypothesis, namely that respondents from different industries rate factor relevance differently.
Table 6.6: Results on hypothesis H2 testing

<table>
<thead>
<tr>
<th>Hypothesis H2</th>
<th>Method of testing</th>
<th>Test statistics</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kruskal-Wallis</td>
<td>$\chi^2 = 23.122$</td>
<td>Reject H2</td>
</tr>
<tr>
<td></td>
<td>$df = 6$</td>
<td>Asymp. Significance = 0.000756</td>
<td></td>
</tr>
</tbody>
</table>

To investigate the particular differences between industries, separate pair wise Mann-Whitney U tests were performed. As this includes multiple comparisons, Holm-Bonferroni correction (Holm, 1979) was applied to correct the significance level for each comparison.

Results of the separate pair-wise Mann-Whitney U tests are presented in appendix 6.4. The test results indicate that for four pair wise comparisons, significant differences were found between industries, namely:

- Infrastructure vs. Chemical Industry
- Semi(Government) vs. Chemical Industry
- Chemical Industry vs. Civil Engineering
- Chemical Industry vs. Other

The outcome of these tests suggests that overall, agreement on factor relevance between respondents from different industries exists, except for respondents from the chemical industry. The latter respondents rate factor relevance differently from respondents from the industries Infrastructure, Semi(Government), Civil Engineering, and Other (Food, ICT, Defense). Amongst other things, this is expected to result in major differences in factor rankings based on the relevance ratings of respondents from the chemical industry on the one hand, and relevance ratings of respondents from other industries on the other hand.

The fact that respondents from the chemical industry rate factor relevance differently might be indicative for the chemical industry in general. One potential explanation for this difference is the fact that compared to some of the other industries represented by survey respondents, the chemical (process) industry has historically put much effort in analyzing and managing (safety related) risks (as indicated by e.g. Pasman et al., 2009), partly driven by regulatory requirements. This might cause people within the chemical industry to have a different perception of the (proactive) management of risk and the relevance of related factors.

Unfortunately, survey findings are non-conclusive in this respect, given the limited representation of the chemical industry (n=4) in the sample. Further research, including more representative sample sizes, should be performed to ascertain whether indeed factor relevance is industry specific. If confirmed, this would mean that prioritization of influencing factors according to factor relevance should be performed per industry, instead of a prioritization of factors across industries as is performed in this thesis.
Hypothesis H3: Respondents from different organizational levels have the same opinion on the relevance of influencing factors

In line with the previous hypotheses, either one-way ANOVA or non-parametric analysis of variance can be performed to test hypothesis H3, depending on whether normality and homogeneity of variance can be assumed. Since tests of normality (Shapiro-Wilk and Kolmogorov-Smirnov) indicated non-normality (p<0.05) of the distributions of factor relevance scores per organizational level, it was decided to use non-parametric analysis of variance to test hypothesis H3, without further testing for the homogeneity of variance.

Since the number of organizational levels to be compared exceeds two, Kruskal-Wallis one-way ANOVA was performed. Kruskal-Wallis test results on hypothesis H3 are presented in table 6.7. Results of this test show significant differences in perceived factor relevance between organizational levels (p<0.001). Hence, H3 can be rejected in favor of the alternative hypothesis, namely that respondents from different organizational levels rate factor relevance differently.

<table>
<thead>
<tr>
<th>Hypothesis H3</th>
<th>Method of testing</th>
<th>Test statistics</th>
<th>Asymp. Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kruskal-Wallis</td>
<td>$\chi^2=13.955$</td>
<td>0.000932</td>
</tr>
<tr>
<td></td>
<td>df=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Result</td>
<td>Reject H3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To further investigate the differences between organizational levels, separate pair wise Mann-Whitney U tests with Holm-Bonferroni correction were performed. Results of the separate pair-wise Mann-Whitney U tests are presented in appendix 6.5. The test results indicate that for two pair wise comparisons, significant differences were found between the organizational levels compared, namely:

- Strategic vs. Operational
- Tactical vs. Operational

The outcome of these tests suggests that respondents active on the operational level within an organization rate factor relevance differently from respondents active on either an organization’s tactical or strategic level. One potential explanation for this difference is the fact that in most cases, people on an operational level are confronted with different kind of risks compared to people on higher organizational levels. The specific viewpoint on risk may consequently affect factor relevance. For example, an operator in the chemical industry will mostly be facing operational risks associated with (the particular part of) the chemical process under his supervision. However, a plant manager will be facing risks that affect the plant in its entirety, which includes not only operational risks, but financial risks, and strategic risks as well. Consequently, it might be argued that the plant manager is more likely to assign a greater value to e.g. influencing factors in the Strategy (sub)category compared to the operator, resulting in differences in perceived factor relevance between an organization’s operational and strategic level.
The fact that early warning signals detected on an operational level are often not picked up or might even be ignored by higher management levels is in support of the potential explanation given for the observed difference on factor relevance between organizational levels. This observation is apparent from the analysis of numerous industrial accidents, including e.g. the investigation of the Deepwater Horizon accident (Graham et al., 2011) and the BP Texas City explosion (Baker et al., 2007). As such, the claim that (perceived) factor relevance at least partly depends on the organizational level on which someone is active becomes more plausible, since the extent to which early warning signals are detected or acknowledged (as part of someone’s perception on risk and its related early warning signals) also appears to be affected by this organizational level.

The test results presented in appendix 6.5 have several implications. Firstly, similar to the conclusions drawn with respect to the observed differences between industries, it can be claimed that ranking results are likely to differ per organizational level. Consequently, the ranking results presented in table 6.5 in all probability do not represent the opinion of respondents that are active on an operational level. Secondly, although respondents from the operational level are better represented in the sample (n=9), further research should nevertheless be performed to ascertain whether perceived factor relevance is indeed level specific. If confirmed, this would mean that when prioritizing factors according to factor relevance, whether for an industry as a whole or for a specific company, representation of insights into factor relevance from all levels (operational, tactical, strategic) should be ensured.

6.2.4 Discussion of the survey results

The previous subsection presented the results of the hypotheses testing, together with a discussion on the outcome for each hypothesis tested. Implications of the overall survey results with respect to factor relevance are summarized here.

Overall, the study presented in this chapter has given more insight into factor relevance. Firstly, survey results indicated that influencing factors are not equally relevant with respect to organizational early warning signal detection (hypothesis H1 was rejected). This is in line with what was intuitively expected, namely that some factors are more relevant than other factors for organizational early warning signal detection. Hence, in principle, insight into factor relevance can act as a means to set priorities among factors, thereby contributing to the potential improvement of organizational early warning signal detection.

Both prioritization on the level of factor categories and prioritization on the level of individual factors were investigated. For the former, it was found that there is no reason to assume that certain factor categories will have a stronger degree of influence on organizational early warning signal detection than other categories (hypothesis H1a was not rejected). This suggests that prioritization on the level of factor categories is impracticable. When considering the tripod of technical, human and organizational failure responsible for the occurrence of most industrial accidents, a similar observation (i.e. the impracticability of prioritization according to general categories) can be made, since no particular category of failures will have a dominant effect on accident occurrence in general. Of course, for a specific accident, one category of failure may have a greater contribution to accident occurrence compared to the other categories, e.g. when an accident can mainly be attributed to human failure.
On the other hand, prioritization on the level of individual factors is feasible, given the difference in relevance between influencing factors. By application of factor ranking, it was found that overall, respondents considered Communication and Experience as the factors with the highest degree of influence on signal detection, whereas Procedures was considered the factor with the lowest degree of influence. Given some of the limitations of this study (see section 6.2.5), such as the limited sample size of the survey, one should be careful though with marking Communication and Experience as the factors that exert the highest degree of influence on organizational early warning signal detection in general.

Furthermore, it was found that overall, agreement on factor relevance between respondents from different industries exists, except for respondents from the chemical industry (rejection of hypothesis H2). Hence, major differences can be expected between factor rankings based on the relevance ratings of respondents from the chemical industry on the one hand, and relevance ratings of respondents from other industries on the other hand. Whether these differences are indicative for the chemical industry in general remains to be investigated, since survey findings are non-conclusive in this respect, given the limited representation of this industry (n=4) in the sample. If further research shows that indeed factor relevance is industry specific, this would mean that prioritization of influencing factors according to factor relevance should be executed per industry, when performed for the purpose of improving organizational early warning signal detection.

Also, it was found that respondents active on the operational level within an organization rate factor relevance differently from respondents active on either an organization’s tactical or strategic level (rejection of hypothesis H3). One potential explanation for this observation was discussed in the previous subsection, namely the fact that in most cases, people on an operational level are confronted with different kind of risks compared to people on higher organizational levels.

Again, further research should be performed to ascertain whether perceived factor relevance is indeed level specific. If confirmed, this would mean that representation of insights into factor relevance from all levels (operational, tactical, strategic) should be ensured, when prioritizing factors based on their degree of influence on signal detection (whether for an industry as a whole or for a specific company). For the survey, given the rather balanced distribution of respondents with regard to the organizational level on which they are active, an adequate representation across organizational levels was reached.

6.2.5 Limitations of the study into factor relevance

As stated earlier, the study presented in this chapter has given more insight into factor relevance. However, it also has its limitations. Some of these limitations were already mentioned earlier, such as the limited sample size. If larger sample sizes could be achieved in future research, it will be possible to determine with more certainty whether indeed factor relevance is industry specific and level specific, and which particular factors exert the highest degree of influence on signal detection (across industries and within industries).

Another limitation of the study is the fact that factor relevance scores could only be obtained for factors in the initial list of influencing factors, and not for the validated list of factors presented at the end of chapter 5.
Consequently, the factor Personal Circumstances (which was included based on respondent’s suggestions to split up the Personal Characteristics factor, as was discussed in section 5.3.4) was not incorporated in the study, and hence was also not included in the factor ranking. It should be noted that the effect of including Personal Circumstances in the ranking is not expected to result in any major change in the highest ranked factors though, given the low ranking of Personal Characteristics based on the results of both ranking methods (rank #15, and #19, respectively).

Lastly, the internet based survey did not take into account factors from the Exogenous category, such as the pace of technological innovations. As was explained in section 3.2.4, the main rationale for not further investigating these factors as part of the research described in this thesis is the fact that such factors to a large extent lie outside an organization’s area of influence. Nevertheless, on the level of factor categories, it would have been interesting to compare the perceived relevance of factors in the Exogenous category to the perceived relevance of factors in the categories Human factors, Internal environment and External environment. Amongst other things, such a comparison can give insight into the extent to which respondents consider the improvement of organizational early warning signal detection to lie within an organization’s area of influence.

### 6.3 Setting the stage for improvement: prioritization of influencing factors

One of the main conclusions of the research into factor relevance described in the previous section was that influencing factors are not equally relevant with respect to organizational early warning signal detection. Hence, factor relevance can act as a means to set priorities among influencing factors.

It should be stressed though that factor relevance is one of several ways in which an organization can set priorities among influencing factors. Although prioritization based on factor relevance can point an organization to the factors with the greatest potential for signal detection improvement (the greater the degree of influence, the greater the potential effect on detection when appropriate measures for the factor(s) in question are taken), other arguments may play a role in prioritization as well.

From a practical point of view for example, an organization would first want to know where problems might be found with regard to its ability to detect early warning signals, in terms of the relative cause of concern of each influencing factor. Once this information is available, amongst other things insight into the degree of influence of high-concern factors can further assist an organization in the prioritization process.

The way in which prioritization of influencing factors can contribute to the improvement of signal detection, as well as other practical means of utilizing insight into influencing factors and their relevance for the same purpose, are further explored in this section and the next. For that purpose, section 6.3.1 firstly describes a diagnostic evaluation tool that organizations in principle might employ to obtain information on which influencing factors to address with priority, specific to the particular organizational context under consideration. Next, section 6.3.2 discusses the additional information on influencing factors which would be required for an organization to define specific improvement initiatives for the high-concern factors identified, and how this information can be of use in the diagnostic evaluation tool.
Lastly, section 6.4 briefly discusses the potential contribution of the proposed tool in two main areas of utilization. Also, this section explores additional ways of utilizing insight into influencing factors and their relevance in these areas, which become feasible once the type of information mentioned in section 6.3.2 is available to an organization.

6.3.1 Diagnostic evaluation tool for organizational early warning signal detection

As a first step towards the improvement of its ability to detect early warning signals, an organization requires information on where problems in this context might be particularly found in the organization, and consequently which related influencing factors to address with priority. This information needs to be specific to the particular organization in question (and/or the industry in which the organization is active).

In this respect, an approach similar to Tripod-Delta (i.e. a diagnostic evaluation tool for safety enhancement) seems appropriate for organizations to obtain information on which factor(s) to address with priority, which was already suggested in section 5.6.2. In its assessment of safety, Tripod-Delta provides information about where problems might be found in an organization or organizational unit, and their relative importance, framed in terms of various General Failure Types or GFTs (Hudson et al, 1994). These assessments are essentially derived from checklists based upon specific indicator items of the presence and degree of each GFT (Reason, 1997).

Similarities exist between GFTs and influencing factors of organizational early warning signal detection, which was explained in section 5.6.2. For that reason, it was explored how Tripod-Delta’s use of indicator item identification by a syndicate of specialists (i.e. people experienced with and involved in the management and operation of the organization’s activities) might be applicable in the context of organizational early warning signal detection. In particular, it was discussed how a syndicate’s generation of indicator items might allow the precondition of influencing factors’ industry and/or organization specificity to be met.

Once the generation process has finished (see section 5.6.2 for more information on this process, and the type of indicators to be identified), indicator items identified can set the stage for utilizing influencing factors as part of a diagnostic tool to enhance organizations’ ability to detect early warning signals. More specifically, an organization might accomplish this in the following way:

1. **Checklist construction and completion.** Checklists consisting of indicator items for each of the influencing factors of organizational early warning signal detection are constructed. This is done by (automatically) sampling a number of indicator items for each influencing factor, from the local database of indicator items established in the generation process (Tripod-Delta approach suggests about 20 to 25 indicator items for each GFT, though a lower amount of items per influencing factor might be appropriate given the number of influencing factors to be considered).
This results in a multi-item checklist to be completed by members of the organization in question, in particular people that have experience with and are involved in managing risk on a day-to-day basis, from all organizational levels (strategic, tactical, operational). Since the survey on factor relevance indicated that someone’s perception of factor relevance might depend on the organizational level on which this person is active (see section 6.2.3, results on testing of hypothesis H3), care should be taken to ensure a representative sample of members across all organizational levels.

Members, as a group or individually, complete the checklist by providing a simple yes/no response to each of the indicator items. See figure 5.11 in section 5.6.2 for some examples of potential indicator items for Communication and Training.

2. **Failure State Profile generation and interpretation.** After checklist completion, response data is analyzed to generate a so-called Failure State Profile, which shows the relative cause of concern for each influencing factor of organizational early warning signal detection. An example of such a Failure State Profile (adapted from Reason (1997)) is given in figure 6.2, which for reasons of conciseness does not encompass the complete list of influencing factors.

![Failure State Profile](image)

**Fig. 6.2: Example of a Failure State Profile (adapted from Reason (1997)), identifying those influencing factors with the highest relative cause of concern**
As is apparent from this figure, a Failure State Profile presents an overview of the profile scores for each influencing factor, i.e., the number of indicators for each influencing factor answered in the ‘concern’ direction. To illustrate, a ‘no’ response on the potential indicator item “Information relevant for work provided in a timely way” shown in table 5.11 would be an answer in the ‘concern’ direction, as would a ‘yes’ response on the potential indicator item “Failure to write down rules/procedures/agreements” from the same table.

When the checklist to be completed consists of twenty indicator items for each influencing factor, the worst possible profile score for an influencing factor would be 20, indicating a high relative cause of concern. Consequently, the lower the scoring, the lower the relative cause of concern would be. It is important to note that multiple people are involved in checklist completion, either as a group or individually. If completed individually, profile scores provided should be either based on the average number of indicator items scoring in the ‘concern’ direction, or another way of weighing members’ individual responses to obtain overall profile scores.

In this way, a Failure State Profile is able to identify those influencing factors most in need of remedial action for the purpose of improving organizational early warning signal detection, i.e., in particular the two or three factors with the highest profile scores. For the Failure State Profile depicted in figure 6.2, this would be Compliance, Communication, and Responsibility & Authority.

Consequently, by adopting the diagnostic evaluation approach described above, an organization should in principle be able to obtain information on which influencing factors to address with priority, as part of the effort to improve its ability to detect early warning signals. For these factors, specific tasks and targets have to be defined next. These tasks and targets should not be aimed at those particular indicator items scoring in the ‘concern’ direction however, since these items are merely symptoms of the underlying influencing factors.

The approach described above is hence only capable of providing an organization with a sense of direction for improvement, namely which influencing factors to target first. Although this in itself can be considered valuable information for an organization, additional information on influencing factors is needed to e.g., allow practical measures, such as specific improvement initiatives, to be taken. The additional information amongst other things needed for such initiatives to be defined is discussed next, as well as how this information can be of use in the proposed diagnostic evaluation tool.

6.3.2 Direction of effect and factor quantification

Most importantly, as will be explained, insight into an influencing factor’s direction of effect is needed and factor quantification is required. Gaining this additional insight into influencing factors is outside the scope of this thesis for practical reasons. Consequently, only the type of information needed is discussed next, together with a brief exploration of how this information might be obtained:
- **Direction of effect.** Once an organization successfully establishes which influencing factor(s) to address with priority (e.g. by application of the diagnostic evaluation approach described in the previous subsection), the question arises how an organization should address these factors for the purpose of signal detection improvement. Insight into the direction of effect of the high priority factors is essential to answering this question. Direction of effect indicates whether the factor in question should be positively or negatively affected for the purpose of signal detection improvement.

For instance, for the factor Experience, it might be argued that a high level of Experience positively affects a person’s ability to detect early warning signals within an organization. However, it might also be argued that a high level of Experience causes a person to become biased towards familiar signals, thereby negatively affecting early warning signal detection.

In the diagnostic evaluation tool described in section 6.3.1, to determine whether a ‘yes’ response or a ‘no’ response on indicator items of an influencing factor indicates an answer in the ‘concern’ direction, such information on direction of effect is also required. This information might be obtained in various ways. Firstly, insight into direction of effect can be acquired based on syndicate specialists’ expertise and experience (ideally extending beyond organizational boundaries), as is now implicitly assumed in the approach.

Since most of the influencing factors identified were taken from literature (see chapter 4), this could be complemented with insights into direction of effect from literature. For example, consider the influencing factors Communication and Experience, i.e. the factors with the highest degree of influence on signal detection based on the results of the survey into factor relevance (see section 6.2.3). A review of the literature on both factors (see appendix A4.2) suggests that clear and open communication channels and a person’s previous experience with managing risk positively affect signal detection. This would mean that an organization should try to stimulate Communication and Experience for the purpose of signal detection improvement.

Influencing factors were also identified that were not mentioned in literature. For these factors, e.g. an analysis of industrial accidents in various organizations specifically aimed at these factors (i.e. to learn how these factors contributed to non-detection of early warning signals) might further contribute to getting (empirical) insight into their direction of effect.

- **Factor quantification.** Currently, insight gained into influencing factors is mainly qualitative in nature. Whereas this is obvious for exploratory insight gained (i.e. factor identification), it is also true for the proposed diagnostic evaluation tool. For instance, although it was described how ‘quantitative’ profile scores for each influencing factor could be obtained, these scores are only suitable for the purpose of indicating which two or three (or more) influencing factors an organization should address with priority. Insight into the (relative) degree of influence of each of the high-priority factors identified is not provided by the profile scores.
One way in which the relative degree of influence of each influencing factor on organizational early warning signal detection might be expressed is by factor weights. In this way, the higher the (relative) factor weight, the higher the expected contribution on signal detection improvement by targeting the factor in question would be.

For the diagnostic evaluation tool, factor weights could prove to be a valuable contribution, as a means to determine which of the ‘high-concern’ factors offers the highest potential contribution to signal detection improvement. Furthermore, within the area of decision analysis and support, factor weights could be of assistance in the evaluation of potential improvement initiatives in terms of their expected effect on signal detection. This is further discussed in section 6.4.1.

Next to factor weights, it is interesting to devote further research efforts to the measurability of influencing factors. Currently, influencing factors are ‘measured’ in the diagnostic evaluation tool by means of indicator items which require a simple yes/no response. Although suitable for the diagnostic tool’s current purpose, exploration of other (more quantitative) means of measurement is suggested. More specifically, this concerns the identification of performance measures for each influencing factor, together with appropriate measurement scales (either natural or constructed). Amongst other things, this will allow additional ways in which insight into influencing factors and their relevance might be employed for signal detection improvement to become feasible, e.g. in support of (organizational) internal benchmarking (see section 6.4.2).

One means to obtain factor weights, performance measures and (constructed) measurement scales is provided by Gifun (2010), Karydas & Gifun (2006) and Li et al. (2009), who describe in detail how prioritization based on the principles of Multi Attribute Utility Theory (MAUT) and the Analytic Hierarchy Process (AHP) might be executed. Given the benefits of the use of MAUT for prioritization purposes as put forward by these authors, and the fact that a systematic approach to prioritization is provided, in which each element (weights, performance measures, scales) is described in great detail, it is suggested to use their work as a point of departure for further research into factor quantification.

6.4 Potential areas of utilization from an organization’s perspective

This section briefly explores two main areas of utilization of insight into influencing factors and their relevance from an organization’s perspective, namely decision analysis and support (section 6.4.1), and (organizational) assessment and benchmarking (section 6.4.2). For these areas of utilization, the potential contribution of the proposed diagnostic evaluation tool in its current form is discussed. Also, additional ways of utilization in these specific areas, that become feasible once the type of information described above is available to an organization, are explored.

6.4.1 Decision analysis and support

Within the area of decision analysis and support, insight into influencing factors and their relevance can help an organization to determine for which particular factor(s) measures could best be taken to improve signal detection. For this purpose, the diagnostic evaluation tool described in section 6.3.1 was proposed.
Once accomplished, additional ways in which insight into influencing factors and their relevance can contribute to the field of decision analysis and support become feasible. Assuming that an organization has information on the direction of effect of the high priority factors, an organization can next start to think of specific improvement initiatives targeted to these factors. To determine which particular initiative(s) to execute, (quantitative) insight into factor relevance (factor weights, performance measures, measurement scales) allows an organization to make explicit the potential benefit of each initiative for signal detection improvement, in terms of expected effect. In this way, it can assist an organization when prioritizing among potential improvement initiatives.

An organization may want to take other aspects besides factor relevance into consideration as well though. For example, the extent to which a potential improvement initiative is likely to result in a short term improvement in signal detection might be another criterion to be taken into account in the prioritization process. Next to the expected benefits of the potential improvement initiatives, an organization will also need to take into account the associated costs of each initiative (in terms of the required amount of money and time to be invested) when prioritizing among initiatives. This will allow a cost-benefit assessment of the potential improvement initiatives. A complicating factor in performing such an assessment is the fact that it is difficult to explicitly express the benefit of the particular investment in signal detection improvement in terms of money saved or accidents prevented. For a further discussion on this topic, see section 2.2.3.

6.4.2 (Organizational) assessment and benchmarking

Insight into influencing factors and their relevance may also be used for other purposes than decision analysis and support. Amongst other things, this insight can help an organization to assess its current status with regard to organizational early warning signal detection, and to perform internal benchmarking. Insight into factor relevance may be utilized for other means of assessment as well.

Organizational assessment and internal benchmarking

The diagnostic evaluation tool described in section 6.3.1 supports organizational assessment in various ways. Firstly, it gives an impression of those influencing factors most in need of remedial action. Once improvement initiatives specifically targeted to these factors have been carried out, reapplication of the approach furthermore allows an assessment of an organization’s level of improvement, in terms of developments in factors’ relative cause of concern.

However, since the (relative) degree of influence of factors is not taken into account in the diagnostic evaluation approach, its application hence does not give an impression of an organization’s competence in early warning signal detection. To allow the latter type of assessment, quantitative insight into factor relevance is required. When factor weights, performance measures and measurement scales are available, it is possible for an organization to assess its current status with regard to organizational early warning signal detection. Such an assessment is performed by rating the organization’s current performance on each of the influencing factors. For rating, associated measurement scales are to be employed. Combined with factor weights on relevance, this will give an impression of an organization’s ability to detect early warning signals.
This assessment might be performed on the organization as a whole, or might be performed separately on various organizational units. In the former case, an overall impression of an organization’s competence in signal detection is obtained, which might act as a point of reference when determining how improvement initiatives undertaken have affected organizational early warning signal detection. In the latter case, an assessment of each organizational unit allows internal benchmarking with regard to signal detection. If results of the internal benchmarking indicate that some business units are less competent in signal detection compared to the other business units, an organization may want to concentrate its efforts in signal detection improvement particularly on these units, for example by sharing best practices.

**Assessment of non-detection of early warning signals prior to industrial accidents**

Also, the proposed diagnostic evaluation tool might support a different kind of assessment, namely the assessment of non-detection of early warning signals prior to (organizational) accidents encountered, such as the one performed on the Nokia-Ericsson case described in chapter 3.

For instance, by focusing checklist completion on the particular context and circumstances of the (organizational) accident(s) under consideration, an organization is able to gain insight into how members of the organization perceive the relative contribution of each influencing factor to non-detection in these specific cases. In this way, those factors likely to have contributed to the accident(s) could be identified. This process could be further facilitated by initially focusing the assessment on those influencing factors that were found to be of high concern for the particular organizational context, as would be indicated by application of the diagnostic evaluation tool on the organizational level.

Since in most cases multiple influencing factors at the same time will affect non-detection of early warning signals prior to industrial accidents, as shown by the analysis of such accidents described in section 5.4, insight into factor relevance (in particular, factor weights) can further help an organization to determine which of the factors found to address with priority.

**6.5 Summary and conclusions**

This chapter examined the way in which insight gained into influencing factors of organizational early warning signal detection might be used to potentially improve (industrial) organizations’ ability to detect early warning signals. Thereby, the third research question put forward in chapter 2 was addressed.

Firstly, for exploratory insight gained into influencing factors, it was concluded that despite the fact that this insight is limited to an overview of influencing factors with accompanying descriptions, it can nevertheless contribute to signal detection improvement on a basic level. For one thing, it raises awareness about the extent to which an organization can exert influence on signal detection.

Furthermore, exploratory insight contributes to signal detection improvement, because it can act as input to further research into influencing factors. From an organization’s perspective, information on which factor(s) to address with priority is desirable, since it can help determine how an organization’s usually limited resources are best to be allocated in order to try to improve signal detection.
For that purpose, one particular means of prioritization was firstly explored, i.e. prioritization according to the degree of influence of a factor on signal detection, referred to as factor relevance. Research into factor relevance (by means of an internet based survey) indicated that what was intuitively expected, namely that some factors have a higher degree of influence on signal detection than other factors. Factor ranking provided insight into which factors were deemed most relevant by the survey respondents (Communication and Experience), but for several reasons (limitations of the survey; the fact that respondents from the chemical industry rated factor relevance differently, which suggests that factor ranking might be industry specific), this ranking was non-conclusive.

Next, the way in which prioritization of influencing factors can contribute to the improvement of signal detection, as well as other practical means of utilizing insight into influencing factors and their relevance for the same purpose, were explored.

Firstly, a diagnostic evaluation tool based on an existing tool for safety enhancement was proposed. This tool was designed to allow organizations to learn where problems might be found with regard to their ability to detect early warning signals, in terms of the relative cause of concern of each influencing factor. As such, the tool is able to provide an organization with a sense of direction for improvement, i.e. to target influencing factors with high relative causes of concern with priority.

To allow practical measures such as specific improvement initiatives to be taken for these high-concern factors, an organization requires additional information though. The type of additional information required, as well as how this information can be of use in the proposed diagnostic evaluation tool, was discussed. Most importantly, this concerns information on influencing factors’ direction of effect and factor quantification (factor weights, performance measures, measurement scales). Also, ways in which this information might be obtained were presented.

Lastly, the potential contribution of the diagnostic evaluation tool in its current form in the areas of decision analysis and support, and (organizational) assessment and benchmarking, was discussed. Some additional ways of utilizing insight into influencing factors and their relevance in these specific areas, that become feasible once the type of information described above is available to an organization, were explored too. Amongst other things, this includes prioritization of potential improvement initiatives, and internal benchmarking.
7 Conclusions and recommendations for future research

This chapter gives an overview of the main conclusions of the research described in this thesis. Implications of the research from a scientific and industrial point of view are discussed, as well as the generalization of the research findings. This chapter concludes by presenting various recommendations for further research, followed by a final reflection.

7.1 Research overview

In today’s society, due to several trends such as increasing product and process complexity, increasing complexity in the business chain, and an increasingly dynamic and competitive environment, there is a strong need for organizations to proactively manage risk. Whereas these trends affect the need for proactive risk management, they also at the same time add to the difficulty in executing proactive risk management.

Consequently, this thesis aimed to gain insight into how organizations, in particular industrial organizations, proactively manage risk, and to investigate how organizations might improve their ability to proactively manage risk. In light of the earlier mentioned trends, of which one consequence is that threats are increasingly unforeseeable in today’s society, it was argued in chapter 2 that increasing effort should be taken to detect potential threats organizations are facing, including those risks organizations are not expecting. This resulted in this thesis’ focus on risk detection and more specifically, the need for organizations to be aware of and understand early warning signals of potential risks. Although there are various ways in which an organization can detect early warning signals, this thesis explored one particular means of detection, i.e. early warning signal detection by the people within an organization, the rationale for which was discussed in chapter 2.

Review of literature from various risk management disciplines demonstrated that the existence of early warning signals is acknowledged in literature, and that most disciplines also recognize the potential of people within an organization to detect such signals. However, beyond (general) guidelines on detection, no structured approaches (tools, methods) on how to conduct or improve this particular kind of detection in an organizational setting are available. A further review of literature on situation awareness provided some valuable insights, amongst other things the fact that detection will be affected by various factors, both individual and environmental. Nevertheless, the concept of situation awareness proved to be insufficiently capable of explaining organizational early warning signal detection.

As a result, the general aim of the thesis was translated in the more specific aim to gain insight into how (industrial) organizations detect early warning signals as regarded in this thesis, and how these organizations might improve their ability to detect such signals. This resulted in the following research questions:

Research question 1: How do (industrial) organizations detect early warning signals, as regarded in this thesis?
Research question 2: How can underlying factors that influence organizational early warning signal detection be identified?

Research question 3: How can insight into these underlying factors be utilized for the purpose of improving an organization’s ability to detect early warning signals?

In the following subsections, for each of these research questions conclusions are discussed.

7.1.1 Research question 1: Organizational early warning signal detection

To gain insight into how (industrial) organizations detect early warning signals by means of the people within an organization, this thesis explored communication theory, organizational systems theory, and theory on the cognitive processing of warnings by individuals. This led to the construction of a conceptual framework of organizational early warning signal detection, which was presented in chapter 3. Fundamental to this framework are three main elements of organizational detection.

Firstly, it was found that organizational early warning signal detection is essentially not an isolated effort by individuals, but rather requires detection by individuals amidst surrounding noise, in the context of a coordinated group of people. This implies that after an early warning signal has been detected by one or more individuals, the resulting signal estimate(s) should be propagated across the organization, at all levels (strategic, tactical, operational). Consequently, early warning signal propagation within an organization is a key element to explaining organizational early warning signal detection, and forms the basis of the conceptual framework.

Secondly, based on organizational systems theory, it was concluded that an organization’s subsystems as well as an organization’s external environment will affect an organization’s ability to detect early warning signals. This was expressed in the framework by distinguishing between four main categories of factors that influence signal detection, namely Human factors, Internal environment, External environment, and Exogenous.

Thirdly, as a prerequisite for organizational early warning signal detection, insight into individual early warning signal detection was gained. It was found that in this context, the full range of signal processing steps (as indicated in the theory on the cognitive processing of warnings) is required to result in signal-directed behavior or action. Furthermore, it was concluded that individual early warning signal detection in an organizational context is not solely affected by individual factors, but also by the organization itself, and by an organization’s environment as well. This corresponds to the categories of influencing factors mentioned above.

To illustrate the value of the developed framework in giving insight into organizational early warning signal detection, a case study was analyzed, in which early warning signal detection played a crucial role in the management of a serious organizational threat for two different organizations.

Case study analysis demonstrated that at a basic level, the conceptual framework is suitable to describe signal detection within organizations, as the analysis confirmed the role of individual detection, organizational signal propagation, and influencing factors that affect both.
Furthermore, analysis showed that despite receiving the same early warning signal, organizations can respond very differently to the signal in question. More specifically, it was found that influencing factors in the four categories identified earlier can either positively or negatively affect the process by which an organization detects early warning signals.

Consequently, based on the framework discussion and the case study analysis, it was concluded that in order to potentially improve an organization's ability to detect early warning signals, insight into influencing factors from the four categories Human factors, Internal environment, External environment, and Exogenous is needed.

As such, regardless of the fact that the conceptual framework only provides a basic understanding of how organizations detect early warning signals, the framework is considered useful for the purpose of this thesis (i.e. to learn how to potentially improve an organization’s ability to detect early warning signals). For a more in depth understanding of organizational early warning signal detection, additional research is required. Further validation of the conceptual framework can act as a good starting point, as part of the effort to arrive at a (validated) theoretical model which is able to capture organizational early warning signal detection in all of its complexity. Construction of such a theoretical model was outside the scope of this thesis though.

7.1.2 Research question 2: identification of underlying factors

As a first step to identifying the underlying factors that affect signal detection, the approach to factor identification to be adopted in this thesis was determined. The approach to be employed had to meet the following criteria, i.e. the approach should be able to capture insights non-specific for any one particular organization, should support an exploratory approach to research, and should utilize both multiple data sources (literature, experts, case studies) and multiple research methods, the integration of which is captured in a structured framework. Based on these criteria, a general approach to factor identification was proposed consisting of two phases or steps (see figure 4.1 in chapter 4):

- **Step 1: model development.** The main purpose of the model development step of the approach is to construct an initial model (in this thesis, an initial list) of factors that either positively or negatively affect organizational early warning signal detection. Characteristic for this first step is the use of a concurrent qualitative strategy to construct the initial model. More specifically, model development takes place along parallel paths, in which initial insights from literature, experts, and/or case studies across organizations and industries are extracted, analyzed and interpreted by concurrent application of various qualitative research methods.

- **Step 2: model validation.** The output of the model development step, i.e. an initial list of influencing factors, acts as input to the next step of the proposed approach, namely model validation. The main purpose of the model validation step is to further validate the initial list of factors, in order to try to obtain a comprehensive overview of factors. Characteristic for this second step is the use of an iterative mixed methods strategy to construct a validated list of influencing factors.

In particular, model validation is achieved by applying both qualitative and quantitative research methods with different sources of evidence (literature, experts, case studies) in various iterations. This iterative process repeats itself until additional results of the last iteration yield very little or no new insight, resulting in a validated overview of influencing factors.
To demonstrate the effectiveness of the approach in identifying influencing factors, and in order to try to obtain a comprehensive overview of influencing factors of organizational early warning signal detection, both steps of the proposed approach were performed.

The main data sources utilized for model development included literature on crisis management and resilience engineering, and risk management experts assembled in an across-industry expertise network. For that purpose, an extensive literature study and focus group were performed. The literature study initially identified 110 potential influencing factors, which after an initial factor grouping and a further refinement resulted in an overview of 18 influencing factors. Furthermore, the literature study confirmed the effect of an organization’s external environment (considered exogenous in this thesis) on organizational early warning signal detection. The focus group yielded comparable results to the literature study, and overall confirmed the existence of influencing factors already obtained from literature. However, focus group findings also pointed to other influencing factors, and suggested the restructuring and renaming of some of the influencing factors obtained from the literature study. The combined interpretation of the literature study findings and focus group findings resulted in an initial list of 21 influencing factors of organizational early warning signal detection.

Model validation was performed in two iterations. An internet based survey was firstly spread among a large group of risk management experts. Results of the survey indicated that none of the influencing factors included in the initial list of factors were deemed irrelevant by survey respondents. More importantly, findings showed that overall, respondents agreed on the relevance of the factors mentioned in the initial list. Nevertheless, results also suggested some minor modifications to the initial list of factors. Consequently, a second iteration was performed, which consisted of the analysis of various case studies (mostly major industrial accidents). Comparison of influencing factors identified in the analysis of case studies with the post-survey model did not yield any new insights. In other words, the analysis of the case studies did not lead to any further modification of the post-survey list of influencing factors. Hence, no further iterations were performed.

Based on application of the approach, several conclusions were drawn. With regard to the sources of information utilized for factor identification, in particular consultation of risk management experts assembled in an expertise network transcending industries was found to be a rich source of information.

With regard to the approach itself, it was concluded that it resulted in a validated list of influencing factors, indicating the approach’s effectiveness. For one thing, the stop criterion in the model validation step (i.e. proceed with factor identification until very little or no new insights are gained) ensured that a list of influencing factors was obtained, for which it can reasonably be assumed that further research will not yield any major modifications.

Furthermore, it was found that each of the particular research methods employed in both the model development step and the model validation step in itself would not have resulted in a validated list of influencing factors by itself, due to the inherent shortcomings in the application of each method. However, through the combination of these research methods in a structured manner and the integration of their results, ensuring data triangulation, methodological triangulation, and (in most cases) investigator triangulation, it was concluded that the employed approach was able to come up with a validated list of influencing factors after the last iteration.
Although the overview of influencing factors can be considered valid at the time at which the overview was obtained, it is important to note its dynamic nature. As is apparent from the trends described in chapter 1 (e.g. increasing complexity in (business) processes and business chains), organizations operate in a highly dynamic environment, to which they ideally adapt, for instance by learning from some of the external (early warning) signals they receive. Consequently, as both organizations and their environment change over time, other factors may become relevant for organizational early warning signal detection. In this respect, reapplication of (part of) the approach at a later stage with the current overview of factors as input seems appropriate. Additionally, this process of (potentially) updating current insight into influencing factors based on new insights and information will allow a stronger claim to be made with regard to whether the current overview indeed encompasses the majority of factors underlying organizational early warning signal detection. Reapplication of (part of) the approach is further discussed in section 7.4.

Moreover, it is important to keep in mind that influencing factors were identified for industrial organizations in general. Differences in factors of influence for any one particular industry or organization under consideration are likely to exist, even though a high level of agreement across industries and organizations was observed in the factor identification process. Consequently, prior to utilizing insight into influencing factors to potentially improve signal detection in practice, the precondition of industry and/or organization specificity should be met. Discussion on a diagnostic evaluation tool to proactively enhance safety known as Tripod-Delta demonstrated one particular means of doing so, i.e. the identification of indicator items for each influencing factor by a syndicate of specialists from the industry and/or organization under consideration.

### 7.1.3 Research question 3: utilization of insight into underlying factors

To learn how insight into influencing factors might be utilized for the purpose of signal detection improvement, the way in which exploratory insight might be of value was explored first. For this type of insight, it was concluded that it can contribute to signal detection improvement at a basic level.

Firstly, it was explained that exploratory insight helps raise awareness about the extent to which an organization can exert influence on signal detection, as the identified influencing factors to a large extent lie within an organization’s range of control.

Secondly, exploratory insight into influencing factors indicates that poor organizational early warning signal detection can not necessarily be attributed to human failure in detection. Rather, as was found in the analysis of the case studies performed as part of the validation of the initial list of factors, non-detection of signals in most cases can be attributed to a combination of influencing factors from all major factor categories. Hence, for the purpose of signal detection improvement, an organization should not solely focus on any one particular factor category.

Thirdly, it was argued that exploratory insight contributes to signal detection improvement, because it can act as input to further research into influencing factors. From an organization’s perspective, information on which factor(s) to address with priority is desirable, since it can help determine how an organization’s usually limited resources are best to be allocated in order to try to improve signal detection.
One particular means of prioritization was explored first, i.e. prioritization according to the degree of influence of a factor on signal detection, referred to as factor relevance. Research into factor relevance by means of an internet based survey indicated that what was intuitively expected, namely that some factors have a higher degree of influence on signal detection than other factors. Factor ranking was performed as well, but these results were non-conclusive.

A diagnostic evaluation tool based on an existing tool for safety enhancement was proposed next, designed to allow an organization to determine which influencing factors to address first. This is achieved by means of identifying those influencing factors with high relative cause of concern for the organization in question. For the purpose of improving an organization’s ability to detect early warning signals, it was concluded that the proposed tool in its current form can contribute in particular to the areas of decision analysis and support, and (organizational) assessment and benchmarking.

To allow practical measures such as specific improvement initiatives to be taken for these high-concern factors, it was concluded that an organization requires additional information. In particular, this concerns information on influencing factors’ direction of effect and factor quantification (factor weights, performance measures, measurement scales).

Gaining this additional insight into influencing factors was outside the scope of this thesis for practical reasons. Instead, it was discussed how this information might be gained, and how it might potentially be used in the diagnostic evaluation tool. For this type of information, it was furthermore argued that it might allow additional ways of utilizing insight into influencing factors and their relevance, such as prioritization of potential improvement initiatives and internal benchmarking.

### 7.2 Research contribution

Based on the conclusions summarized in the previous section, the following scientific and industrial contributions of the research described in this thesis can be distinguished.

#### 7.2.1 Scientific contribution

The scientific contribution of the research is threefold. Firstly, it contributes to the theoretical understanding of a phenomenon which is acknowledged in literature, but for which relatively limited research has been published. Secondly, the scientific contribution relates to the development of a general approach to factor identification. Thirdly, another contribution concerns the utilization of expertise networks to gain insight into organizational early warning signal detection across industries.

**Insight into organizational early warning signal detection**

Most risk management disciplines acknowledge the need for early warning signal detection as part of an organization’s efforts to proactively manage risk, and the particular role that the people within an organization play in the detection of such signals. However, beyond acknowledging the value of organizational early warning signal detection as regarded in this thesis for proactive risk management and giving (general) guidelines on detection, literature provides little insight into how to conduct or improve this particular kind of detection in an organizational setting.
In this respect, a scientific contribution of this research lies in the development of a conceptual framework of organizational early warning signal detection, for which case study analysis indicated that the framework at a basic level is suitable to describe organizational signal detection. As such, the conceptual framework can potentially help to better understand organizational signal detection, by providing a basic understanding of the main elements thereof.

Another contribution lies in the validated list of influencing factors of organizational early warning signal detection, obtained by application of the proposed factor identification approach. This list provides an overview of the various ways in which organizational early warning signal detection is affected, both positively and negatively. Such an overview is currently missing from literature.

Lastly, a minor scientific contribution lies in the fact that research into factor relevance (i.e. the degree of influence of a factor on organizational early warning signal detection) confirmed that what was intuitively expected, namely that not all factors are equally relevant with respect to signal detection.

Additionally, it was found that there is no reason to assume that certain factor categories will have a stronger degree of influence on organizational early warning signal detection than other categories. From a scientific point of view, these results suggest that future research into influencing factors should not necessarily be limited to any one particular factor category, but ideally should be targeted to those factors with the highest (expected) degree of influence on organizational signal detection.

**General approach to factor identification**

Besides providing insight into organizational early warning signal detection, another main scientific contribution of the research described is the development of a general approach to factor identification, consisting of two main steps.

The first step is model development, in which a concurrent qualitative strategy is employed to obtain an initial list of factors. The second step is model validation, in which the initial list of factors is validated by means of an iterative mixed methods strategy. Application of the approach confirmed the effectiveness of the proposed approach to arrive at a validated list of factors. Consequently, the approach is considered useful for factor identification.

The main contribution of the approach lies in the provision of a structured framework which enables the utilization and integration of a variety of research methods (which are not limited to a single source of evidence) for the purpose of factor identification. As such, amongst other things, it enables both methodological triangulation and data triangulation, adding to the validity of the findings of the identification process.

Moreover, because of the iterative nature of the model validation step, factor identification continues until very little or no new insights are gained with regard to the influencing factors of interest. In this way, the approach ensures that a list of influencing factors is obtained, for which it can reasonably be assumed that further research will not yield any major modifications.
Lastly, the approach does not prescribe which specific research methods to employ (other than the basic distinction between qualitative and quantitative methods), leaving a wide variety of research methods to be potentially incorporated in both the model development step and the model validation step. As a result, the approach appears to be adaptable to the particular circumstances (e.g. data availability and data access) under which research into influencing factors is performed.

**Utilization of expertise networks to gain insight into organizational early warning signal detection across industries**

As one of the multiple data sources employed for factor identification, risk management experts assembled in an expertise network transcending industries were consulted in various ways (focus group, internet based survey). Besides for factor identification, these experts were consulted to investigate factor relevance. In this thesis, the expertise network employed concerned a professional association for risk analysis.

Utilization of such an expertise network was found to be an effective and efficient way to gain insight into influencing factors across industries. From a practical point of view, utilization of expertise networks allows access to experts from a variety of industries, and facilitates the process of getting these people together for research purposes.

More importantly, expertise networks enable people to share their experience with managing risk on a day to day basis with fellow experts, and to learn from the experience and insights of others, either from the same industry or from other industries. In this way, these networks present a platform for consolidating knowledge and insight into managing risk across industries. As such, consultation of experts involved in these networks can be considered a rich source of information with regard to organizational early warning signal detection.

In a field of study in which sources of evidence are not widely available given the topic of interest (i.e. organizational detection of imprecise, early indications of impending risk), identification and utilization of such a rich source of information can be marked as a contribution of this research.

**7.2.2 Industrial contribution**

In this thesis, insight into organizational early warning signal detection was not pursued for purely theoretical purposes. Rather, this thesis aimed to use insight gained to potentially improve organizational early warning signal detection. Although valuable from different perspectives and for various stakeholders, this thesis specifically considered the topic of signal detection and its improvement from an organization’s perspective, or put differently, how (industrial) organizations can potentially improve their ability to detect signals.

Insight gained into organizational early warning signal detection was mainly qualitative, inherent to the exploratory nature of the research. At a basic level, such qualitative insight can contribute to the potential improvement of organizations’ ability to detect early warning signals, in the following ways:
Awareness about the extent to which an organization can exert influence on signal detection

Research described in this thesis amongst other things resulted in a validated list of influencing factors in four main categories. This overview of factors not only makes explicit the various ways in which signal detection might be affected, but also shows that these factors to a large extent are within an organization’s range of control. This helps both organizations and other parties (e.g. regulators) realize that responsibility for successful organizational early warning signal detection and consequently, responsibility for signal detection improvement, at least partly lies with the organization(s) in question.

The overview furthermore indicates that although organizational early warning signal detection as regarded in this thesis concerns detection of signals by people within an organization, poor detection can not necessarily be attributed to human failure (i.e. individual factors, in the category Human factors). Besides individual factors, other (organizational) factors will affect signal detection, which also need to be taken into account when trying to improve signal detection.

Prioritization of influencing factors for the purpose of signal detection improvement

Whereas in most cases multiple factors simultaneously will affect signal detection and it is reasonable to assume that an organization only has limited resources available for signal detection improvement, information on which factors to address with priority is needed. In various ways, this thesis has given insight into how such a prioritization might be performed.

Firstly, research described in this thesis demonstrated that one means of prioritization that an organization can employ is prioritization according to the degree of influence of factors on signal detection (i.e. factor relevance), since statistical analysis suggested that some factors are more relevant than other factors for organizational early warning signal detection. Insight into factor relevance can thus help an organization to focus its efforts with regard to signal detection improvement to those influencing factors with the greatest potential effect on detection.

Secondly, a diagnostic evaluation tool was proposed (based on an existing diagnostic tool for safety enhancement called Tripod-Delta), which in principle allows an organization to learn where problems might be found with regard to its ability to detect early warning signals, in terms of the relative cause of concern of each influencing factor. Through the identification of high-concern factors, the tool is thus able to provide an organization with information on which influencing factors to address with priority. Given the potential contribution of the diagnostic evaluation tool in its current form to the areas of decision analysis and support, and (organizational) assessment and benchmarking, further research on the proposed tool is suggested. In particular, implementation of the tool in various organizational settings for testing and validation purposes is recommended, which is further discussed in section 7.4.

7.3 Generalization

Triggered by the need for and difficulty in proactively managing risk in today’s society, the research presented in this thesis specifically dealt with investigating how (industrial) organizations detect early warning signals by means of a particular way of detection (i.e. by the people within an organization), and how an organization’s ability to do so might be improved. When placing this research in the broader context of risk management within organizations, it appears that research findings are generalizable to varying degrees.
Firstly, the approach to factor identification proposed in this thesis appears to be applicable for other purposes than the identification of influencing factors of organizational early warning signal detection as well.

As was already indicated, a *general* approach to factor identification was developed, instead of an approach specifically tailored to the context of this thesis. For one thing, this is apparent from the fact that the approach does not prescribe which particular data sources or research methods to employ for factor identification. Rather, the approach provides a structured framework which enables the utilization and integration of a variety of research methods (which are not limited to a single source of evidence) to arrive at a validated list of factors.

In this way, not the approach itself, but the application of the approach is specific to the particular context, given the type of data available for factor identification and consequently, the type of research methods that might be employed in the approach. As such, the approach appears to be adaptable to the particular circumstances (e.g. data availability and data access) under which research into influencing factors is performed. This suggests the potential of the approach to be applied in a broader context than the particular context of this thesis, such as the identification of factors in fields of study other than (proactive) risk management.

However, application of the approach in different fields of study does rely on multiple sources of evidence to be available for factor identification, and the employment of multiple research methods. Since such availability can not necessarily be assumed, this is considered a restriction on the applicability of the approach beyond the context of this thesis.

To arrive at a validated list of influencing factors of organizational early warning signal detection, a variety of data sources was utilized in this thesis. These consisted of literature from various risk management disciplines, risk management experts assembled in an expertise network transcending industries, and case studies on major industrial accidents not limited to a single industry. The validated list of influencing factors was thus not obtained by a single case study in a single industry, but was built on the combined insights gained from various industries. As such, the overview of influencing factors obtained presents the various ways in which early warning signal detection is affected in industrial organizations in general, which appears to be valuable for (organizations in) similar industries to the ones incorporated in the study as well. However, before insights gained into influencing factors might be utilized to improve signal detection in practice, the precondition of industry and/or organization specificity (i.e. that factors found need to be specific to the particular industrial context and/or organizational context) should be met, as was already discussed in section 7.1.2. This applies both to industries (and organizations in those industries) considered in the study, and similar industries that were not taken into account.

Given the reliance on industry specific insights to construct the overview of influencing factors, extrapolation of these findings to organizations other than industrial organizations, such as financial or service organizations, seems less suitable. For one thing, when comparing the industrial sector with e.g. the financial sector, it appears that factors that affect organizational early warning signal detection are at least partly sector specific. For example, consider the system of financial bonuses, which is characteristic for the banking industry. This system might be considered an inhibiting factor on early warning signal detection specific to this industry, as it could act as an incentive to ignore early warning signals that might threaten bonus payment.
Moreover, industrial organizations and non-industrial organizations differ with regard to the types of risk they are facing; whereas industrial organizations in general are more likely to face hazard and operational risks compared to financial and strategic risks, the opposite is true for financial or service organizations. Since it is reasonable to assume that differences exist in the management of these types of risks given their different nature, influencing factors related to the proactive management of mainly hazard/operational risks are thus not expected be equivalent to factors that affect the proactive management of mainly financial/strategic risks. As a result, the validated list of factors obtained does not appear to be fully applicable to non-industrial organizations, at least on the level of individual factors.

Nevertheless, a certain level of overlap between influencing factors of signal detection in industrial organizations and non-industrial organizations is expected, since factors were identified in factor categories that are assumed to play a role in any organization (i.e. Human factors, Internal environment, External environment). As such, performing an assessment of the identified factors in each of these categories in the context of non-industrial organizations appears to be a good starting point, in order to learn how early warning signal detection in non-industrial organizations is affected.

7.4 Recommendations for further research

The previous sections summarized the main conclusions of the research described in this thesis, the associated contributions, and generalizability of the research findings. Based on this research overview, various directions for future research can be identified, which are discussed next.

Construction of a validated theoretical model of organizational early warning signal detection

Although considered adequate for the purpose of this thesis, the constructed conceptual framework of organizational early warning signal detection only provides a basic understanding of how organizations detect such signals. Based on this basic insight, research efforts concentrated on one of the main elements of organizational signal detection, i.e. the factors that influence signal detection. As such, how early warning signals propagate within an organization, how individuals detect early warnings in an organizational context, and how these various elements interact to cause an organization to (un)succesfully detect early warning signals was not further investigated.

To learn how organizational early warning signal detection might be improved, fundamental insight into all of these elements is required. Consequently, it is suggested to focus future research efforts on gaining a better understanding of organizational early warning signal detection in all of its complexity, by constructing a validated theoretical model which is capable of capturing the dynamics of signal propagation, individual detection, and influencing factors that affect both. Further validation of the elements in the conceptual framework and their integration appears to be a good starting point to arrive at such a theoretical model.

Within this theoretical model, it would be interesting to further investigate the role of an organization’s external environment on signal detection, which was largely considered exogenous in this thesis.
In particular, insight into the role of an organization’s (direct) stakeholders in signal detection appears worthwhile to be pursued, as this will allow a shift in perspective from detection within a single organization to detection within the context of a business chain, for example. Given the increasing complexity and interdependencies in business chains in today’s society (as indicated in chapter 1), such an exploration is of current interest.

**Updating of the obtained overview of influencing factors**

Although considered valid at the time at which the overview was obtained, organizations in today’s society operate in a highly dynamic environment to which they (ideally) adapt, and consequently, other factors may become relevant for organizational early warning signal detection in time. In this respect, reapplication of (part of) the proposed factor identification approach at a later stage with the current overview of factors as input seems appropriate, as it will give insight into the extent to which updating is needed. At the same time, reapplication of (part of) the approach will allow a stronger claim to be made with regard to whether the current overview indeed encompasses the majority of factors underlying organizational early warning signal detection.

Of particular interest for the purpose of updating is the utilization of expertise networks, which was found to be a rich source of information for factor identification. Risk management experts in such networks are expected to have current insight into risk management, through their own experience with managing risk in practice, and through benchmarking with fellow experts both within the same industry and other industries.

As such, an appropriate first step to ascertain validity of the obtained overview of influencing factors across industries over time would be to consult risk management experts assembled in expertise networks transcending industries. Of the various ways in which consultation may take place, the use of a focus group consisting of multiple group meetings, with varying combinations of participants, is suggested.

Firstly, its use of expert collaboration is expected to provide more in depth insight into organizational early warning signal detection compared to the individual consultation of experts. Secondly, by having multiple meetings, ideally until no new insights are gained, the likelihood of reaching theoretical saturation in the process is strongly increased. If the outcome of the focus group would yield new insight into influencing factors, another iteration as part of the model development step of the approach may then be performed.

**Industry specificity of factor relevance**

Survey results indicated that overall, agreement on the degree of influence of factors on organizational early warning signal detection (i.e. factor relevance) between respondents from different industries existed, except for respondents from the chemical industry. Whether these differences are indicative for the chemical industry in general remains to be investigated, since survey findings are non-conclusive in this respect, given the limited representation of this industry (n=4) in the sample. One potential means of investigation is to resubmit the internet based survey performed in this thesis among a sufficiently large sample size of risk management experts in various industries (including the chemical industry), to assess the industry specificity of factor relevance. If confirmed, this would imply amongst other things that prioritization of influencing factors according to factor relevance should be executed per industry, when performed for the purpose of improving organizational early warning signal detection.
Implementation of the proposed diagnostic evaluation tool for organizational early warning signal detection

A diagnostic evaluation tool was proposed in chapter 6, designed to support organizations that want to improve their ability to detect early warning signals. Its main contribution lies in the identification of those influencing factors (specific to the particular organizational and/or industrial context under consideration) with a high relative cause of concern, which an organization should consequently address with priority.

Although based on a diagnostic tool to enhance safety which has been validated in various organizations and industries, the proposed tool itself also needs to be tested and validated. In particular, implementation of the proposed tool in various organizational settings across industries is suggested. Literature on the Tripod-Delta approach, as well as documentation on case studies involving the application of Tripod-Delta in industrial organizations, is of particular interest in this respect. Most importantly, these sources of information can act both as a starting point and as a guideline on how to implement and validate the diagnostic evaluation tool for organizational early warning signal detection.

Direction of effect and factor quantification

Once an organization has information on which influencing factors to target with priority (e.g. by application of the proposed diagnostic evaluation tool), the next step would be to try to define practical measures for these factors, such as specific improvement initiatives. This requires additional information to be available though. As was explained in chapter 6, this mainly concerns information on influencing factors’ direction of effect and factor quantification.

It is hence suggested to perform further research in these areas. For the former type of information, literature studied for factor identification in this thesis appears to be a good source of information. For one thing, most of the influencing factors in the obtained overview originate from literature, but more importantly, literature in most cases provides insight into how these factors can either obstruct (i.e. negatively affect) or stimulate (i.e. positively affect) signal detection. With regard to the influencing factor Communication for example, literature indicates that clear and open communication channels will positively affect signal detection, thereby suggesting that Communication should be stimulated instead of obstructed. For Communication, this might be considered an obvious conclusion. For other factors however, the direction of effect is less obvious, rendering further research on this topic necessary.

To gain a better understanding of the particular differences in relevance between influencing factors, and to be able to measure the effect of influencing factors on signal detection, quantitative insight into influencing factors (such as factor weights, performance measures, and measurement scales) is essential. Although there are various ways to obtain this type of information, a potentially interesting point of departure for further research into factor quantification might be the work by Gifun (2010), Karydas & Gifun (2006) and Li et al. (2009). These authors present a systematic approach to prioritization based on the principles of Multi Attribute Utility Theory (MAUT) and the Analytic Hierarchy Process (AHP), in which the integrated construction of weights (by means of pairwise comparisons), performance measures and scales is incorporated. Although promising, before factor quantification becomes feasible, requirements have to be met for the approach to be applied, such as the availability of a decomposable hierarchical tree of factors as input. Consequently, factor quantification based on this approach should not be performed without scrutiny.
7.5 Final reflection

Performing research into proactive risk management is in itself an exercise in managing risk: both threats and opportunities will present themselves along the way, and it is mainly up to the researcher to identify them in a timely manner to allow for an appropriate ‘risk treatment’. Unfortunately, doing research into risk management does not automatically make oneself a skilled risk manager. Hence, opportunities were sometimes missed, and the researcher in some cases had to revert to reactive risk management.

With regard to the former, the fact that this thesis’ main research effort was devoted to the identification of influencing factors of organizational early warning signal detection (i.e. exploratory in nature) resulted in what the researcher considers a missed opportunity, namely to indicate more concretely how insights gained might be utilized by an organization to improve its ability to detect early warning signals.

With regard to the latter, in particular early in the factor identification process, methodology wise some decisions were made that could have potentially seriously threatened overall research validity, for which the researcher had to revert to risk mitigation strategies. An example of this is involving a second researcher in the assessment of a classification of factors found in literature initially performed by a single researcher. Having to perform these strategies early on in the factor identification process proved to be a valuable experience though, as it helped shape the general approach to factor identification proposed in this thesis, which amongst other things is built on the principles of (data and methodological) triangulation. This approach is considered one of the main contributions of this thesis.

Lastly, in this respect, the researcher would also like to emphasize one particular opportunity seized in the research process, i.e. to utilize risk management experts in an expertise network transcending industries (through his association with one such network) as one of the main data sources for the identification of influencing factors of early warning signal detection within industrial organizations in general.
References


Appendices Chapter 4
Appendix 4.1 Initial overview of influencing factors identified in literature

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<th>Identified factors organized per factor (sub)category</th>
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<tbody>
<tr>
<td>1</td>
<td>Human factors</td>
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<td>2</td>
<td>Reluctance to probe the theory of the business</td>
<td>(Drucker, 1994)</td>
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<td>3</td>
<td>Crisis management expertise</td>
<td>(Elsubbaugh et al., 2004)</td>
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<td>4</td>
<td>Previous experience</td>
<td>(Hensgen et al., 2003)</td>
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<td>5</td>
<td>Numbed awareness due to recurrent, previous success</td>
<td>(Miller, 1992)</td>
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<td>6</td>
<td>Commitment to chosen course of action</td>
<td>(Miller, 1993)</td>
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<td>7</td>
<td>Faulty rationalizations by senior executives that hinder crisis management efforts</td>
<td>(Pearson &amp; Mitroff, 1993)</td>
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<td>Cognitive biases</td>
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<td>Overreliance on past success</td>
<td>(Sheaffer et al., 1998)</td>
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<td>Biased managerial decision making patterns</td>
<td>(Sheaffer et al., 1998)</td>
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<td>Dearth of skepticism</td>
<td>(Sheaffer et al., 1998)</td>
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<td>Managerial stress</td>
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<td>14</td>
<td>Risk aversion</td>
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<td>15</td>
<td>Fear of failing supervisors and standing out</td>
<td>(Sheaffer et al., 1998)</td>
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<td>16</td>
<td>Deep (system) understanding</td>
<td>(Sheffi, 2005)</td>
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<td>Analytical capability</td>
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<td>Experienced management</td>
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<td>Individual biases</td>
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<td>Internal environment: technology</td>
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<td>21</td>
<td>Supporting information system for scanning</td>
<td>(Elsubbaugh et al., 2004)</td>
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<td>22</td>
<td>Environmental scanning by organizational early warning systems</td>
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<td>23</td>
<td>Various early warning systems in place</td>
<td>(Mitroff, 1988)</td>
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Supporting procedures (e.g. checklists) (Weick & Sutcliffe, 2007)

**Internal environment: culture**

Different organizational parts and levels that act as opponents to decisions taken or ongoing analysis (Axelsson, 2006)
Perception of organizational vulnerability (Mitroff et al., 1987)
Organizational imperviousness to bad news (Mitroff et al., 1987)
Inflated organizational self-image (Mitroff, 1988)
Organizational blocking of weak signals (Mitroff & Anagnos, 2001)
Integration of lessons learned (Pearson & Mitroff, 1993)
Organizational learning (Pearson & Mitroff, 1993)
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<td>89</td>
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<td>(Westrum, 2006)</td>
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<td>Reward signal detection</td>
<td>(Mitroff &amp; Anagnos, 2001)</td>
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<td>Integration of crisis management in statements of corporate excellence</td>
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<td>Visibility of strong top management commitment</td>
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<td>Dedication of budget expenditures for crisis management</td>
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<td>95</td>
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<td>External stakeholders’ relationships</td>
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<td>Management’s query of extended networks (partners, suppliers, customers…)</td>
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<td>Organizational participation in extended networks</td>
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<td>103</td>
<td>Industry wide dissemination of information</td>
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<td><strong>Exogenous</strong></td>
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<td>104</td>
<td>Stressful conditions</td>
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<td>105</td>
<td>Accelerated technological innovations</td>
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<td>Frequent de-regulations</td>
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<td>107</td>
<td>Information overload</td>
<td>(Sheaffer et al., 1998)</td>
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<td>Selfish aspiring stakeholders</td>
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<td>Hyper-competition</td>
<td>(Sheaffer et al., 1998)</td>
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<td>110</td>
<td>Complex technologies</td>
<td>(Sheaffer et al., 1998)</td>
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Appendix 4.2  Initial factor grouping

**Table A4.2: Initial grouping of influencing factors found in literature**

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<td>Reluctance to probe the theory of the business</td>
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<td>Numbed awareness due to recurrent, previous success</td>
<td>(Miller, 1992)</td>
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<td></td>
<td>Commitment to chosen course of action</td>
<td>(Miller, 1993)</td>
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<td></td>
<td>Faulty rationalizations by senior executives that hinder crisis management efforts</td>
<td>(Pearson &amp; Mitroff, 1993)</td>
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<td></td>
<td>Cognitive biases</td>
<td>(Roberto et al., 2006)</td>
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<td></td>
<td>Overreliance on past success</td>
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<td>Biased managerial decision making patterns</td>
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<td>Individual biases</td>
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<td>Personal psychology of top-managers</td>
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<td></td>
<td>Risk aversion</td>
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<td></td>
<td>Managerial stress</td>
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<td><strong>Dearth of skepticism</strong></td>
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<td>Managerial arrogance</td>
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<td>Fear of failing supervisors and standing out</td>
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<td></td>
<td>Analytical capability</td>
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<td>3</td>
<td><strong>Crisis management expertise</strong></td>
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<td>Previous experience</td>
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<td>Environmental scanning by organizational early warning systems</td>
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<td>Suspicion</td>
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Empowerment of field personnel | (Sheffi, 2005)  
Organizational culture with high alignment, awareness and empowerment | (Westrum, 2006) |
| 18 | Perception of organizational vulnerability | (Mitroff et al., 1987)  
Organizational risk aversion | (Sheaffer et al., 1998)  
Conservatism | (Sheaffer et al., 1998)  
Organizational resistance to change | (Sheaffer et al., 1998) |

| **Internal environment: strategy** |  |
| Reward signal detection | (Mitroff & Anagnos, 2001)  
Integration of crisis management in statements of corporate excellence | (Pearson & Mitroff, 1993) |
| Visibility of strong top management commitment | (Pearson & Mitroff, 1993)  
Dedication of budget expenditures for crisis management | (Sheaffer et al., 1998)  
Constraints on safety costs | (Sheaffer et al., 1998) |
| Integration of crisis management in strategic planning | (Pearson & Mitroff, 1993)  
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Outdated strategies | (Sheaffer et al., 1998) |

| **External environment** |  |
| External environmental scanning | (Elsubbaugh et al., 2004)  
External stakeholders’ relationships | (Mitroff & Anagnos, 2001) |
| Management’s query of extended networks (partners, suppliers, customers…) | (Pearson & Mitroff, 1993)  
Organizational participation in extended networks | (Schoemaker & Day, 2009) |
| External communication lines | (Pearson & Mitroff, 1993)  
Industry wide dissemination of information | (Weick & Sutcliffe, 2007) |

| **Exogenous** |  |
| Stressful conditions | (Pearson & Mitroff, 1993)  
Accelerated technological innovations | (Sheaffer et al., 1998)  
Frequent de-regulations | (Sheaffer et al., 1998) |
| Information overload | (Sheaffer et al., 1998)  
Selfish aspiring stakeholders | (Sheaffer et al., 1998)  
Hyper-competition | (Sheaffer et al., 1998)  
Complex technologies | (Sheaffer et al., 1998) |
### Appendix 4.3 Resulting overview of influencing factors (post assessment) and associated references

**Table A4.3: Overview of influencing factors identified in literature (post assessment) and associated references**

<table>
<thead>
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<th>Factors identified in literature</th>
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<tr>
<td>1. Cognitive Bias</td>
<td>(Drucker, 1994), (Miller, 1992), (Miller, 1993), (Pearson &amp; Mitroff, 1993), (Roberto et al., 2006), (Sheaffer et al., 1998), (Schoemaker &amp; Day, 2009)</td>
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<tr>
<td>2. Risk Attitude</td>
<td>(Sheaffer et al., 1998)</td>
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<tr>
<td>3. Level of Stress</td>
<td>(Sheaffer et al., 1998)</td>
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<tr>
<td><strong>Internal environment: technology</strong></td>
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<tr>
<td>4. System Coverage</td>
<td>(Elsubbaugh et al., 2004), (Mitroff et al., 1987), (Mitroff, 1988), (Pearson &amp; Mitroff, 1993), (Roberto et al., 2006), (Sheaffer et al., 1998), (Sheffi, 2005)</td>
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<td>5. System Span</td>
<td>(Sheaffer et al., 1998)</td>
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<td><strong>Internal environment: structure</strong></td>
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<tr>
<td>7. Training</td>
<td>(Mitroff et al., 1987), (Pearson &amp; Mitroff, 1993), (Roberto et al., 2006), (Sheaffer et al., 1998)</td>
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<tr>
<td>10. Procedures</td>
<td>(Axelsson, 2006), (Barton, 1993), (Regester, 1987), (Hale et al., 2006), (Schoemaker &amp; Day, 2009), (Sheaffer et al., 1998), (Sheffi, 2005), (Weick &amp; Sutcliffe, 2007)</td>
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<td><strong>Internal environment: culture</strong></td>
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<td>11. Organizational Risk Attitude</td>
<td>(Mitroff et al., 1987), (Sheaffer et al., 1998)</td>
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<td>12. Organizational Learning</td>
<td>(Pearson &amp; Mitroff, 1993), (Roberto et al., 2006), (Sheaffer et al., 1998)</td>
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<td>13. Internal Stakeholder Involvement</td>
<td>(Axelsson, 2006), (Roberto et al., 2006), (Schoemaker &amp; Day, 2009), (Sheaffer et al., 1998), (Sheffi, 2005), (Weick &amp; Sutcliffe, 2007)</td>
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<tr>
<td><strong>Internal environment: strategy</strong></td>
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<tr>
<td>15. Management Commitment</td>
<td>(Mitroff &amp; Anagnos, 2001), (Pearson &amp; Mitroff, 1993), (Sheaffer et al., 1998)</td>
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<td><strong>External environment</strong></td>
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<tr>
<td>17. External Stakeholder Involvement</td>
<td>(Elsubbaugh et al., 2004), (Mitroff &amp; Anagnos, 2001), (Pearson &amp; Mitroff, 1993), (Schoemaker &amp; Day, 2009)</td>
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<tr>
<td>18. External Communication Channels</td>
<td>(Pearson &amp; Mitroff, 1993), (Weick &amp; Sutcliffe, 2007)</td>
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</table>

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<thead>
<tr>
<th><strong>Exogenous</strong></th>
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<tbody>
<tr>
<td>19. Exogenous</td>
<td>(Pearson &amp; Mitroff, 1993), (Sheaffer et al., 1998)</td>
</tr>
</tbody>
</table>
Appendix 4.4 Example of case material used in focus group

Note: additional case material besides the short description of the accident and the accompanying request for analysis presented in this appendix was provided to each group, consisting of the official investigation report of the accident, and a video in which an official reconstruction of the accident was given. Both the report and the video can be accessed via the U.S. Chemical Safety and Hazard Investigation Board website (http://www.csb.gov/investigations/).

Case: Propane explosion Little General Store, Ghent, WV, USA

Description

On January 30, 2007, a propane explosion at the Little General Store in Ghent, West Virginia, killed two emergency responders and two propane service technicians, and injured six others. The explosion leveled the store, destroyed a responding ambulance, and damaged other nearby vehicles.

On the day of the incident, a junior propane service technician employed by Appalachian Heating was preparing to transfer liquid propane from an existing tank, owned by Ferrellgas, to a newly installed replacement tank. The existing tank was installed in 1994 directly next to the store’s exterior back wall in violation of West Virginia and U.S. Occupational Safety and Health Administration regulations.

When the technician removed a plug from the existing tank’s liquid withdrawal valve, liquid propane unexpectedly released. For guidance, he called his supervisor, a lead technician, who was offsite delivering propane. During this time propane continued releasing, forming a vapor cloud behind the store. The tank’s placement next to the exterior wall and beneath the open roof overhang provided a direct path for the propane to enter the store.

About 15 minutes after the release began, the junior technician called 911. A captain from the Ghent Volunteer Fire Department subsequently arrived and ordered the business to close. Little General employees closed the store but remained inside. Additional emergency responders and the lead technician also arrived at the scene. Witnesses reported seeing two responders and the two technicians in the area of the tank, likely inside the propane vapor cloud, minutes before the explosion.

Minutes after the emergency responders and lead technician arrived, the propane inside the building ignited. The resulting explosion killed the propane service technicians and two emergency responders who were near the tank. The blast also injured four store employees inside the building as well as two other emergency responders outside the store.

Fig. A4.1: Case material for case 1: Propane explosion Little General Store, Ghent, WV, USA
**Analysis**

The CSB investigation report is provided for further information. To guide the discussion on influencing factors of signal detection, you are requested to look particularly to the following (weak) signals, after which other signals can be included as well:

Signal: Leaky tank, Signal receiver: Appalachian Heating (junior technician, lead technician, technical support)

Signal: Propane smell. Signal receiver: Store employees

As a group, discuss the case and try to answer the following questions:

1. Which factors from the Human factors category were active? Did they strengthen or weaken the signal?

2. Which factors from the Internal environment category were active? Did they strengthen or weaken the signal?

3. Which factors from the External environment category were active? Did they strengthen or weaken the signal?

Please use the provided answering form (poster size) to write down the identified factors.
Appendix 4.5  Focus group evaluation form

POST WORKSHOP QUESTIONNAIRE

To help us assess the effectiveness of this workshop, please complete and return this questionnaire to the workshop organizer before you leave. Thank you.

Name participant: _____________________________________________________________

Area of expertise:  □ Transport  □ Process Industry  □ Aerospace  □ Finance
                      □ Infrastructure  □ Energy  □ Other, namely ___________________

Overall

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>To a large extent</th>
<th>Do not know</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How much has this workshop helped increase your knowledge about organizational weak signal detection and processing?</td>
<td>□</td>
<td>□</td>
<td>□</td>
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<td></td>
<td>□</td>
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<td>□</td>
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</tbody>
</table>

Please explain your answer:
___________________________________________________________________________
___________________________________________________________________________

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<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>To a large extent</th>
<th>Do not know</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. How effective was this workshop in identifying the majority of the organizational factors that affect weak signal detection and processing?</td>
<td>□</td>
<td>□</td>
<td>□</td>
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<tr>
<td></td>
<td>□</td>
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<td>□</td>
</tr>
</tbody>
</table>

Please explain your answer:
___________________________________________________________________________
___________________________________________________________________________

Please fill in the other side of the form as well, thank you.
3. How effective was this workshop in identifying the *most relevant* organizational factors that affect weak signal detection and processing?  

Please explain your answer:
___________________________________________________________________________
___________________________________________________________________________

4. To what extent do you think you can apply what you learned from the workshop to your work?  

Please explain your answer:
___________________________________________________________________________
___________________________________________________________________________

**Organization**
How would you rate the different modules of the workshop?

5. Presentation on weak signal detection and processing

6. Case 1 - Propane explosion Little General Store

7. Case 2 - Own experience

8. Discussion of case study findings / identification of factors

9. Ranking of organizational factors*

10. *Optional:* Case 3 – Turkish Airlines crash Schiphol

11. Do you have any additional comments or suggestions? (fill in here, or send to j.luyk@tue.nl)
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

* Though initially planned, time available for the focus group did not permit a ranking of the identified influencing factors. Hence, scores for factor ranking are not included in the evaluation results.
Appendices Chapter 5
Appendix 5.1 Impression of the internet based survey

Fig. A5.1: Introduction to the survey

Beïnvloedingsfactoren Proactief Risicomanagement

Bedoelde namens het NWB bezwaar wil ik u alvast hartelijk danken voor uw interesse in deelname aan ons onderzoek op het gebied van proactief risicomanagement.

Context

Proactief risicomanagement begint met het tijdig detecteren van -en reageren op - vroege indicaties van potentiële risico’s en aanstaande crises. Deze vroege indicaties worden ook wel zwakke signalen genoemd en komen in veel verschillende vormen voor. In dit onderzoek bogen we ons tot de categorie signalen, waarvoor ze wat betreft betrouwbaar afhankelijk kent van de mensen in de organisatie. Echter onderzoek heeft aangemerkt dat er verschillende factoren binnen een organisatie kunnen spelen die signalen tot beïnvloeden. Afhankelijk van de specifieke factor kan het effect op detectie, versterking of juist belemmering zijn.

In deze online vragenlijst zijn wij geïnteresseerd in hoeverre u de aangegeven factoren als relevant beschouwt voor signalen. Ook zijn wij bereid om er volgens u factoren onthouden in het gegeven overzicht.

Instructie

Het inleiden van de vragenlijst kost u ongeveer 15 minuten. Als dank voor uw deelname wordt een MINI Iris sleeptje ter waarde van €1,00,- verloopt onder de deelnemers. Deze toe te kennen op de ‘volgende’ knop rechtsonder begint u aan de vragenlijst. De vragenlijst bestaat uit meerdere pagina’s, waarbij u op ieder moment kunt terugkeren naar een vorige pagina.

Bij vragen of opmerkingen kunt u die allen tijdens contact met ons opnemen via info@nwb.nl. Voor meer informatie over ons onderzoek verwijzen wij u graag naar onze bijdrage aan de eerstvolgende NWB-nieuwsbrief.

Met vriendelijke groet,

I. H. Link
Promovendus TUE

Opmerking: deze vragenlijst kunt u het beste openen in Internet Explorer.

[Link naar vragenlijst]
**Fig. A5.2: Part 1 of the survey – Background information**

**DEEL 1: ACHTERGRONDINFORMATIE**
In dit eerste gedeelte van de vragenlijst worden u een aantal korte vragen gesteld met betrekking tot uw achtergrond en uw relatie met (proactief) risicomanagement. Dit gebeurt aan de hand van een aantal algemene vragen en stellingen.

*Vraag 1.1: In welke sector bent/was u voornamelijk werkzaam?*
- [ ] Transport
- [ ] Infrastructuur
- [ ] (zenuw)overheid
- [ ] Energie
- [ ] Chemische Sector
- [ ] Civiele Techniek
- [ ] Lucht en Ruimtevaart
- [ ] Financiële Sector
- [ ] Anders

*Vraag 1.2: Welke van onderstaande aanspraken is het meest van toepassing op uw situatie?*
- [ ] Sturing op lange termijn doelen (strategisch, Marco management)
- [ ] Sturing op korte termijn doelen (achtig, middel management)
- [ ] Uitvoerende taken (operaties)

*Vraag 1.3: In hoeverre bent u het eens met onderstaande stellingen?*  
(1 = Volledig mee eens, 7 = Volledig mee eens)

<table>
<thead>
<tr>
<th>Stelling</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td>Ik weet vrij veel van risicomanagement</td>
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<tr>
<td>Het beheersen van risico’s is onderdeel van mijn dagelijkse werkzaamheden</td>
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<tr>
<td>Vergelijken met de meeste andere mensen weet ik weinig van risicomanagement</td>
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</table>

Vraag 1.4: Hoeveel jaren ervaring heeft u met het beheersen van risico’s? (Optioneel)

[Antwoorden en antwoorden verwijderen]
Fig. A5.3: Part 2 of the survey – Validation of the initial list of influencing factors (Human factors)
Fig. A5.4: Part 3 of the survey – Additional insights beyond the initial list of influencing factors
Appendix 5.2 Results factor analysis

PASW output for factor analysis on Knowledge_1, Knowledge_2 and Knowledge_3 is indicated in table A5.1.

<table>
<thead>
<tr>
<th>Component matrix</th>
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</thead>
<tbody>
<tr>
<td>Knowledge_1</td>
</tr>
<tr>
<td>0.844</td>
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</tbody>
</table>

a: Extraction method: Principal components analysis
No rotation
1 component extracted

b: Knowledge_3 was negatively worded (a high score on Knowledge_3 would thus indicate little subjective knowledge on risk management), hence the negative score.
### Table A5.2: Results case study analysis - Bopal

<table>
<thead>
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<tbody>
<tr>
<td>Bhopal, India (1984)</td>
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<tr>
<td>Signal 1: &quot;Our technology just can't go wrong, we just can't have such leaks.&quot;</td>
<td>X</td>
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<tr>
<td>Signal 1 (post-Flixborough &amp; internal) reports on the desirability of inherently safer design</td>
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<td>Signal 1: Disgruntled employees</td>
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<td>Signal 1: Frequent earlier releases</td>
<td>X</td>
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<td>Signal 1: Safety procedures ignored/not carried out (correctly)</td>
<td>X</td>
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<td>Signal 1: Water allowed near the equipment; no HAZOP performed</td>
<td>X</td>
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<td>Signal 1: Safety systems not in full working order</td>
<td>X</td>
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<td>Signal 1: Poor maintenance of instruments known to be unreliable</td>
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<td>Signal 1: Joint venture Union Carbide and Indian government (little supervision)</td>
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<tr>
<td>Signal 1: Personnel discontinuity; 8 different managers in 15 years</td>
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<tr>
<td>Signal 1: Shift in direction Union Carbide/Bhopal less interesting due to losses</td>
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<td>Signal 1: Poor technical design</td>
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<td>6</td>
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### Table A5.3: Results case study analysis - Davis-Besse

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<th>Internal Environment</th>
<th>External Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technology</td>
<td>Structure</td>
</tr>
</tbody>
</table>

- **Davis-Besse (2002)**
  - Signal: failure mechanism dismissed in NRC and Davis-Besse examinations
    - Technology: X X
    - Structure: X X
    - Culture: X X
    - Strategy: X
  - Signal: timing of the inspection delayed for several months
    - Technology: X X
    - Structure: X X
    - Culture: X X
    - Strategy: X
  - Signal: inadequate inspections for years
    - Technology: X
    - Structure: X X
    - Culture: X X
    - Strategy: X
  - Signal: early indications by different plant systems not put together
    - Technology: X
    - Structure: X X
    - Culture: X X
    - Strategy: X

- **Overall**
  - Technology: 0 1 0 0 0 3 2 0 1 0 3 3 0 0 0 4 4 0 0 0 2
Exogenous Signal: failure mechanism dismissed in NRC and Davis-Besse examinations for several months. For early indications by different plant systems already, however, investigations at Davis-Besse were inadequate to determine whether boric acid corrosion was taking place.

<table>
<thead>
<tr>
<th>Human Factors</th>
<th>Technology</th>
<th>Internal Environment</th>
<th>Strategy</th>
<th>External Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal Circumstances</td>
<td>Structure</td>
<td>Culture</td>
<td>Management Commitment</td>
</tr>
<tr>
<td></td>
<td>System Architecture</td>
<td>Procedures</td>
<td>Responsibility &amp; Authority</td>
<td>Vision</td>
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<tr>
<td></td>
<td>System-User Interaction</td>
<td>Communication</td>
<td>Leadership</td>
<td>External Stakeholder Engagement</td>
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<td>Training</td>
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<td>Group Behavior</td>
<td>Communication</td>
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<td>External Communication</td>
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<td></td>
<td>Exogenous</td>
</tr>
</tbody>
</table>

Table A5.4: Davis-Besse - Arguments related to early warning signals

| Signal: failure mechanism dismissed in NRC and Davis-Besse examinations | X | X | X | X |
| Signal: timing of the inspection delayed for several months | X | X | X | X |
| Signal: inadequate inspections for years | X | X | X | X |
| Signal: early indications by different plant systems not put together | X | X | X | X |
| Overall | 0 | 0 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 4 | 4 | 0 | 0 | 2 |

Several early warning signs such as excessive clogging of containment air filters and inability to completely clean crud off the RPV head during previous refueling outages not considered in an integrated fashion.
Table A5.5: Davis-Besse - Arguments related to influencing factors

<table>
<thead>
<tr>
<th>Human Factors</th>
<th>Technology</th>
<th>Structure</th>
<th>Culture</th>
<th>Strategy</th>
<th>External Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>Experience</td>
<td>Cognitive Bias</td>
<td>Personal Characteristics</td>
<td>System Architecture</td>
<td>System-User Interaction</td>
</tr>
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<td>Davis-Besse (2002)</td>
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</tr>
<tr>
<td>Signal: failure mechanism dismissed in NRC and Davis-Besse examination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal: timing of the inspection delayed for several months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal: inadequate inspections for years</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Signal: early indications by different plant systems not put together</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Certain risks were downplayed. PRAs performed with naive assumptions excluding realistic (albeit unlikely and uncertain) risks.
- (Foreign) operating experience not systematically collected, communicated and evaluated.
- NRC failed to integrate known or available information into its assessments of Davis-Besse.
- Both long term and short term safety culture not (actively) advocated by management; monetary incentive program rewards production more than safety at senior levels of the organization.
- Incomplete investigations; sensitivity study to examine the impact of alternative assumptions not included.
- Certain risks were downplayed. PRAs performed with naive assumptions excluding realistic (albeit unlikely and uncertain) risks.
- Lack of Hazard Analyses, less than adequate implementation of the corrective action program.
- Planned inspection, maintenance and modification activities frequently deferred.
### Table A5.6: Results case study analysis - Deepwater Horizon (preliminary)

<table>
<thead>
<tr>
<th>Human Factors</th>
<th>Internal Environment</th>
<th>External Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Structure</td>
<td>Culture</td>
</tr>
<tr>
<td>System</td>
<td>Training</td>
<td>Compliance</td>
</tr>
<tr>
<td>Architecture</td>
<td>Compliances</td>
<td>Internal Stakeholder</td>
</tr>
<tr>
<td>Procedures</td>
<td>Communication</td>
<td>Engagement</td>
</tr>
<tr>
<td>Responsibilities &amp; Authority</td>
<td>Leadership</td>
<td></td>
</tr>
<tr>
<td>Communication &amp; Authority</td>
<td>Group Behavior</td>
<td></td>
</tr>
<tr>
<td>System User Interaction</td>
<td>Empowerment</td>
<td></td>
</tr>
<tr>
<td>Personal Circumstances</td>
<td>Management Commitment</td>
<td></td>
</tr>
<tr>
<td>Personal Characteristics</td>
<td>Vision</td>
<td></td>
</tr>
<tr>
<td>Cognitive Bias</td>
<td>External Stakeholder Engagement</td>
<td></td>
</tr>
<tr>
<td>Experience</td>
<td>External Communication</td>
<td>Exogenous</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Deepwater Horizon (2010)**

- **Signal: lax Quality Assurance/Quality Control**
  - X
  - X
  - X
  - X
  - X
  - X

- **Signal: fragmentation of responsibility between BP, Transocean and Halliburton**
  - X
  - X

- **Signal: excessive economic and schedule pressures (Transocean pressured by BP)**
  - X
  - X

- **Signal: evidence of damaged parts of the Blow Out Preventer (BOP) weeks earlier ignored**
  - X
  - X

**Overall**

| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 0 | 3 | 1 | 2 | 0 | 1 | 0 | 0 | 2 | 1 | 2 | 0 | 1 |
Table A5.7: Results case study analysis - Fires semiconductor plant (Nokia vs. Ericsson)

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal: glitch in the flow of chips before Philips' communication - Nokia's response</td>
<td>Experience</td>
<td>Education</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: Philips' communication about plant fire (&quot;back to normal within a week&quot;) - Nokia's response</td>
<td>Cognitive Bias</td>
<td>System Architecture</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: Philips' communication about plant fire (&quot;back to normal within a week&quot;) - Ericsson's response</td>
<td>Personal Characteristics</td>
<td>Procedures</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Overall</td>
<td>Internal Circumstances</td>
<td>Communications &amp; Authority</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>System-User Interaction</td>
<td>Responsibility &amp; Authority</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>Compliance</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Internal Stakeholder Engagement</td>
<td>Internal Organizational Risk Attitude</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Organizational Learning</td>
<td>Leadership</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Group Behavior</td>
<td>Empowerment</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Management Commitment</td>
<td>Vision</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>External Stakeholder Engagement</td>
<td>External Communication</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Exogenous</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</table>

<table>
<thead>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal: glitch in the flow of chips before Philips' communication - Nokia's response</td>
<td>Experience</td>
<td>Education</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: Philips' communication about plant fire (&quot;back to normal within a week&quot;) - Nokia's response</td>
<td>Cognitive Bias</td>
<td>System Architecture</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: Philips' communication about plant fire (&quot;back to normal within a week&quot;) - Ericsson's response</td>
<td>Personal Characteristics</td>
<td>Procedures</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Overall</td>
<td>Internal Circumstances</td>
<td>Communications &amp; Authority</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>System-User Interaction</td>
<td>Responsibility &amp; Authority</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
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<td>X</td>
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<td>X</td>
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<tr>
<td></td>
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<td>Leadership</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Group Behavior</td>
<td>Empowerment</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Management Commitment</td>
<td>Vision</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>External Communication</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Exogenous</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Overall | Education | Experience | Cognitive Bias | Personal Characteristics | Internal Circumstances | System Architecture | Procedures | Communications & Authority | Responsibility & Authority | Training | Internal Stakeholder Engagement | Internal Organizational Risk Attitude | Organizational Learning | Leadership | Group Behavior | Empowerment | Management Commitment | Vision | External Stakeholder Engagement | External Communication | Exogenous | 1 | 3 | 0 | 1 | 0 | 2 | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 3 | 2 | 1 | 0 | 1 | 2 | 2 | 2 | 2 | 0
Table A5.8: Results case study analysis - Flixborough

<table>
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<tr>
<th>Human Factors</th>
<th>Technologies</th>
<th>Internal Environment</th>
<th>Strategy</th>
<th>External Environment</th>
<th>Exogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flixborough (1974)</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: no Works Engineer, no mechanical engineer on site of sufficient qualification</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal: non qualified people constructing emergency piping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Signal: bypass assembly not constructed according to standards and codes of practice.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Signal: temporary piping &amp; scaffolding solution allowed for several months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>2</td>
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<td>Technology</td>
<td>Internal Environment</td>
<td>Culture</td>
<td>Strategy</td>
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<td>Education</td>
<td>Experience</td>
<td>Cognitive Bias</td>
<td>Personal Circumstances</td>
<td>System Architecture</td>
</tr>
<tr>
<td>Imperial Sugar (2008)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Signal: growing accumulation of granulated sugar and sugar dust over a long period in several manufacturing and packaging areas, a lo near electrical equipment</td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal: poorly maintained equipment</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Signal: frequent earlier small fires due to ignited spilled sugar or airborne sugar dust</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Signal: Imperial Sugar made aware of the OSHA combustible dust national emphasis program months prior to the accident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal: unsafe design of the enclosed steel conveyor belts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
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</table>
### Table A5.10: Results case study analysis - Texas City BP

<table>
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<th>Internal Environment</th>
<th>Strategy</th>
<th>External Environment</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>Experience</td>
<td>Cognitive Bias</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience</td>
<td>Cognitive Bias</td>
<td>Personal Characteristics</td>
<td></td>
<td></td>
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<tr>
<td>Cognitive Bias</td>
<td>Personal Circumstances</td>
<td>System Architecture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal Circumstances</td>
<td>System-User Interaction</td>
<td>Procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System-User Interaction</td>
<td>Responsibility &amp; Authority</td>
<td>Training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Responsibility &amp; Authority</td>
<td>Compliance</td>
<td>Internal Stakeholder Engagement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td>Compliance</td>
<td>Internal Stakeholder Engagement</td>
<td></td>
<td></td>
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<tr>
<td>Compliance</td>
<td>Internal Stakeholder Engagement</td>
<td>Organizational Risk Attitude</td>
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<td>Internal Stakeholder Engagement</td>
<td>Organizational Risk Attitude</td>
<td>Organizational Learning</td>
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<td>Leadership</td>
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<td>Organizational Learning</td>
<td>Leadership</td>
<td>Group Behavior</td>
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<td>Leadership</td>
<td>Group Behavior</td>
<td>Empowerment</td>
<td></td>
<td></td>
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<tr>
<td>Group Behavior</td>
<td>Empowerment</td>
<td>Management Commitment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empowerment</td>
<td>Management Commitment</td>
<td>Vision</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management Commitment</td>
<td>Vision</td>
<td>External Stakeholder Engagement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vision</td>
<td>External Stakeholder Engagement</td>
<td>External Communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Communication</td>
<td>External Communication</td>
<td>Exogenous</td>
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</tbody>
</table>

**Texas City BP (2005)**

<table>
<thead>
<tr>
<th>Human Factors</th>
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<th>Internal Environment</th>
<th>Strategy</th>
<th>External Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal: incrementally lower safety standards accepted throughout operations</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: frequent loss of containment incidents and process incidents (such as fires) prior to and after the accident</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: as early as 1992, incidents warned of the unsafe nature of the blowdown and stack system</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal: BP management focus on occupational safety instead of process safety</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Overall</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tbody>
</table>
**Table A5.11: Results case study analysis - Three Mile Island**

<table>
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<th>Strategy</th>
<th>External Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Mile Island (1979)</td>
<td>Signal: previous incidents in which PORV had been stuck in open position</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Signal: difficult to interpret instrumentation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Signal: strong focus on major accidents, small accidents considered less relevant</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Signal: in design, ancillary systems not given as much attention as the main system</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Signal: two valves on the auxiliary feedwater pumps inadvertently been left shut</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Overall</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Appendices Chapter 6
Appendix 6.1 Factor relevance scores for each influencing factor

Fig. A6.1: Factor relevance scores Education to System User Interaction

Fig. A6.2: Factor relevance scores Procedures to Training

Fig. A6.3: Factor relevance scores Internal Stakeholder Engagement to Group Behavior
Fig. A6.4: Factor relevance scores Empowerment to External Communication
Appendix 6.2 Calculation of normalized ratings

Let $r_{ij}$ be the original relevance score of the $i^{th}$ factor by the $j^{th}$ respondent.

**Step 1:** Normalize $r_{ij}$’s to obtain normalized weights:

$$ w_{ij} = \frac{r_{ij}}{\sum_{l=1}^{m} r_{lj}} $$

where $m$ equals the number of factors that respondent $j$ indicated as being relevant.

**Step 2:** Average the normalized weights to get a final normalized weight for each factor:

$$ \bar{w}_i = \frac{\sum_{j=1}^{n_i} w_{ij}}{n_i} $$

where $n_i$ equals the number of respondents that indicated factor $i$ as being relevant.

**Step 3:** Apply linear interpolation to transform the final normalized weights $\bar{w}_i$ into final normalized ratings $\bar{x}_i$, between 1 and 5 (similar to the 5-point scale used in the survey):

$$ \bar{x}_i = 1 + (\bar{w}_i - \bar{w}_{min}) \ast \left( \frac{5 - 1}{\bar{w}_{max} - \bar{w}_{min}} \right) $$

where $\bar{w}_{min}$ is the lowest final normalized weight obtained, and $\bar{w}_{max}$ is the highest final normalized weight obtained.
## Appendix 6.3  Factor ranking

Table A6.1: Factor ranking based on Kruskal-Wallis mean ranks and normalized factor ratings

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>Kruskal-Wallis mean ranks</th>
<th>Rank #</th>
<th>Normalized factor ratings</th>
<th>Rank #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>310.81</td>
<td>13</td>
<td>2.15</td>
<td>12</td>
</tr>
<tr>
<td>Experience</td>
<td>432.06</td>
<td>2</td>
<td>5.00</td>
<td>1</td>
</tr>
<tr>
<td>Cognitive Bias</td>
<td>349.00</td>
<td>8</td>
<td>3.47</td>
<td>6</td>
</tr>
<tr>
<td>Personal Characteristics</td>
<td>278.92</td>
<td>19</td>
<td>1.51</td>
<td>15</td>
</tr>
<tr>
<td>System Architecture</td>
<td>296.11</td>
<td>17</td>
<td>1.30</td>
<td>18</td>
</tr>
<tr>
<td>System User Interaction</td>
<td>306.82</td>
<td>15</td>
<td>1.48</td>
<td>16</td>
</tr>
<tr>
<td>Procedures</td>
<td>252.04</td>
<td>21</td>
<td>1.00</td>
<td>21</td>
</tr>
<tr>
<td>Compliance</td>
<td>350.88</td>
<td>7</td>
<td>3.36</td>
<td>7</td>
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<td>Communication</td>
<td>456.85</td>
<td>1</td>
<td>4.75</td>
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</tr>
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<td>Responsibility &amp; Authority</td>
<td>307.79</td>
<td>14</td>
<td>1.76</td>
<td>14</td>
</tr>
<tr>
<td>Training</td>
<td>325.48</td>
<td>11</td>
<td>2.18</td>
<td>11</td>
</tr>
<tr>
<td>Internal Stakeholder Engagement</td>
<td>418.77</td>
<td>3</td>
<td>4.00</td>
<td>3</td>
</tr>
<tr>
<td>Organizational Risk Attitude</td>
<td>384.09</td>
<td>5</td>
<td>3.76</td>
<td>5</td>
</tr>
<tr>
<td>Organizational Learning</td>
<td>377.21</td>
<td>6</td>
<td>3.20</td>
<td>8</td>
</tr>
<tr>
<td>Leadership</td>
<td>315.40</td>
<td>12</td>
<td>2.04</td>
<td>13</td>
</tr>
<tr>
<td>Group Behavior</td>
<td>345.30</td>
<td>9</td>
<td>2.67</td>
<td>9</td>
</tr>
<tr>
<td>Empowerment</td>
<td>295.77</td>
<td>18</td>
<td>1.44</td>
<td>17</td>
</tr>
<tr>
<td>Management Commitment</td>
<td>395.76</td>
<td>4</td>
<td>3.84</td>
<td>4</td>
</tr>
<tr>
<td>Vision</td>
<td>297.15</td>
<td>16</td>
<td>1.12</td>
<td>19</td>
</tr>
<tr>
<td>External Stakeholder Engagement</td>
<td>338.02</td>
<td>10</td>
<td>2.57</td>
<td>10</td>
</tr>
<tr>
<td>External Communication</td>
<td>278.42</td>
<td>20</td>
<td>1.02</td>
<td>20</td>
</tr>
</tbody>
</table>
## Appendix 6.4 Separate Mann-Whitney U tests (industry)

### Table A6.2: Separate Mann-Whitney U tests on industry, with Bonferroni correction

<table>
<thead>
<tr>
<th>#</th>
<th>Comparison</th>
<th>Mann Whitney U</th>
<th>Z-value</th>
<th>Asympt. Sign.</th>
<th>P-value (corrected)</th>
<th>Result*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transport vs. Civil Engineering</td>
<td>6366.00</td>
<td>-0.01</td>
<td>0.99</td>
<td>0.05/1</td>
<td>No significant difference</td>
</tr>
<tr>
<td>2</td>
<td>Transport vs. Energy</td>
<td>1235.00</td>
<td>-0.03</td>
<td>0.98</td>
<td>0.05/2</td>
<td>No significant difference</td>
</tr>
<tr>
<td>3</td>
<td>Infrastructure vs. (Semi) Government</td>
<td>1561.50</td>
<td>-0.04</td>
<td>0.97</td>
<td>0.05/3</td>
<td>No significant difference</td>
</tr>
<tr>
<td>4</td>
<td>Energy vs. Civil Engineering</td>
<td>4514.50</td>
<td>-0.05</td>
<td>0.96</td>
<td>0.05/4</td>
<td>No significant difference</td>
</tr>
<tr>
<td>5</td>
<td>Energy vs. Other</td>
<td>3441.00</td>
<td>-0.07</td>
<td>0.94</td>
<td>0.05/5</td>
<td>No significant difference</td>
</tr>
<tr>
<td>6</td>
<td>Transport vs. Other</td>
<td>4818.50</td>
<td>-0.12</td>
<td>0.90</td>
<td>0.05/6</td>
<td>No significant difference</td>
</tr>
<tr>
<td>7</td>
<td>Civil Engineering vs. Other</td>
<td>17644.50</td>
<td>-0.17</td>
<td>0.86</td>
<td>0.05/7</td>
<td>No significant difference</td>
</tr>
<tr>
<td>8</td>
<td>(Semi) Government vs. Energy</td>
<td>1072.50</td>
<td>-0.77</td>
<td>0.44</td>
<td>0.05/8</td>
<td>No significant difference</td>
</tr>
<tr>
<td>9</td>
<td>Transport vs. (Semi) Government</td>
<td>1503.00</td>
<td>-0.87</td>
<td>0.39</td>
<td>0.05/9</td>
<td>No significant difference</td>
</tr>
<tr>
<td>10</td>
<td>(Semi) Government vs. Other</td>
<td>4257.00</td>
<td>-0.92</td>
<td>0.36</td>
<td>0.05/10</td>
<td>No significant difference</td>
</tr>
<tr>
<td>11</td>
<td>Infrastructure vs. Energy</td>
<td>1043.50</td>
<td>-1.00</td>
<td>0.32</td>
<td>0.05/11</td>
<td>No significant difference</td>
</tr>
<tr>
<td>12</td>
<td>(Semi) Government vs. Civil Engineering</td>
<td>5515.50</td>
<td>-1.07</td>
<td>0.29</td>
<td>0.05/12</td>
<td>No significant difference</td>
</tr>
<tr>
<td>13</td>
<td>Transport vs. Infrastructure</td>
<td>1463.00</td>
<td>-1.11</td>
<td>0.27</td>
<td>0.05/13</td>
<td>No significant difference</td>
</tr>
<tr>
<td>14</td>
<td>Infrastructure vs. Other</td>
<td>4160.00</td>
<td>-1.17</td>
<td>0.24</td>
<td>0.05/14</td>
<td>No significant difference</td>
</tr>
<tr>
<td>15</td>
<td>Infrastructure vs. Civil Engineering</td>
<td>5349.00</td>
<td>-1.41</td>
<td>0.16</td>
<td>0.05/15</td>
<td>No significant difference</td>
</tr>
<tr>
<td>16</td>
<td>Energy vs. Chemical Industry</td>
<td>1274.00</td>
<td>-2.72</td>
<td>0.01</td>
<td>0.05/16</td>
<td>No significant difference</td>
</tr>
<tr>
<td>17</td>
<td>Transport vs. Chemical Industry</td>
<td>1802.00</td>
<td>-2.97</td>
<td>0.00</td>
<td>0.05/17</td>
<td>No significant difference</td>
</tr>
<tr>
<td>18</td>
<td>(Semi) Government vs. Chemical Industry</td>
<td>1601.00</td>
<td>-3.40</td>
<td>0.00</td>
<td>0.05/18</td>
<td>Significant difference</td>
</tr>
<tr>
<td>19</td>
<td>Chemical Industry vs. Other</td>
<td>5027.50</td>
<td>-3.75</td>
<td>0.00</td>
<td>0.05/19</td>
<td>Significant difference</td>
</tr>
<tr>
<td>20</td>
<td>Chemical Industry vs. Civil Engineering</td>
<td>6583.50</td>
<td>-3.92</td>
<td>0.00</td>
<td>0.05/20</td>
<td>Significant difference</td>
</tr>
<tr>
<td>21</td>
<td>Infrastructure vs. Chemical Industry</td>
<td>1462.00</td>
<td>-4.02</td>
<td>0.00</td>
<td>0.05/21</td>
<td>Significant difference</td>
</tr>
</tbody>
</table>

* If the test’s significance value is below the corrected P-value, a significant difference between the two industries in question is observed. If not, no significant difference is found.
Appendix 6.5  Separate Mann-Whitney U tests (organizational level)

Table A6.3: Separate Mann-Whitney U tests on organizational level, with Bonferroni correction

<table>
<thead>
<tr>
<th>#</th>
<th>Comparison</th>
<th>Mann Whitney U</th>
<th>Z-value</th>
<th>Asympt. Sign.</th>
<th>P-value (corrected)</th>
<th>Result*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strategic vs. Tactical</td>
<td>47625.50</td>
<td>-0.80</td>
<td>0.43</td>
<td>0.05/1</td>
<td>No significant difference</td>
</tr>
<tr>
<td>2</td>
<td>Strategic vs. Operational</td>
<td>31582.50</td>
<td>-2.60</td>
<td>0.01</td>
<td>0.05/2</td>
<td>Significant difference</td>
</tr>
<tr>
<td>3</td>
<td>Tactical vs. Operational</td>
<td>38520.50</td>
<td>-3.69</td>
<td>0.00</td>
<td>0.05/3</td>
<td>Significant difference</td>
</tr>
</tbody>
</table>

* If the test’s significance value is below the corrected P-value, a significant difference between the two industries in question is observed. If not, no significant difference is found.
Curriculum Vitae

Joël Luyk was born in Eindhoven, the Netherlands, on the 21st of July, 1981. In 2005 he received his Masters degree (cum laude) in Industrial Engineering and Management Science from the Eindhoven University of Technology. The topic of his M.Sc. graduation project was reliability optimization and its impact on product (re)design. During his work as a business analyst for a global consulting firm, he was involved in multiple strategic projects within the Dutch energy sector. Being involved in these projects, he became increasingly interested in the field of risk management.

Based on this initial interest, he started his Ph.D. research project at the sub department of Quality and Reliability Engineering at the faculty of Technology Management at Eindhoven University of Technology in June 2006. From January 2008 onwards, this project was continued at the sub department of Operations, Planning, Accounting and Control within the same faculty, which was renamed to the faculty of Industrial Engineering and Innovation Sciences. His Ph.D. project was performed in cooperation with various academic and industrial partners.