Assessing the risk position of Enexis

Research to a methodology to assess the overall risk position of Enexis

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ENEXIS

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Summary

Risk management is of major importance for companies nowadays and the lack of it can have enormous consequences as it is currently illustrated by the world wide credit crunch. Enexis uses risk management on a corporate and operational level. On the operational level Enexis uses risk management to find the optimal way to manage its physical asset base. Therefore Enexis is availed by an adequate operational risk management process. In this research a risk is defined as an event with a certain probability of occurrence, which negatively affects one of the business values of Enexis.

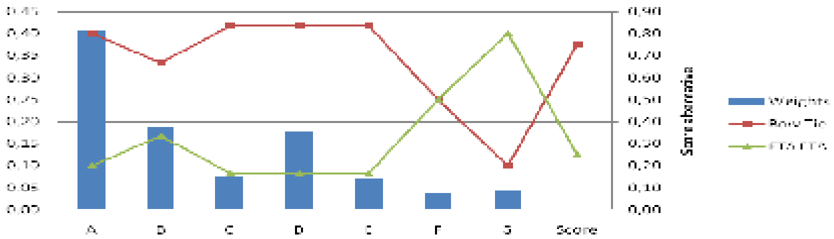
Enexis uses asset management to meet its mission, to be and stay an excellent network operator, and to meet the goals related to this mission. To be able to take complex decisions over the large number of assets, which show a big diversity, Enexis implemented the Risk Based Asset Management (RBAM) methodology (Essent Netwerk, 2006). This methodology has to guarantee an optimal risk reduction within the existing constraints of available funds and people. Within the current methodology most risks are treated as individual events that happen independent from each other. In practice risk are not independent events and for some risks policies are already in place. The current risk management process results in a over-estimated risk position. Due to problems with interrelations/overlap the calculated risk position of Enexis shows an over-estimation of the true position. A over-estimated risk position may trigger more actions and expenses than can be justified on the basis of the actual risks Enexis faces. Eventually this may lead to a culture of incorrect decision-making and overspending. Therefore Enexis want to optimize their risk management process. Hence the goal of this research is:

How can Enexis determine its risk position, make the effectiveness of her policy on the risk position theoretically and practically provable and how could this be secured in the future?

To answer this question the research is divided in two parts. The first part consists of a literature review of risk categorization, risk assessment methodologies and the choice of the optimal risk assessment methodology for Enexis. The second part consists of the application of the risk assessment methodology and the calculation of the improved risk position.

Within the current literature on risk categorization there is no unique best way for the categorization of risks. Each categorization of risks serves different objectives and therefore needs a specific categorization. Hence it is important that risk categories reflect management objectives instead of following a guideline for risk categorization. However there is no best way of categorization Morgan *et al.* (2000) defined a list of desirable attributes for an ideal risk categorization.

A literature study of risk assessment methodologies resulted in 28 different assessment methods. A quick scan of all methods resulted in two possible useful risk assessment methodologies for Enexis: Bow Tie Analysis or a combination of Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). The Analytic Hierarchy Process (AHP) is used to determine the optimal risk assessment methodology for Enexis. As shown in the graph below the Bow Tie Analysis outperforms the combination of FTA and ETA on almost all criteria. From the graph it follows that the Bow Tie Analysis is the best risk assessment methodology for Enexis. A sensitivity analysis confirmed that changes in priorities do not significantly affect the outputs and therefore the ranking of the alternatives is assumed to be robust and satisfactory.



With the desired attributed for ideal risk categorization in mind the risks identified by Enexis are categorized in eleven risk catogories. This results in about 25 till 30 risk per categorie, which is a well manageble amount of risk per category.

The Bow Tie methodology is applied on two of the defined risk categories to show its applicability on the risk register and specifically its use within the utility sector. As a result of the Bow Tie Analysis relations between risks and the relations between risks and risk management policies are visualized. During the process the quantification of Bow Tie Analysis appeared to be a complex matter. Quantification of Bow Tie Analysis require detailed information and knowledge about the effectively of barriers, since this information and knowledge is currently not available Enexis is at this moment in time not able to perform the final step of the Bow Tie Analysis and quantify the Bow Tie Analysis

The Bow Tie Analysis provided the desired insight in the relation between risks and the link between risks and policies. However to prove its effectiveness Enexis has to perform further research to the quantification of Bow Tie Analysis. It is recommended that Enexis starts with the determination of the effectiveness of barriers.

Monte Carlo Simulation is used to determine the risk position of Enexis. During the analysis of the risk register for the Bow Tie Analysis it became apparent that the data used for the Monte Carlo Simulation was not as accurate as it should be. Since simulations cannot be more accurate than the input variables they are based on this directly affects the accuracy of the simulation. This research limits itself to an improvement of the current input variables without questioning whether the type of probability distribution of the input variables is correct.

Based on the insight provided by the Bow Tie Analysis overlapping risks are excluded from the Monte Carlo Simulation. The combination of excluding overlapping risk and the improvement of the data quality resulted in an improved accuracy of the risk position between 100% and 270%. Therefore it is recommended that Enexis pays greater attention to the accuracy of the data in the risk register. However the theoretical risk position is improved it is still overestimating the actual risk position. Further research is needed to make a next step in the improvement of the theoretical risk position. It is expected that the assumed Poisson distribution might not be the best distribution to model the risk variables. However further research to the type of probability distribution used to model the risk variables is needed to justify this assumption

.

Preface

This report presents the final results of my graduation project at Enexis in Arnhem, The Netherlands. I conducted the project from May 2008 until Januari 2009 in order to finish my study and receive my Master's Degree in Industrial Engineering and Management (Financial Engineering and Management track) at the University Twente in Enschede, The Netherlands.

The past seven months I have had the opportunity to work in an instructive, informal and pleasant work environment. Enexis has given me thereby much space to work independent on my research project, but on the other side involved me in work meetings and risk assessment sessions. Beside these formal matters I have experienced that there are within Enexis many opportunities to meet colleagues in an informal way. I had the opportunity to participate in their three of their 'themadagen'. At this place I like to thank all my colleagues at Enexis for the interesting, educational but most of all pleasant time!

Throughout the duration of the research I had the privilege to be coached by three supervisors. My supervisor at Enexis, Martijn Korn, you where always available to answer my question and discuss my ideas. Your critical attitude allowed me to get to this result. Thanks for that! Furthermore my supervisors at the University Twente, Peter Boorsma en Joop Halman. Thanks for your valuable and critical remarks and additions during the whole process!

Last but not least I like to thank my parents, my girlfriend Brit, family and friends who all contributed in their own specific way!

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1 Research Plan

This chapter will give an introduction to the problem (1.1) and will outline the derived problem definition and research questions (1.2). Furthermore it will elaborate on the research methods used during the study and clarify the choices for the particular research methods (1.3). The chapter will end with a research plan which indicates the subject that will be discussed in the next chapters (1.4).

1.1 Introduction

This graduation project takes place within Enexis BV. Enexis BV is a non-listed public company with limited liability, incorporated in 2009 and with its head office resident in Rosmalen. Its shareholders are Dutch provincial and municipal authorities. Figure 1.1 shows the organization chart of Enexis B.V.

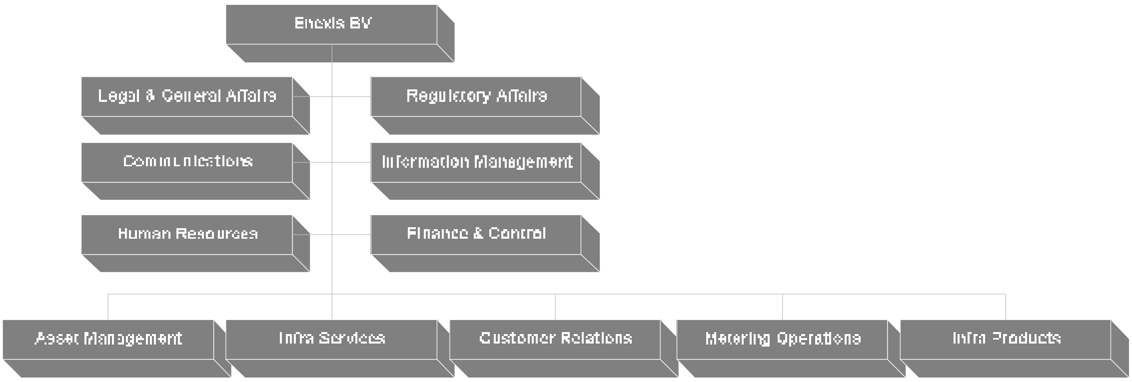


Figure 1.1 Organization chart Enexis BV (Essent Netwerk, 2007a)

Enexis is responsible for the construction, maintenance and management of the gas and electricity distribution networks. It is operating mainly in the northern, eastern and southern parts of the Netherlands, manages approximately 146,000 km of electricity cables and 40,000 km of gas pipelines. As well as managing the energy networks, Enexis conducts a number of non-regulated activities. These are services relating to street lighting and traffic and parking systems, as well as the rental of medium-voltage equipment and electricity and gas meters (Essent Netwerk, 2007a).

In its capacity of network operator, Enexis is accountable to the Office of Energy Regulation (Energiekamer), the Dutch supervisory authority for energy.

1.2 Problem definition and research questions

"*Risk management is a rapidly developing discipline and there are many and varied views and descriptions of what risk management involves, how it should be conducted and what it is for*" (AIRMIC, ALARM & IRM, 2002).

Enexis uses asset management to meet its mission, to be and stay an excellent network operator, and to meet the goals related to this mission. To be able to take complex decisions over the large number of assets, which show a big diversity, Enexis implemented the Risk Based Asset Management (RBAM) methodology (Essent Netwerk, 2006). This methodology has to guarantee an optimal risk reduction within the existing constraints of available funds and people. Furthermore RBAM has to quantitatively ground decisions, make decision-making between different products (electricity and gas) comparable and provide openness and transparency toward stakeholders (including the Dutch supervisor on the electricity law and gas law, the Office of Energy Regulation (Energiekamer)). RBAM roughly comprises the following five steps: (1) Risk identification and analysis, (2) development of alternative solutions, (3) Choice and approval of the optimal solution, (4) implementation and program management and (5) evaluation of the implemented solution (e.g. risk reduction). This methodology is summarized in figure 1.2

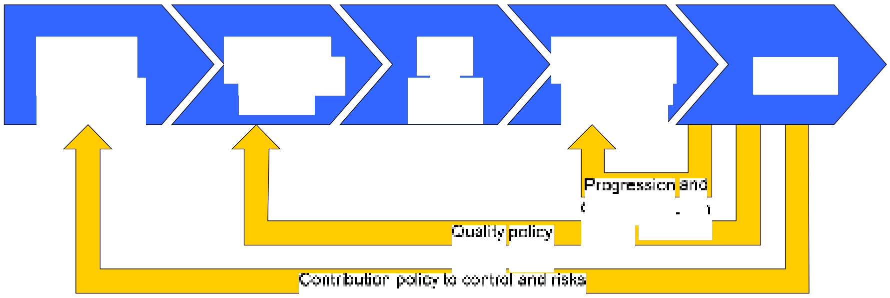


Figure 1.2 Summary of the Risk Based Asset Management methodology (Essent Network, 2006)

The RBAM methodology results in four primary products: (1) Risk analysis, (2) Strategies, (3) Tactics and (4) Evaluations of tactics. These products form the basis for the asset management process within Enexis. Furthermore there are three other products which are realized within the RBAM: (1) Strategic Asset Management Plan, (2) Tactic Register and (3) Risk Register. This study focuses on the Risk Register; in this register all identified and analyzed risk are stored and collected. Currently this register is mainly used to develop asset related policies. The purpose of the Risk Register is twofold: (1) it gives an overview of the risk position and (2) it is used to develop asset related policies.

Enexis realizes that for effective asset management it needs a complete and clear image of its overall risk position. To provide insight into its risk position it wants to use its Risk Register. The Risk Register gives an overview of the risk position to the Asset Owner including the relations between the individual risk, the mapping of these relations and it supports the prioritization of risk for detailed analysis and the development of strategies and tactics. Furthermore it links identified risks to the developed policy for that specific risk (Essent Netwerk, 2007b). With the passing of time the Risk Register of Enexis became too extensive, containing over 900 risks nowadays, and the theoretical risk position generated by the risk register is much higher then it is in practice. Because of this unrealistic risk position generated by the risk register the effectiveness of the policy measures on this risk position are vague. To create transparency there has to be developed a methodology which can link all individual risks in such a way that the overall risk position becomes clear. Furthermore it should make policy measures additive and linked to the right main risks. Enexis needs a clear view of its risk position, but the lack of insight in its position created the following problem definition

How can Enexis determine its risk position, make the effectiveness of her policy on the risk position theoretically and practically provable and how could this be secured in the future?

To come to a well founded research several research questions are formulated in order to come up with an answer to the problem as it is formulated before.

1. *Which definitions are the basis of risk management and what do they mean according to literature?*
   1.1. What is the meaning of the definition of risk?
   1.2. What is the meaning of the definition of risk management?

2. *How is the risk management process organized at Enexis?*
   2.1. Which definition of risk does Enexis use?
   2.2. How is the risk management process organized at Enexis?
   2.3. How does Enexis determine its current risk position?

3. *What does the literature prescribe for a solid methodology to assess the risk position?*
   3.1. Which methodologies does literature prescribe for risk categorizing?
   3.2. Which methodologies does literature prescribe to provide insight in the relation between hazards, risks associated with it and consequences?
   3.3. Which methodologies does literature prescribe for risk assessment?

4. *What is Enexis's current and future risk position?*
   4.1. What is a reasonable risk categorization for Enexis?
   4.2. Are there identified risks which relate to each other and the developed risk categories, and if so how do they relate?
   4.3. What is the current risk position of Enexis according to the developed methodology for the assessment of the risk position?
   4.4. How could the developed method be used to make the effectiveness of the policy provable?

1.3 Research methods

In this paragraph the research methods for each research question will be explained including the pros and cons for the chosen research methods and why the particular research method is chosen.

1.3.1 Overall research method

This study is a combination of a literature study and a case study (Cooper & Schindler, 2006). The first part of the study consists of a literature study to develop a model to asses the risk position of an organization. The second part the developed model will be used to asses the risk position of Enexis. With the use of the developed model and several individual and group interviews the Risk Register will be analyzed.

1.3.2 Research question 1

To get a clear idea about the basis of risk management this study starts with a literature review to find the different meanings of the basis concepts of risk management and to come up with general definitions of the concepts risk and risk management. These definitions will form the basis of this study.

1.3.3 Research question 2

This part of the study will give the general outline of the risk management process at Enexis, based on interviews with specialists and internal documents about guidelines. The combination of interviews and written documents should give a clear view of the intended risk management process and the actual practice of the process.

1.3.4 Research question 3

Based on a literature review the current knowledge and ideas on risk categorization, finding relations between risk and risk assessment, and the strengths and weaknesses of these knowledge and ideas are put into words. To answer this research question is chosen for a literature review since a review creates, if it is preformed effectively, a solid foundation for bringing knowledge to a next level (Webster & Watson, 2002). Problem with a literature review is that it is easy to let it end in endless lists of citations and findings without a plot (Bem, 1995), therefore it is necessary to use a well structured plan. With the current theories as a starting point a risk assessment model is developed to assess the overall risk position of a company

1.3.5 Research question 4

This part of the study will be a case study at Enexis, based on the developed model the Risk Register will be analyzed. This analysis will exist of three parts: (1) Defining risk categories, (2) Mapping relations between hazards, risks and consequences and (3) Assessing the risk position. Each of the three parts will need its own specific research method to tackle the problem. The analysis starts with defining risk categories according to the developed methodology, to come up with a reasonable categorization. The categories are determined during several session, starting with brainstorming sessions per category of the risk register to come to possible risk categories and it will end with a group interview (Cooper & Schindler, 2006), a small group of experts of all fields, which will determine the definite risk categories from the suggestion in brainstorm session. The next step is to map all the relations between hazards, risks and consequences. This will be done on the basis of interviews and group meetings with specialists in each field (gas and electricity) and the overall risk analysts, since they have most insight in the relations between all problems. The sample size of all these sessions varied between six and ten people. After the mapping all risks have to be quantified and with the use of the assessment model the overall risk position will be determined.

1.4 Research outline

This paragraph will briefly discuss the content of the report. *Chapter 1* will elaborate on the research plan and will define scope of the research, in the next chapter, *Chapter 2*, the most important concepts behind risk management will be explained. In *Chapter 3* will elaborate on how the risk management process is organized within Enexis, next a methodology to assess the overall risk position will be developed in *Chapter 4*. In *Chapter 5* this methodology will be used to assess the current and expected future risk position of Enexis. Finally the results of the assessment of the risk position will be summarized and conclusion will be drawn from the results, which will lead to recommendations to improve the risk assessment in *Chapter 6*.

2 Risk Management

This chapter examines the basis concepts of risk management. First the concept of risk is extensively studied (2.1). With a good understanding of the concept risk the concept of risk management is analyzed (2.2)

2.1 Risk

The typification of risk started in 1921 with the work of Knight (1921). According to Knight (1921) there is a distinction between measurable and unmeasurable uncertainties, where the term risk can be used to designate the former and the term uncertainty for the latter one.

"The essential fact is that "risk" means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character. and there are far-reaching and crucial differences in the bearings of the phenomenon depending on which of the two is really present and operating. It will appear that a measurable uncertainty, or "risk" proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all. We shall accordingly restrict the term "uncertainty" to cases of the non-quantitive type. It is this "true" uncertainty, and not risk, as has been argued, which forms the basis of a valid theory of profit" (Knight, 1921)

The distinction between risk and uncertainty appeared to be a major struggle in defining risk (van den Tillaart, 2003). According to van den Tillaart (2003) it is about the fundamental difference between '*expected – average losses*' and '*unexpected losses*'. Although many definitions of risk refer to (undesired) consequences, only the unexpected consequences that could not be foreseen are to be feared. Therefore risk should be defined in the way Knight (1921) defines uncertainty and this 'true' uncertainty should form the basis for the risk management profession (van den Tillaart, 2003).

The work of Knight started an exhaustive discussion about the concept of risk. One of the major distinctions that came into existence is the discussion between objectivists and constructivists (van Asselt, 2000; Denney, 2005, Lupton, 1999).The objectivists perceive risk as an objective hazard, threat or danger that exists and can be measured independently of social and cultural processes (Lupton, 1999). They define risk as the probability of the occurrence of an event multiplied with the magnitude of the consequence (ISO/IEC, 2002; Jaafari, 1999; MacCrimmon and Wehrung, 1986; March and Shapira, 1987; Muhlbauer, 2004, Sitkins and Pablo, 1992; Williams, 1995), where constructivists define risk in vague phrasing as "*nothing is a risk in itself, what we understand to be a risk is a product of historically, socially and politically contingent 'ways of seeing'*" *(Lupton, 1999)*, this view is supported by Douglas (1992), Fisschhoff, Watson and Hope (1984), Holton (2004) and Slovic (1999). Limitation of 'risk = probability × magnitude consequence' is that it scores risks with a low probability and a large consequence the same as risks with a high probability and a small consequence. This limitation becomes clear when looking at the risk of becoming ill. The risk of getting a flu, which has a large probability and limited consequences, and getting cancer, which has a low probability but major consequences, can result in the same risk level. Table 2.1 shows characteristics of the two major schools in the discussion about the definition of risk.

According to van den Tillaart (2003) the objectivists are focusing on 'risk' as it is defined by Knight (1921) and the constructivists are focusing on 'uncertainty' as defined by Knight (1921). Therefore the arguments of the constructivists should dominate the risk management profession (van den Tillaart, 2003). However this research does not distinct between risks and uncertainties. It assumes that there is a uncertainty component in each risk, because each risk can be expressed in the form of probability or the degree of likelihood (Halman, 1994)

Objectivists	Constructivists
Science is value free (i.e. positivism)	Science is entirely social (i.e. social or cultural relativism)
Distinction between objective and perceived Risks	Risk is a social construct. There is no objective definition of risk
Objective risks are measurable in terms of probability and utility	Risk analysis should involve qualitative factors that are difficult to measure
Risk assessment and risk management have to be separated	Risk assessment and management are inseparable activities in which value differences are at the core
Right expert calculations can settle risk issues	Participatory processes are needed to manage risk issues

Table 2.1 Characteristics of the two major schools thought in risk analysis (van Asselt, 2000)

Another often seen distinction in the literature is between the positive and negative perception of risk (Denney, 2004). In the negative perception risk corresponds solely to downside loss potential, it refers to negative outcomes (Douglas, 1990; Fisschhoff *et al*, 1984; MacCrimmon and Wehrung, 1986, McNamara and Bromily, 1999, Muhlbauer, 2004, Williams, 1995). The positive school includes a full range of outcomes, both positive and negative, in their conceptualization of risk (Hull, 2007, ISO/IEC, 2002, Jaafari, 1999; March and Shapira, 1992, Sitkin and Pablo, 1992). However this view does not correspond to the finding from the empirical study by March and Shapira (1987). Their study found that the vast majority of all managers do not treat uncertainty about positive outcomes as an important aspect of risk. Managers only consider the possibility of negative outcomes as a risk. Furthermore it has to be noted that there are types of risk with only negative consequences, like safety risks and technical risks. Therefore the management of these risks is focused on prevention and mitigation of harm. It can be concluded that there are on the one side risks which could be positive as well as negative, but in that case managers only consider the negative outcomes and on the other side there are risks with only negative consequences. Therefore the focus should be on the negative or 'pure' risks.

2.2 Risk Management

Risk management is increasingly popular and practiced every day by every individual. This can be illustrated with the following example. In operating a motor vehicle compensating for poor visibility by slowing down demonstrates a simple application of risk management (Muhlbauer, 2004). Nowadays risk management is a key activity for all corporations, since many disastrous losses could have been avoided if good risk management practices had been in place (Hull, 2007; AIRMIC *et al*, 2002)

In contrast to the discussion about the definition of risk there are no notable differences between the various definitions of risk management. The risk management function's primary responsibility is to understand the current and future risk position it faces. It must decide whether the risks are acceptable and, if they are not acceptable, what action should be taken to bring the risk at an acceptable level (Hull, 2007). Therefore risk management can be defined as the coordinated activities to direct and control an organization with regard to risk (ISO/IEC, 2002, Hull (2007); Muhlbauer, 2004; Klinke and Renn, 2002)

Petts (1992) states that risk management is the general term applied to the whole process of risk identification, estimation, evaluation, reduction and control, which indicates that there the risk management is composed out of various phases. According to Chapman (1997) all methodologies describe all relevant phases, although not all methodologies explicitly mention all steps. The Risk Management Platform at the University of Twente did a literature review to estimate the basic steps of the risk management process. For the purpose of this study this review is extended with the COSO framework for risk management. The main findings of this review are summarized in table 2.2. Based on this research there are four main phases in the risk management process: (1) preparation, (2) risk analysis, (3) risk response and (4) monitoring and control. Figure 2.1 shows the risk management process.

The first phase of the risk management process is not part of the risk management cycle, but defines the principle of the risk management process. This phase defines the scope of the risk management process as well as the organization of the risk management process. Phase two is the actual start of the risk management cycle. Within this phase there is a distinction between steps: (1) risk identification and (2) risk assessment. The first step is to identify all relevant (internal and external) risks the organization faces.

Phasing Risk Management										
		Define Focus	Risk management planning		Initial briefing			Internal Environment Objective Setting	Information & Communication	Preparation
Risk identification	Identification	Identify Structure Ownership	Risk identification	Identification	Kick-off meeting Individual interviews Design questionnaire	Execute / update risk analysis	Risk Assessment	Event Identification		Risk Analyse
Risk Analysis	Analysis Assessment	Estimate Evaluate	Qualitative risk analysis Qua... risk analysis	Estimation Evaluation	Answering questionnaire Risk profile			Risk Assessment		
		Plan	Risk response planning	Planning countermeasures Identifying and allocating resources	Preparing risk management session Risk management session	Select management measure	Risk Response	Risk Response		Risk Response
Risk control Risk reporting	Control	Manage	Risk monitoring and control	Monitoring Controlling	Drawing up and executing risk management plan	Execute management measure Evaluate management measure		Control Activities Monitoring		Monitor and Control

Table 2.2 Phasing of risk management (van der Heijden, 2006)

In the second step all identified risks have to be assessed on its probability of occurrence and its potential consequences. The third phase is about development of management measure and selecting appropriate measures out of all generated measures. According to Hillson (1999) and COSO (2004) there are four response strategies to develop management measures: (1) avoid risk, directed at the elimination of risk, (2) transfer risk, directed at transferring risk to a third party, (3) mitigate risk, directed at reducing the size of the risk by tackling either its probability to make it less likely, or its impact to make it less severe, or both and (4) risk acceptance, directed at the acceptance, monitoring and control of the remaining risks.
The fourth phase takes care of the implementation, control and evaluation of the selected management measures. After the implementation all measures have to be evaluated on progression and effectiveness, in other words is the implementation on schedule and are the target for risk reduction met. In case the targets are met there has to be feedback so the risk position can be updated and in case the evaluation shows that the measures do not meet the targets one of the previous steps have to be adjusted.

Risk management is not strictly a serial process, where one component affects only the next. It is a multidirectional, iterative process in which almost any component can and does influence another (COSO, 2004).

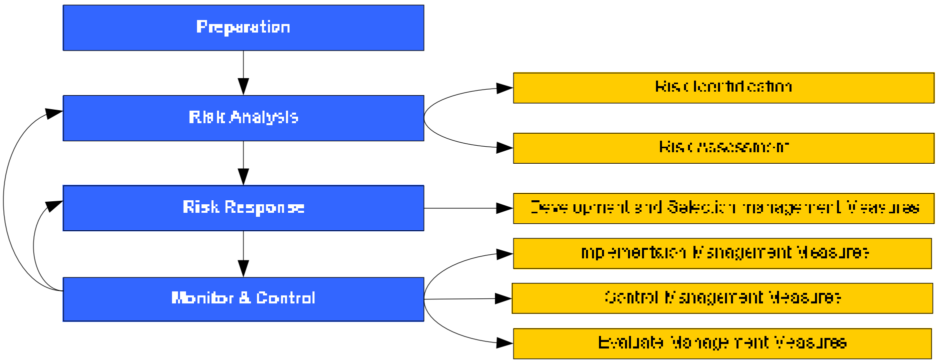


Figure 2.1 Risk management process

As stated above risk management is a key activity for all corporations which should be treated as a strategic business process (Clarke and Varna, 1999; Hulett, 2001, Francis and Paladino, 2008), however it is treated tactically (Clarke and Varna, 1999). The traditional risk management responsibilities and responses are typically fragmented as a result of their differing origins (Clarke and Varna, 1999). As a result risks are treated from separate and specialized departments. With each department concentrating on its own risks the relation with company goals get blurred and each risk becomes a goal in itself. Furthermore a lack of internal communication causes several departments to work on the same risk without knowing it from each other (Visser, 2006). To prevent this management needs an overall, bird's-eye view of the risk position (Clarke and Varna, 1999). To come to an enterprise wide risk management function the COSO (2004) offers a framework (figure 2.2) which integrates the risk management process in all levels of the organization and has the ability to focus on the entirety of an entity's enterprise risk management, or by objectives category, step of the risk management process, entity unit, or any subset thereof.

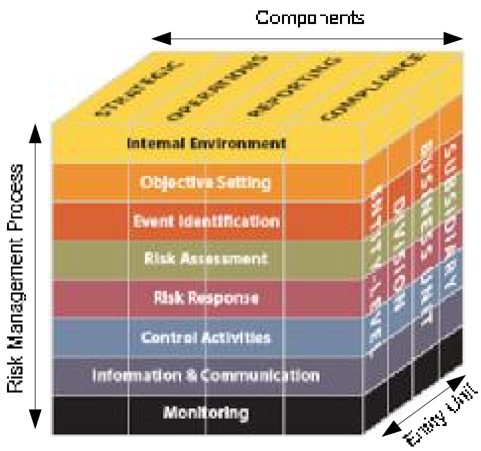


Figure 2.2 COSO enterprise risk management framework (COSO, 2004)

3 Risk Management at Enexis

This chapter describes the composition of the risk management process at Enexis (3.1) and how Enexis assesses its risks and risk position (3.2).

3.1 Risk management process

To clarify where the risk management process is about at Enexis this paragraph starts with a definition of risk according to Enexis (3.1.1). The remainder of this paragraph will elaborate on the risk management process at Enexis (3.1.2).

3.1.1 Risk according to Enexis

Enexis uses the following (constructive) definition of risk: Risk is an uncertain situation with several possible outcomes from which at least one is undesirable and about which a decision has to be taken (Essent Netwerk, 2007b) and is determined by the probability of the occurrence of an event multiplied with its consequence. Furthermore it is stated that a risk (1) has to be related to the regulated electricity and gas network, (2) has to be asset related and (3) it has to affect the defined business values (Essent Netwerk, 2008)

3.1.2 Risk management process

Enexis became the first company in the Netherlands to fully control its maintenance and capital expenditure by means of a risk management process (Wijnberg, 2007). To become a leading firm at risk management Enexis developed the Risk Based Asset Management (RBAM) process. Risk Based Asset Management is the process of managing a large asset base and dealing with the risks that are inherent to this process. This requires decisions on investing in, replacing and maintaining assets. In Risk Based Asset Management these decisions are driven by an assessment of what risk exposure is considered unacceptable by the stakeholders of the company. The Risk Based Asset Management process guarantees that the budget spent by Enexis on their asset base is adding value in terms of business values. These business values are determined by the Asset Owner and can change over time. The current business values applicable to Enexis are: (1) quality of supply, (2) safety, (3) legislation, (4) finance, (5) customer satisfaction and (6) sustainability.

The risk management process at Enexis shows great overlap with the general risk management process. The Asset Owner is responsible for the first step by determining the scope and objectives. The remaining steps are done by the Asset Manager and comprise the following five steps: (1) Risk identification and analysis, (2) development of alternative solutions, (3) Choice and approval of the optimal solution, (4) execution of the chosen solution and (5) evaluation of the implemented solution (e.g. risk reduction). The actual execution of the developed tactics is situated at the Service Provider, which is responsible for the effective and efficient execution of the asset related policies. The relation between these three is shown in figure 3.1

Figure 3.1 Relation between Asset Owner, Asset Manager and Service Provider (Essent Netwerk, 2006

To provide insight in the risk management cycle the next part will elaborate on the five steps that are identified within the process of the Asset Manager.

1. *Risk identification and analysis:* identify, inventory and analyze risks which form a (potential) treat for the business objectives of the Asset Owner, including the determination of the risk level based on the evaluation framework provided by the Asset Owner.
2. *Development of alternative solutions:* determination of possible measures to reduce the level of the individual risk and the overall risk position
3. *Choice and approval:* Selection of an optimal combination of measures based on their effectiveness.
4. *Implementation and program management:* Execution of the chosen combination of measures by means of concrete plans, assignment granting to the Service Provider and progress monitoring.
5. *Evaluation:* Evaluation of the implementation of the granted assignments on three levels, (1) the actual progress, (2) the costs and the implementation of the measure and possible improvements and (3) the contribution of the measure on the decrease of the risks

The relation between these steps is depicted in figure 3.2. A more detailed description of the risk management process can be found in Appendix A.

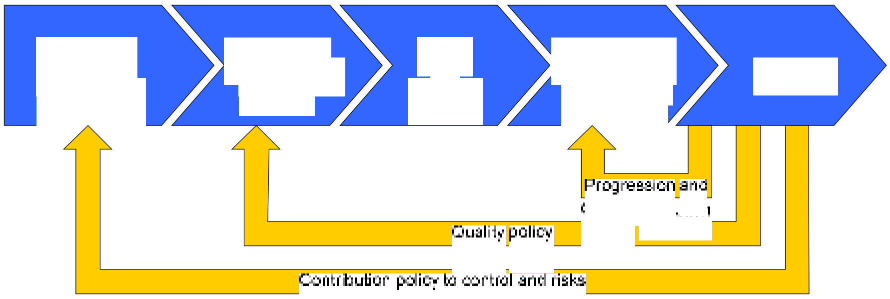


Figure 3.2 Risk management process at the Asset Manager (Essent Netwerk, 2006)

3.2 Risk position Enexis

The focus of this study is on the risk position of Enexis, therefore this paragraph describes how Enexis determines its risk position. This starts with the assessment of the individual risks (3.2.1). All individual risks together determine the total risk position of Enexis department asset mananagement.

3.2.1 Individual risk assessment

Enexis uses a consequence-likelihood matrix, also called risk matrix (figure 3.3 and Appendix B), to assess individual risks. The risk matrix is used to rank risks or sources of risk on the basis of the level of risk. This ranking is used to determine which risks need more detailed analysis or which risks need handling first. The risk matrix consists out of two customized scales, one for the consequences and one for the likelihood. The consequence scale determines the possible consequence of the occurrence of an event on each of the business values. The likelihood scale determines the probability of the occurrence of the event. The combination of a likelihood and consequence results in a risk level. Enexis has defined six levels of risk: negligible (N), low (L), medium (M), high (H), very high (VH) and unacceptable (U). To determine which risks need priority for treatment Enexis developed a policy which states that risks with a risk level unacceptable are solved and all other risks are treated if there is an effective policy ($NPV > 0$) within the available budget.

Risk matrix Essent Netwerk 2008															
Possible consequences							**Probability of an accident**								
							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Category	Quality of supply	Safety	Compliance	Financial	Customer satisfaction	Sustainability	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Enormous	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N	L	M	H	VH	U	U	U	U
Serious	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N	N	L	M	H	VH	U	U	U
Considerable	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N	N	N	L	M	H	VH	U	U
Moderate	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N	N	N	N	L	M	H	VH	U
Small	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N	N	N	N	N	L	M	H	VH
Negligible	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N	N	N	N	N	N	L	M	H

Figure 3.3 Risk matrix Essent Netwerk 2008 (Essent Netwerk, 2008)

The assessment of individual risk starts with a risk report. These reports can come from several sources inside or outside Enexis (figure 3.4). These so called open reports *(status 1)* are collected by the risk analysts. Risk analysts evaluate all reports against the following criteria: (1) fits the potential risk the definition of a risk as defined by Enexis, (2) is the potential risk already known in the risk register, (3) is the risk report a reference to a existing risk, (4) is the risk report related to the assets and does it influence the business values and (5) is it a request for recommendation in stead of a risk. Based on this evaluation the risk report will be. (1) rejected if it does not meet the criteria of a risk, (2) closed if the risk is already known or (3) accepted and goes to the next process step for a risk analysis. Accepted risks proceed for risk estimation with respect to the business values in the risk matrix. The risk estimation can be divided into two steps: (1) temporary estimation *(status 2)* and (2) definitive estimation *(status 3)*. The temporary estimation is done by the risk analysts. These temporary estimations will be discussed with experts in a risk assessment session and result in a definitive estimation. Bases on the definitive estimations all risks are ranked, where risks with the highest priority will be analyzed first. This final step results in a detailed analysis of the risk. Each time the status of a risk changes the risk register is updated.

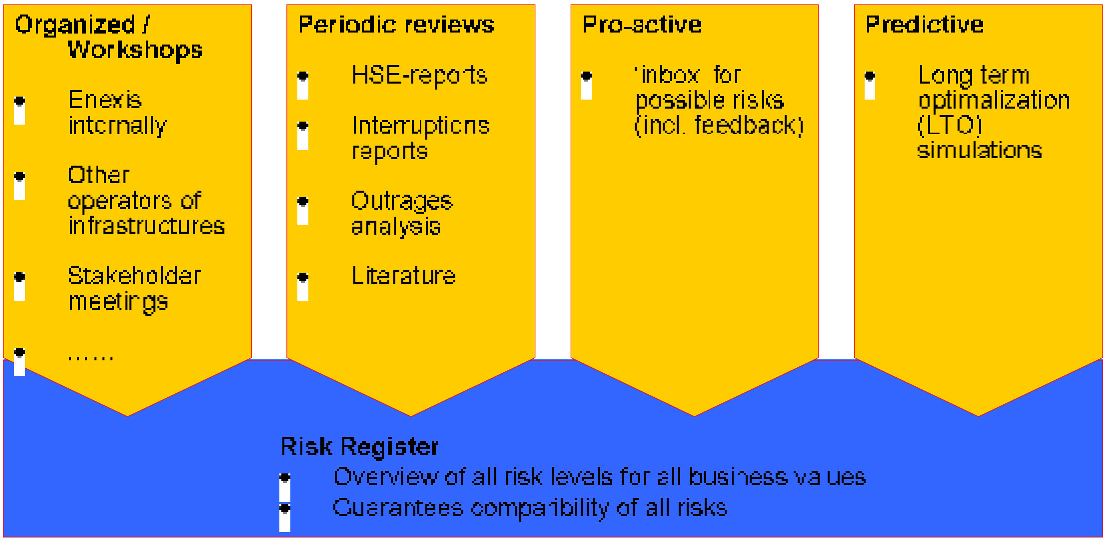


Figure 3.4 Different way Enexis identifies risks

3.2.2 *Risk position*

Theoretically the calculated, expected risk position from the risk register of Enexis should equal the actual risk exposure. For Enexis this can for example be done by comparing the predicted customers minutes lost (CML), calculated from the risk register, with the actual measured CML. In practice these two values should align with a certain bandwidth. However due to problems with interrelations/overlap the calculated risk position of Enexis shows a worse situation than the true risk position (Korn & Veldman, 2008)

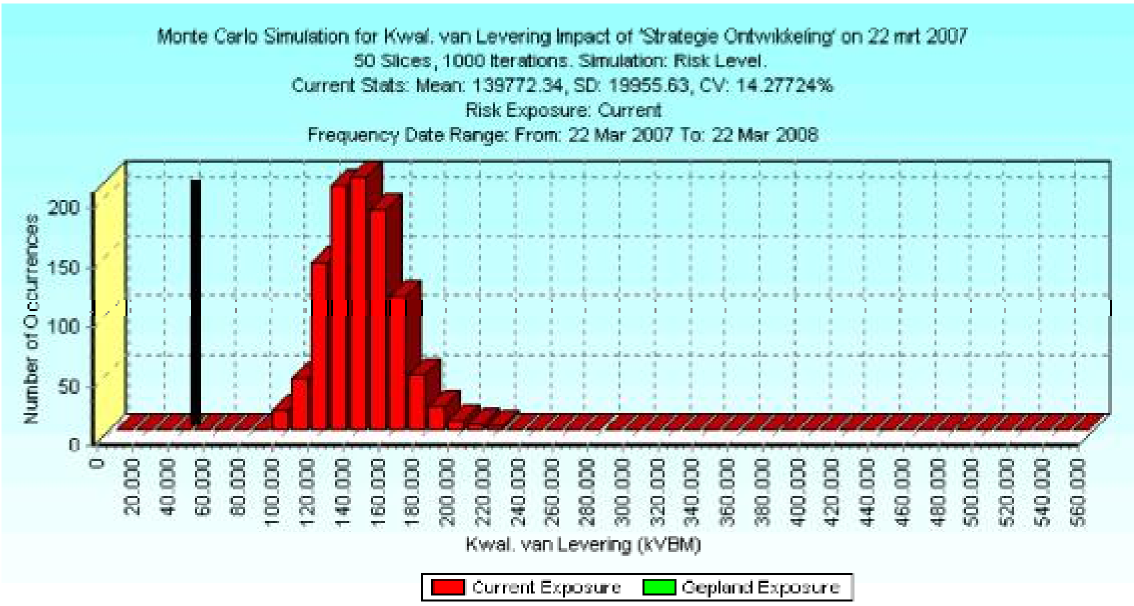


Figure 3.5 Risk Position CML Black line marks actual performance. Red line simulated risk position (Korn & Veldman, 2008)

As can be seen from figure 3.5 the actual number of CML is about 60 million per year. The Monte Carlo simulation based on the data in the risk register in the same figure shows a figure that seems to be normally distributed with a fat right tail and had a mean of approximately 140 million CML per year, which is more then twice as high as the actual number of CML. A calculated, over-estimated, risk position may trigger more actions and expenses than can be justified on basis of the actual risks a company faces. Eventually this may lead to a culture of incorrect decision-making and overspending (Korn & Veldman, 2008).

Enexis tried to tackle the problem by describing risks in more detail, clear distinguishing between future and current risks and cross checking risks and solutions. As a result of this approach part of the interrelated risks and overlap is solved. As the calculated expected risk position is still too high in comparison with the actual risk position, further research is and will be performed (Korn & Veldman, 2008). This ongoing research is illustrated in the remainder of this report which describes the research for a better risk assessment method for Enexis.

4 Methodology for assessment of the risk position

This chapter defines the optimal methodology to assess the overall risk position of Enexis. This methodology consists out of three steps. First of all risks have to be categorized into a manageable number of categories (4.1). After that the optimal assessment methodology has to be chosen, which can map the relation between hazards, risks and consequences (4.2). Finally, there has to be a way to assess the risk position (4.3)

4.1 Methodology for categorizing risks

The risk management function is typically responsible for hundreds of risks. To get a clear view of the risk position risks have to be grouped into a manageable number of categories. This grouping will be defined as the ordering or arrangement of objects into groups or sets on the basis of their relationship (Sokal, 1974).

According to Cvetkovich and Earle (1985) categorization has several advantages. One of the advantages of categorization is that is provides a simplification of phenomena under consideration. The grouping of objects avoids working in a world of single cases only. Another advantage is that categorization provides a means of easily manipulating information. If objects are arranged in groups their relationships are more easily discovered and retrieved. Furthermore, categorization can help with determining priorities for risk management. Finally, categorization can be useful in the process of generalizing research findings.

The psychological literature on categorization is concerned with how people learn existing categorization schemes and how they develop classifications for sets of objects or concepts (Morgan, Florig, DeKay and Fischbeck, 2000). Within the psychology there are two main streams, which are termed by Komatsu (1992): (1) similarity-based view and (2) explanation-based view. In the similarity-based view the inclusion of a particular instance in a category is based upon the similarity of that instance to some abstract specification. In the explanation-based view categorizations are viewed as constructed on the basis of relationships that exist between instances and categories (Morgan *et al*, 2000).

In the natural science the purpose of classification is to describe objects in such a way that their "true" relationships are displayed. This classification is known as the "natural system" and is believed to be in accordance with nature (Sokal, 1974). Within this natural system there are two classification systems. (1) monothetic and (2) polythetic (Sokal, 1974). In monothetic classification the established classed differ by at least one property which is uniform among the members of each class. In polythetic classification on the other hand objects share a large proportion of their properties, but do not necessarily agree in any one property (Sokal, 1974). The latter has strong parallels with the previously mentioned similarity-based view.

Cvetkovich and Earle (1985) have identified two streams within the classification of hazardous events: (1) essentialists and (2) constructivists. Essentialists try to devise systems that accurately reflect categories of phenomena as they exist in nature (Cvetkovich and Earle, 1985). Constructivists consider classification systems as aid to thinking and communicating and assume that there is no single best classification system. The quality of a classification system depends upon how well the functions of analysis and communication are preformed. Thus, whether one system is better than another depends upon the specific aim of its user (Cvetkovich and Earle, 1985)

It can be concluded that there is no unique categorization for risks, and that different categorizations will best serve different objectives. Nevertheless it is important to note that risk categories should reflect risk management objectives. A similarity-based view to categorize risks is ambiguous, due to the wide variety of dimensions along which risks can be similar or dissimilar (Morgan *et al.*, 2000) and therefore not of use for risk management purposes. An explanation-based view to categorize risks, in which risks are characterized an

accordance with the goals of the organization, is more appropriate to meet the requisite of reflecting risk management objectives (Morgan *et al.*, 2000).
Besides reflecting the management objective Morgan *et al.* (2000) formulated some additional attributes which all defined categories should have. Each category should be logically consistent, compatible with administrative systems, equitable and compatible with human cognitive limitations. Although Morgan *et al.* (2000) formulated their attributes for risk categories for risk ranking purposes they are generalizable for all categorizing purposes. Table 4.1 summarizes a generalized version for all desirable attributes for an ideal risk categorization, based on Morgan *et al.* (2000).

Categories should be:

Logically consistent
- Exhaustive so that no risks are overlooked
- Mutually exclusive so that risks are not double-counted
- Homogeneous so that all risk categories can be evaluated on the same set of attributes

Administratively compatible
- Compatible with existing organizational structures and legislative mandates so that lines of authority are clear and management actions at cross purposes are avoided
- Relevant to management so that risk priorities can be mapped into risk management actions
- Large enough in number so that regulatory attention can be finely targeted, with a minimum of interpretation by agency staff
- Compatible with existing databases, to make best use of available information

Equitable
- Fairly drawn so that the interests of various stakeholders, including the general public, are balanced

Compatible with cognitive constraints and biases
- Chosen with an awareness of inevitable framing biases
- Simple and compatible with people's existing mental models so that risk categories are easy to communicate
- Few enough in number so that the following processes are tractable
- Free of "lamp-post" effect, in which better understood risks are categorized more finely then less understood risks

Table 4.1 Desirable attributes for an ideal risk categorization (free from Morgan *et al.*, 2000)

4.2 Methodology for assessment risk position

As mentioned before Enexis has a good risk identification and assessment process in place to identify and assess individual risks. Therefore the methodology to assess the risk position should be an extension of the current process. This paragraph starts with the selection of possibly useful assessment methods from a broad range of assessment methodologies (4.2.1). From all assessment methodologies only four appeared to be possibly useful and are discussed in more detail: (1) Fault Tree Analysis (FTA) (4.2.2), (2) Event Tree Analysis (4.2.3), (3) Bow-Tie Analysis (4.2.4) and (4) Environmental Risk Assessment (4.2.5). This paragraph will conclude with the method which seems most appropriate for Enexis (4.2.6).

4.2.1 Risk assessment techniques

ISO/IEC (2008) composed a list with all known risk assessment techniques (Appendix C) and tested their applicability on six steps of the risk assessment process (appendix D). (1) risk identification, (2) risk analysis – consequence, (3) risk analysis – likelihood, (4) risk analysis – level of risk and (5) risk evaluation. Based on this test the methodologies can be roughly classified into three classes: (1) methodologies which focus on risk identification, (2) methodologies which focus on risk analysis and (3) methodologies which cover the full range of the process. Since the purpose of the research is to assess the risk position of Enexis the methodologies which focus solely on risk identification do not fit in the scope of this research. A more in-depth analysis of the remaining methodologies justifies a further classification in methodologies which focus on individual risks and methodologies which focus on risks and the relationship between them. This latter group of methodologies is in line with the purpose of this research and consists out of four methodologies. (1) Fault Tree Analysis (FTA), (2) Event Tree Analysis, (3) Bow-Tie Analysis and (4) Environmental Risk Assessment

4.2.2 Fault Tree Analysis (FTA)

FTA (figure 4.1) is concerned with the identification and analysis of conditions and factors which cause or contribute to the occurrence of a define undesired event, the so called top event, usually one which significantly affects system performance, economy, safety or other required characteristics (IEC, 1990). The fault tree itself is a graphical representation of the analysis of the undesired event, referred to as the top event. FTA is basically a deductive (top-down) method of analysis aimed at pinpointing the causes or combinations of causes that can lead to top event (IEC, 1990). FTA is particularly suited for analyzing complex systems comprising several functionally related or dependent subsystems (ICE, 1990). The main results of a FTA are: (1) a graphical representation of how the top event can occur, (2) a list of minimal cuts set for failure, with their likelihood and (3) the likelihood of the occurrence to the top event (ISO/IEC, 2008).

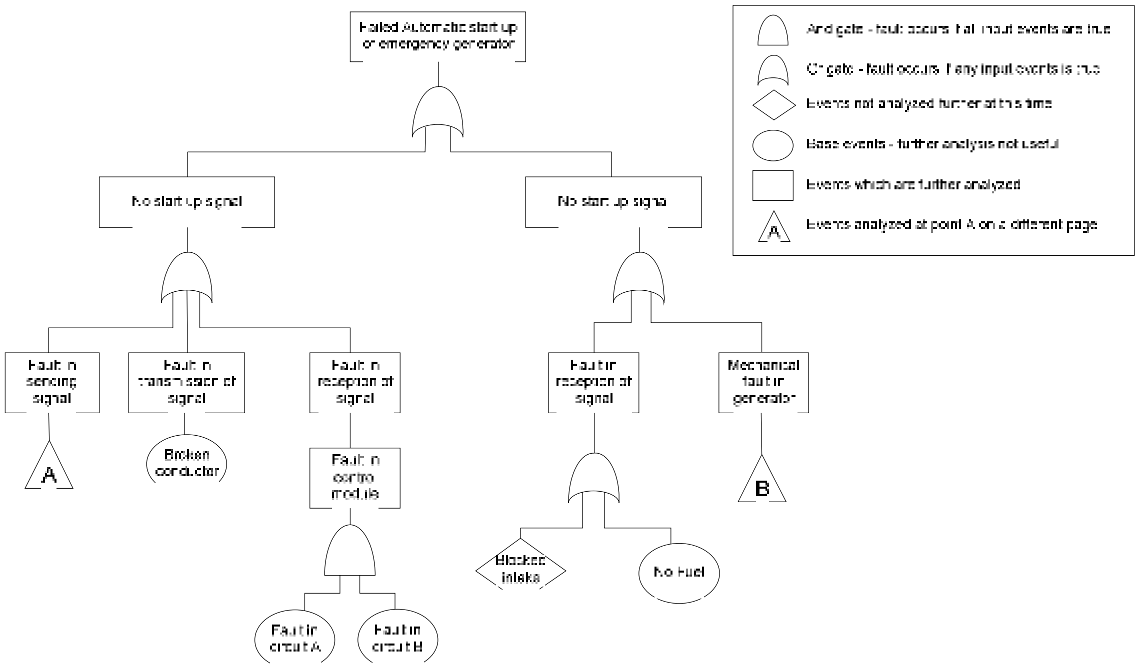


Figure 4.1 Example FTA (ISO/IEC, 2008)

In their analysis of all risk assessment techniques the ISO/IEC (2008) gives strengths and limitations of each technique. The strengths and limitations for the FTA are given below

Strengths of FTA:

- It affords a disciplined approach which is highly systematic, but at the same time sufficiently flexible to allow analysis of a variety of factors, including human interactions and physical phenomena
- The application of the "top-down" approach, implicit in the technique, focuses attention on those effects of failure which are directly related to the top event
- FTA is especially useful for analyzing systems with many interfaces and interactions.
- The pictorial representation leads to an easy understanding of the system behavior and the factors included, but as the trees are often large, processing of fault trees may require computer systems. This feature enables more complex logical relationships to be included (EG NAND and NOR) but also makes the verification of the fault tree difficult
- Logic analysis of the fault trees and the identification of cut sets is useful in identifying simple failure pathways in a very complex system where particular combinations of events which lead to the top event could be overlooked

Limitations

- There is a high level of uncertainty in the calculated likelihood or frequency of the head event
- In some situations causal events are not bounded and it can be difficult to ascertain whether all important pathways to the top event are included. (For example including all ignition sources is an analysis of a fire as a top event. In this situation likelihood analysis is not possible)
- While human error can be included in a qualitative fault tree there is much disagreement on whether and how probabilities of error can be included in a quantified model. In general failures of degree or quality which often characterize human error cannot easily be included
- A fault tree does not enable domino effects or conditional failures to be included easily

4.2.3 Event Tree Analysis (ETA)

Event trees analysis (ETA) function similarly to FTA, but in the opposite direction. ETA is an analysis technique which is used to identify possible pathways following an initiating event and assess the frequency of the various outcomes ISO/IEC, 2008). In other words ETA identifies the possible consequences, the undesired event that can happen, and their chance of occurrence. Figure 4.2 gives an example of an event tree analysis. The main results of an ETA are. (1), qualitative descriptions of potential problems as combinations of events producing various types of problems (range of outcomes) from initiating events (2), quantitative estimates of event frequencies or probabilities and relative importance of various failure sequences and contributing events; (3) list of recommendations for reducing risks, (4) quantitative evaluations of recommendation effectiveness (ISO/IEC, 2008)

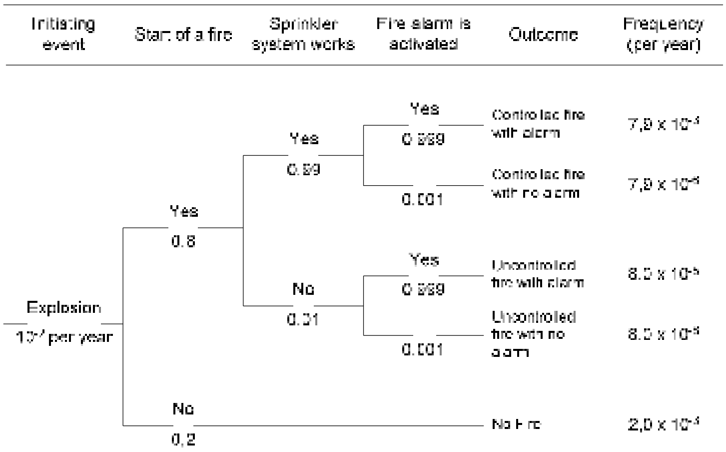


Figure 4.2 Example ETA (ISO/IEC, 2008)

In their analysis of all risk assessment techniques the ISO/IEC (2008) gives strengths and limitations of each technique. The strengths and limitations for the ETA are given below.

Strengths of ETA:

- ETA displays potential scenarios following an initiating event are analyzed and the influence of the success or failure of mitigating systems or functions in a clear diagrammatic way;
- It accounts for timing, dependence, and domino effects that are cumbersome to model in fault trees

Limitations

- In order to use ETA as part of a comprehensive assessment, all potential initiating events need to be identified. There is always a potential for missing some important initiating events. Furthermore, with event trees, only success and fault states of a system are dealt with, and it is difficult to incorporate delayed success or recovery events
- Any path is conditional on the events that occurred at previous branch points along the path. Many dependencies along the possible paths are therefore addressed. However, some dependencies, such as common components, utility systems, and operators, may be overlooked – if not handled carefully leading to optimistic estimations of risk

4.2.4 Bow Tie Analysis

Bow Tie Analysis is a simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes and reviewing controls. It can be considered to be a combination of the thinking of a fault tree analyzing the cause of an event (represented by the knot of a bow tie) and an event tree analyzing the consequences (ISO/IEC, 2008). Bow-Tie Analysis can be used for known problems, but do not support the identification of risks (ISO/IEC, 2008). Therefore the input requirements for Bow-Tie Analysis are identified hazard, causes and outcomes. A Bow Tie Analysis results in a simple diagram (figure 4.3) showing relationship between hazards, top event and consequences and the barriers in place to prevent or mitigate the undesired consequences and promote the desired consequences. Table 4.2 gives an overview of all important definitions in a Bow Tie Analysis

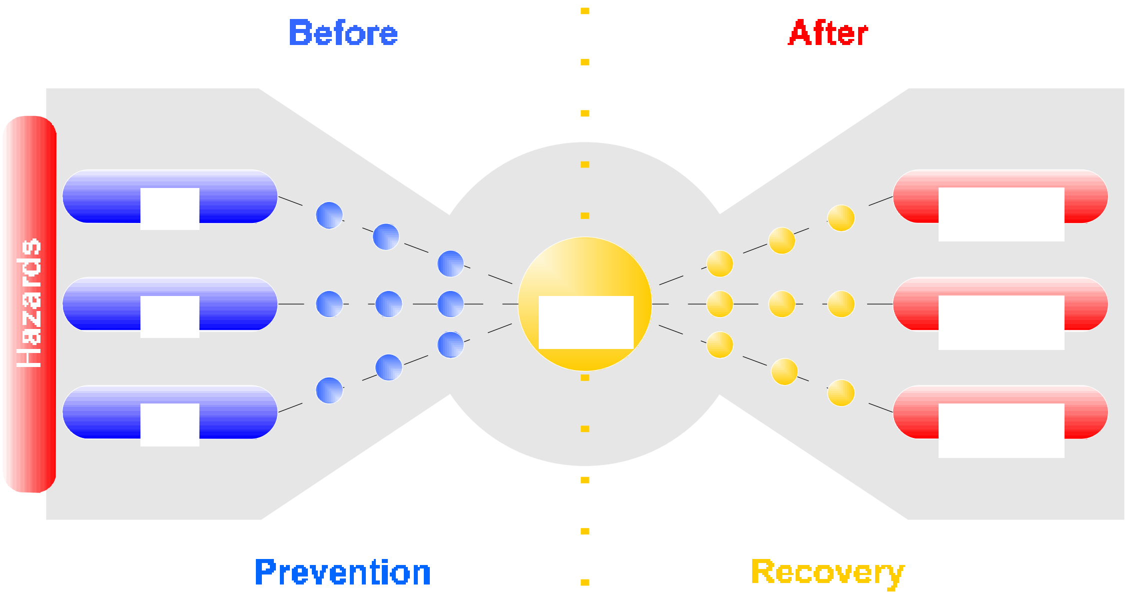


Figure 4.3 Example Bow Tie Analysis (free from Governors B.V., 2004)

Term	Definition	Example
Hazard	This is a condition that could potentially lead to injury, damage to property or the environment	Flammable chemicals in storage Flammable chemicals at pressure
Threat	An event which has the potential to release a hazard	Corrosion of pipeline Human error (line-up failure)
Preventive barrier	Preventative control measures put in place to prevent releasing the hazard	Materials selection Safety valves Control systems Procedural controls Preventative maintenance Training
Critical event / Top event	The initial consequence which involves the release of the hazard	loss of containment
Mitigative barrier	Mitigative control measures put in place to prevent the critical/top event from escalating to a consequence resulting in injury, damage to property or the environment	Secondary containment (bunds) Fire or gas detection systems Fire fighting systems
Consequence	An event resulting from the hazard, its initiating event, failure of preventative control measures and failure or success of mitigative control measures	Controlled liquid spill (failure of preventative control measures, success of mitigative control measures - secondary containment) Pool fire (failure of preventative control measures, failure of mitigative control measures - control of ignition sources)

Table 4.2 Definition and examples of used terms (free from Cockshott, 2005)

As well as for all other risk assessment techniques the ISO/IEC (2008) also listed the strengths and limitations for Bow Tie Analysis.

Strength of Bow tie analysis:

- It is simple to understand and gives a clear pictorial representation of the problem
- It focuses attention on barriers which are supposed to be in place for both prevention and mitigation and their effectiveness
- It can be used for desirable consequences
- It does not require a high level of expertise to use

Limitations

- It cannot depict where multiple causes must occur simultaneously to cause the consequences (i.e. where there are and gates in a fault tree depicting the left hand side of the bow)
- It may over simplify complex situations particularly where quantification is attempted

4.2.5 Environmental Risk Assessment

Hazards are identified and analyzed and possible pathways by which a specified target might be exposed to the hazard are identified. Information on the level of exposure and the nature of harm caused by a given level of exposure are combined to give a description of the nature of risk and its level. The process is used to assess risk to plants, animals and humans as a result of exposure to hazards such as chemicals, micro organisms or other species (ISO/IEC, 2008). Given the limited applicability of the Environmental Risk Assessment this technique does not fit with the purpose of this research and will therefore be let outside examination

4.2.7 Methodology for Enexis

The Analytic Hierarchy Process (AHP) is used to determine the optimal risk assessment methodology for Enexis. AHP is a method for decision formulation and analysis (Saaty, 1990). AHP has thus been successfully applied to a diverse array of problems (Golden, Wasil & Levy, 1989). The process proposed in this study for selecting the optimal risk assessment methodology for Enexis comprises the following steps.

2.1. Step 1. Define the evaluative criteria used to select the optimal performing risk assessment methodology, and establish a hierarchical framework

The methodology for assessment of the risk position should cover the whole scope from causes to top event and from top event to consequences. Therefore there are only two possible methodologies imaginable. (1) Bow-Tie Analysis or (2) a combination of FTA and ETA. ISO/IEC (2008) did not only score the techniques on their applicability on the steps of the risk assessment, but also on four more criteria: (1) resources and capability, (2) nature and degree of uncertainty, (3) complexity and (4) quantitative output

- Resources and capabilities which may affect choice of risk assessment methods including the skills, experience, capacity and capability of the risk assessment team, the availability of management time and other resources within the organization, as well as the budget available if external resources are required.
- The nature and degree of uncertainty require an understanding of the quality, quantity and integrity of information available about the risk under consideration. Those undertaking risk assessment need to understand the type and nature of the uncertainty and appreciate the implications for the reliability of the risk assessment results. These must always be communicated to decision makers.

- Complexity is another important characteristic which should be taken into account in risk. Understanding the complexity of a single risk or of a portfolio of risks of an organization is crucial for the selection of the appropriate option for risk assessment
- Not all risk assessment techniques are equally suitable to deliver quantitative output. Therefore it is important to think about the purpose of the risk analysis and whether a quantitative output is important

The scores of the three risk assessment techniques are shown in table 4.3. The table shows the impact of the criteria on the method

Techniques	Resources and Capability	Nature and degree of uncertainty	Complexity	Quantitative output
Fault Tree Analysis	High	High	High	++
Event Tree Analysis	Medium	Medium	Medium	++
Bow Tie Analysis	Medium	High	Medium	+

Table 4.3 Scores on Resources and capability, nature and degree of uncertainty, complexity and quantitative output (ISO/IEC, 2008)

Since the two alternatives are Bow Tie Analysis on the one hand and a combination of FTA and ETA on the other hand the scores of FTA and ETA have to be aggregated. Since a combination of two methods can never perform better then the worst method the worst score is assumed to be the score that determines the overall score of on each criteria. Table 4.4 shows the aggregated scores.

Techniques	Resources and Capability	Nature and degree of uncertainty	Complexity	Quantitative output
FTA + ETA	High	High	High	++
Bow Tie Analysis	Medium	High	Medium	+

Table 4.4 Aggregated scores Alternatives

Beside these criteria Enexis defined three specific criteria for Enexis (1) Provide insight, (2) Fit with current process and (3) link with market developments.

- Providing insight in the relation between risks and relations between risks and policies is the first criteria defined by Enexis. Risk can relate to each other and one policy can reduce more than one risk, however not all risk assessment methodologies are equally suitable to visualize these relations.
- Fit with current process determines the degree of possible integration with the current risk management process. Enexis is searching for a risk assessment methodology which is an extension to the current risk management process without the need to change the current process to be able to integrate the new methodology.
- Link with developments in the market is the final criteria defined by Enexis. The sector Enexis is operating in is continually evolving through new laws, guidelines and norms. Within the sector there are expectations about a risk management standard in the future. Not all assessment methods fit equally in these expectations

The optimal risk assessment methodology can be selected and valuated based on seven evaluation criteria and the alternatives (figure 4.4).

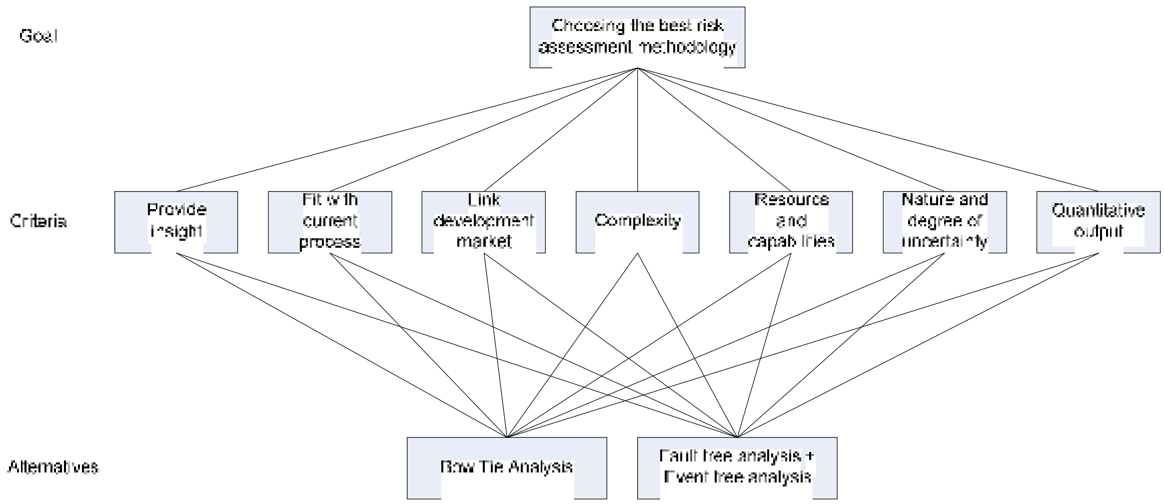


Figure 4.4 decomposition of the problem into a hierarchy

Step 2. Establish each factor of the pair-wise comparison matrix

In this step, the elements of a particular level are compared pair-wise, with respect to a specific element in the immediate upper level. A judgment matrix is formed and used for computing the priorities of the corresponding elements. First, a criterion is compared pair-wise with respect to the goal. The judgment matrix, denoted as A, will be formed using the comparison. Let $A_1,\ldots,A_n$, be the set of objects. The quantified judgments on pairs of objects A_i, A_j, are represented by

$$A = [a_{ij}] \quad i, j = 1,2,\ldots,n$$

The comparison of any two criteria C_i and C_j with respect to the goal is made using the questions of the type: of the two criteria C_i and C_j which is more important and how much. Saaty (1980) suggests the use of a 9-point scale to transform the verbal judgments into numerical quantities representing the values of a_{ij}. Table 4.5 lists the definition of 9-point scale. Larger number assigned to the pair-wise comparisons means larger differences between criteria levels. The entries a_{ij} are governed by the following rules:

$$a_{ij} > 0,\ a_{ji} = \frac{1}{a_{ij}},\ a_{ii} = 1 \text{ for all } i$$

This scale can be applied with ease to criteria that can be defined numerically as well as to those cannot be defined numerically. Relative importance scale is presented. The decision maker is supposed to specify their judgments of the relative importance of each contribution of criteria towards achieving the overall goal.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

Table 4.5 The pairwise comparision scale (Saaty, 1977)

A group session was conducted to find out an expert opinion in the form of a pair-wise comparison. The group consisted out of the 2 risk experts responsible for the calculation of the risk position. This are the people who have to work with the new methodology. Table 4.6 and table 4.7 presents the resulting pair-wise comparison matrix from the session

Criteria	A	B	C	D	E	F	G	Priority vector
A	1	4	7	2	6	7	8	0,4079
B	¼	1	4	½	3	6	7	0,1884
C	⅐	¼	1	½	2	1	3	0,0762
D	½	2	2	1	2	4	3	0,1765
E	⅙	⅓	½	½	1	3	2	0,0700
F	⅐	⅙	1	¼	⅓	1	½	0,0389
G	⅛	⅐	⅓	⅓	½	2	1	0,0420

λ_{max} = 7,541768; CI = 0,090295; RI = 1,32; CR = 0,068405 < 0.1

Table 4.6 Pair-wise comparison matrix for criteria and priorities

A	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	4	0,8
FTA ETA	0,25	1	0,2
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

B	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	2	0,6667
FTA ETA	0,5	1	0,3333
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

C	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	5	0,8333
FTA ETA	0,2	1	0,1667
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

D	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	5	0,8333
FTA ETA	0,2	1	0,1667
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

E	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	5	0,8333
FTA ETA	0,2	1	0,1667
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

F	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	1	0,5
FTA ETA	1	1	0,5
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

G	Bow Tie	FTA ETA	Priority vector
Bow Tie	1	0,25	0,2
FTA ETA	4	1	0,8
	$\lambda_{max} = 2; CI = 0; RI = 0; CR = 0 \le 0.1$		

Table 4.7 Pair-wise comparison matrix for alternatives and priorities

Step 3. Calculate the eigenvalue and eigenvector
Next step is to find the weights of the objects from the matrix. The priorities are calculated as the elements in the eigenvector associated with the maximum eigenvalue of the matrix.

According to Saaty (1977) the folling steps have to be taken to find the elements in the eigenvector associated with the maximum eigenvalue of the matrix denote the objects by $A_1, \ldots A_n$ and their weights by $w_1, \ldots, w_n$. The pair-wise comparisons can be represented by the following matrix:

$$A = \begin{array}{c|cccc} & A_1 & A_2 & & A_n \\ \hline A_1 & w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ A_2 & w_2/w_1 & w_2/w_2 & & w_2/w_n \\ & & \cdot & & \\ & & \cdot & & \\ & & \cdot & & \\ A_n & w_n/w_1 & w_n/w_2 & & w_n/w_n \end{array}$$

This matrix has positive entries everywhere and satisfies the reciprocal property $a_{ji} = 1/a_{ij}$. It is called a reciprocal matrix. We note that if we multiply this matrix by the transpose of the vector $w^T = (w_1, \ldots, w_n)$ we obtain the vector wn and the problem takes the form:

$$Aw = nw$$

This is a system of homogenous linear equations. It has a non-trivial solution if and only if the determinant of $A - nI$ vanishes, that is, n is an eigenvalue of A. I is an $n \times n$ identity matrix. Saaty's method computes w as the principal right eigenvector of the matrix A (Golden;Wasil and Harker, 1989).

$$Aw = \lambda_{max} w$$

where λ_{max} is the principal eigenvalue of the matrix A. If matrix A is a positive reciprocal matrix, then $\lambda_{max} \geq n$ (Saaty, 1990). If A is a consistency matrix, eigenvector w can be calculated by

$$(A - \lambda_{max})w = 0$$

Solving this inequality depends on relatively advanced matrix algebra. In stead of solving this relative complex inequality the solution of the eigenvalue problem can be obtained by raising the matrix A to a sufficiently large power then summing over the rows and normalizing to obtain the priority vector $w = (w_1, ..., w_n)^T$. The process is stopped when the difference between components of the priority vector obtained at the k^{th} power and at the $(k+1)^{st}$ power is less than some predetermined small value (Saaty, 1990). For the purpose of this study successive iterations have to show no difference to four decimal places. Table 4.6 summarize the priority vector, or eigenvectors, for criteria and table 4.7 shows the priority vectors for the two alternative solutions

Step 4. Perform the consistency test

The eigenvector method yields a natural measure of consistency. Saaty (1990) defined the consistency index (CI) as

$$CI = (\lambda_{max} - n)/(n-1), \qquad (1)$$

where λ_{max} is the maximum eigenvalue, and n is the number of factors in the judgment matrix. Accordingly, Saaty (1990) defined the consistency ratio (CR) as

$$CR = CI/CR, \qquad (2)$$

for each size of matrix n, random matrices were generated and their mean CI value, called the random index (RI). Where RI represents the average consistency index over numerous random entries of same order reciprocal matrices. The consistency ratio CR is a measure of how a given matrix compares to a purely random matrix in terms of their consistency indices. A value of the consistency ratio $CR \leq 0.1$ is considered acceptable. Larger values of CR require the decision-maker to revise his judgments.

According to equations (1) and (2) the criteria comparison matrix of consistency for each criterion is calculated, as shown in Table 4.6. Results of the consistency test and the CR of the comparison matrix is < 0.1, indicating ''consistency''.

Step 5. Calculate the overall level hierarchy weight to select the optimal risk assessment methodology for Enexis

The last step is to determine to overall priorities of the risk assessment methodologies. To do so the priorities of the risk assessment methodologies with respect to each criterion are laid out in a matrix and each column of vectors is multiplied by the priority of the corresponding criteria and added across each row which results in the vector of risk assessment methodologies in table 4.8. From here it follows that the Bow Tie Analysis is the best risk assessment methodology for Enexis. Figure

	A	B	C	D	E	F	G	Score	Rank
	0,4079	0,1884	0,0762	0,1765	0,0700	0,0389	0,0420		
Bow Tie	0,8000	0,6667	0,8333	0,8333	0,8333	0,5000	0,2000	0,74876	1
FTA ETA	0,2000	0,3333	0,1667	0,1667	0,1667	0,5000	0,8000	0,25124	2

Table 4.8 Overall priorities of risk assessment methodologies

Sensitivity analysis

In many decision rules it is assumed that complete information is available so that the criterion outcomes of each alternative are precisely known. However, in real world situations, this is not the case and analysis should be made to investigate whether the preliminary conclusions are robust or not. Sensitivity analysis aims to identify the effects of changes in the inputs which are the decision maker's preferences on the outputs, in other words, on the ranking of alternatives. If the changes do not significantly affect the outputs, then the ranking is assumed as robust and satisfactory. If the result is unsatisfactory, it should be return to the problem formulation step (Belton & Stewart, 2002).

To check whether the ranking is robust a gradient sensitivity analysis is preformed. The gradient sensitivity analysis assigns each criterion a separate gradient graph. The vertical line represents the current priority of the selected criterion. The slanted lines represent the alternatives. The current priority of an alternative is where the alternative line intersects the vertical criterion line. This resulted in seven different graphs (figure 4.5) all showing the sensitivity of the ranking for one criteria.

All graphs show that small changes in the priority of criteria do not affect to choice of the risk assessment methodology. In five of the seven cases a change in the priority does not even change the choice of assessment methodology at all. In one of the two remaining sensitivity analysis the two alternatives can score at best fifty-fifty. Only the sensitivity analysis shows a possibility for a change in the choice of the risk assessment methodology if the weights for criteria G change significant from 4,2% to at least 50%. It can be concluded that changes do not significantly affect the outputs and therefore the ranking of alternatives is assumed to be robust and satisfactory.

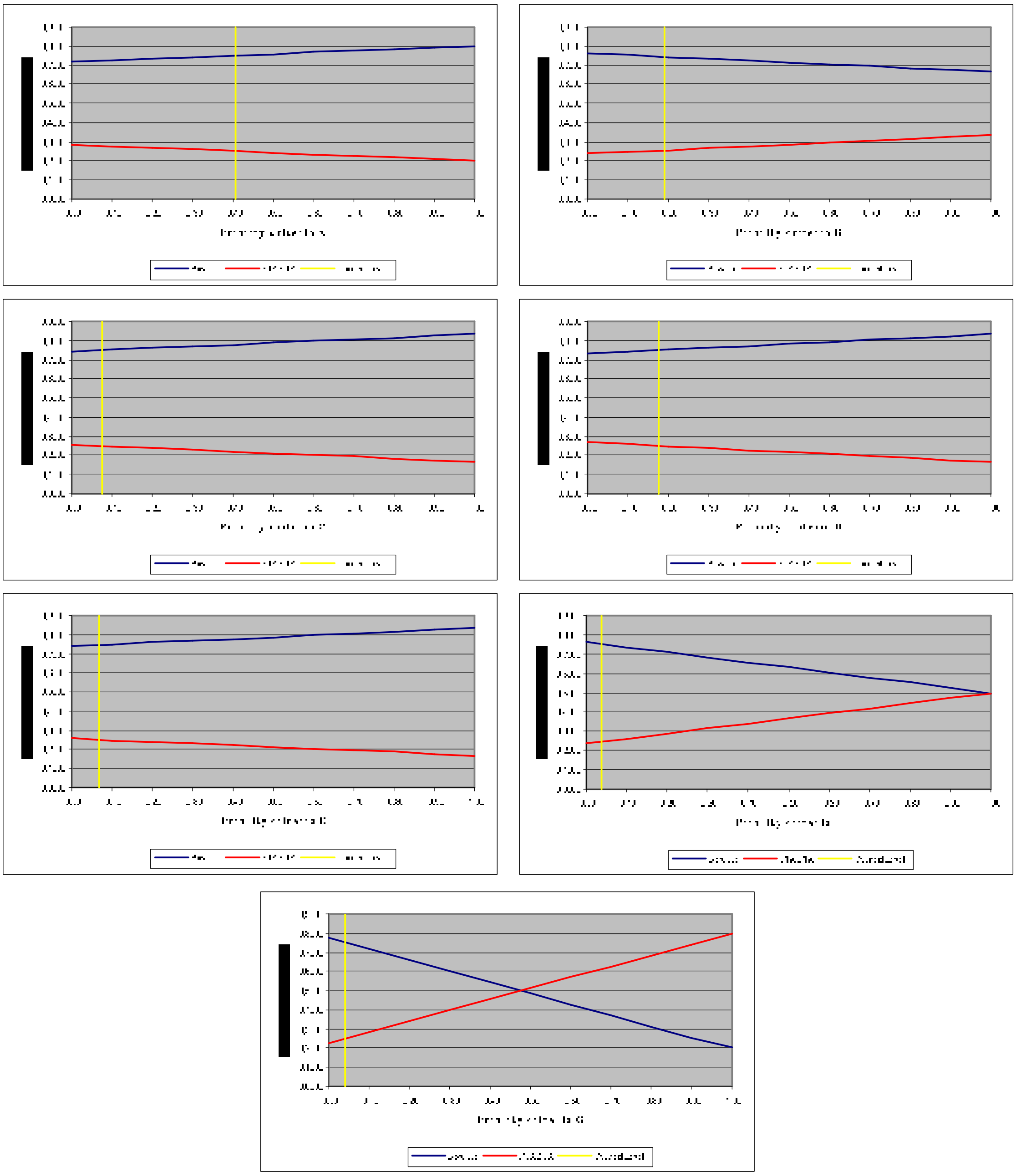


Figure 4.5 Gradient Sensitivity analysis

4.3 Monte Carlo Simulation

The Monte Carlo simulation is a general method for representing and simulation of stochastic processes by systematic drawing for probability density functions. Monte Carlo methods tend to be used when it is infeasible or impossible to compute an exact result with a deterministic algorithm (Hubbard, 2007). An example of how Monte Carlo can simplify a problem can be found in Appendix E. Currently the method is used in various industries for risk analysis.

In case the Monte Carlo simulation is applied for the assessment of the risk position it is necessary that, prior to the start of the simulation, all risk variables are assigned to a probability distribution. With use of the Monte Carlo simulation all risk variables can vary simultaneously. Enexis uses, based on practical considerations and limited amount of data, a Poisson distribution for each risk variable. The Poisson distribution is used to model the number of events occurring within a given time interval and is given by the following formula $p(x,\lambda) = \frac{e^{-\lambda}\lambda^x}{x!}$ for $x = 0,1,2,...X$ is the expected number of occurrences of an certain event and λ is the shape parameter which indicates the average number of events in the given time interval. Figure 4.6 shows Poisson probability density function for four values of λ. The value of λ is relative easy to estimate based on expert knowledge and historical data. Whether the Poisson distribution is the best choice for Monte Carlo simulation is not within the scope of the research. Therefore this research will use the Poisson distribution and limits itself to a check if the current input data for the Poisson distribution is correct, since predictions cannot be more accurate than the values they are based on.

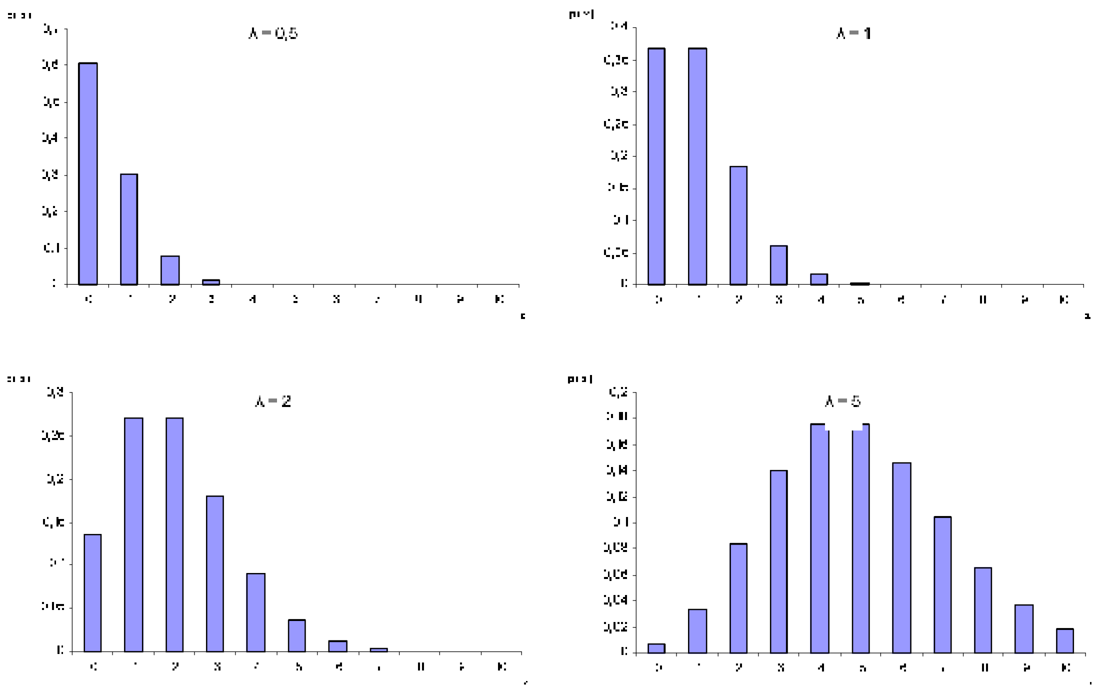


Figure 4.6 Probability mass functions for four values of λ

A Monte Carlo simulation requires a computer program which contains the probability distribution and the corresponding parameters. Enexis uses the Monte Carlo program which is integrated in the Active Risk Manager (ARM), the tool used as risk register. Beside this program there are several Excel add-ins which could be used for Monte Carlo simulation like Crystal Ball and @Risk.

The Monte Carlo successively executes three steps. (1) for each risk variable a value is randomly drawn from the defined probability distribution, also known as input value. In the case of Enexis these values depend on the Poisson distribution, (2) the complete set of input variables is used to perform a deterministic computation to calculate the risk position, (3) step one and two are frequently repeated to come to a reliable probability distribution of the risk position. The computer program gives the opportunity the set the number of iterations, where the number of iterations determines the reliability of the Monte Carlo simulation. By the law of large numbers (Appendix F) this method shows a $\frac{1}{\sqrt{N}}$ convergence, so quadrupling the number of iterations will halve the error.
The Monte Carlo simulation results in a probability distribution for the selected business value. The result shows, based on the premises, an objective insight in the expected risk position.

5 Categorization Risks Enexis

The first step in the assessment of the risk position is the creation of a proper risk classification. This chapter describes the process of creating risk classes and the reasoning behind the choices. The chapter starts with a general classification between electricity and gas (5.1). The chapter will continue with a detailed classification within the fields of gas (5.2) and electricity (5.3)

5.1 Separation of two classical fields

The current risk register of Enexis contains over 900 risks, from which there are 300 active risks. Active risk are risk which are currently faced by Enexis, where inactive risks are risk which Enexis faced in the past. The categorization is based on the active risks since this are the risks under consideration in this research. To perform a Bow Tie Analysis these risks have to be classified into manageable groups of risks (Cvetkovich and Earle, 1985). This categorization is line with the current risk management process (Morgan *et al*, 2000), and is based on the attributed defined by Morgan *et al.* (2000). A natural distinction within Enexis is between risk related to the gas grid and risk related to the electricity grid.

As mentioned earlier Enexis is responsible for the construction, maintenance and management of the gas and electricity distribution networks. Since the gas and electricity grids are two separate networks there is a natural distinction between these two disciplines. Furthermore gas and electricity have such different characteristics that they cannot be compared in one risk category. This first categorization results in almost 100 risks related to the gas grid and over 200 risks related to the electricity grid. This first step in categorization did not result in de desired manageable groups of risks. Therefore both categories need a further classification in subcategories as shown in figure 5.1 and discussed in the following paragraphs.

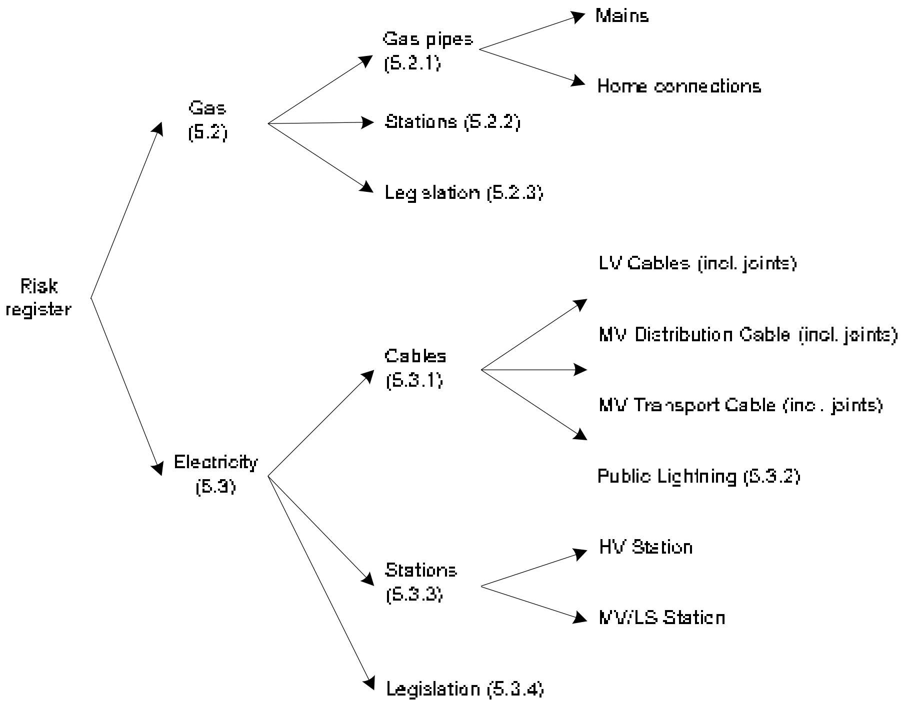


Figure 5.1 Risk categories Enexis

5.2 Gas

As is shown in figure 5.1 within the category of gas there are three subcategories: (1) gas pipes, (2) gas station, (3) and legislation. The distinction is based on the location of the assets, the function of the assets and the orientation of the risk (Table 5.1). The following paragraphs will elaborate on the three subcategories.

Risk category	Asset location	Function	Orientation
Gas pipes	Underground	transport of gas	Technical
Gas stations	Above the ground	Transport and treatment of gas / distribution gas	Technical
Legislation	-	-	Non-technical

Table 5.1 Distinction between risk categories within the gas category

5.2.1 Gas pipes

The first subclass within the gas category is pipelines. Enexis is responsible for the construction, maintenance and management of about 40000 kilometres of pipeline. Pipelines are a separate class because they represent all underground assets. Since not all pipelines fulfil the same purpose these is a distinction between two types of pipelines: (1) mains and (2) home connections. The distinction is made based in the distinction in purpose of the pipelines. Home connections take care of the connection of a single household with the mains and the mains are responsible for the distribution of the gas from the gas receiving stations to the home connections.

5.2.2 Gas stations

Beside 40000 kilometres of pipelines Enexis is also responsible for the construction, maintenance and management of more than 24000 gas stations. Gas stations represent all assets above the ground. The distinction between pipelines and gas stations is based on the purpose they serve. Pipelines are responsible for the distribution of gas and gas station are responsible for managing the difference in pressure levels between different pipelines. Based on this difference in purpose gas stations and pipelines are different groups.

5.2.3 Legislation

Beside all technical orientated risks there is a large group of non-technical orientated risks. In its capacity of network operator, Enexis is accountable to the Office of Energy Regulation and is committed to the gas law (Wet van 22 juni 2000, houdende regels omtrent het transport en de levering van gas (Gaswet)). The commitment to the gas law brings several risks to Enexis, since breaking one of the requirements in the law results in a penalty. Because the risks related to legislation are different from the technical risks related to the other classes legislation is a separate class within gas risks.

5.3 Electricity

As is shown in figure 5.1 within the category of electricity there are three subcategories: (1) cables, (2) electricity station, (3) legislation. The following paragraphs will elaborate on the three subcategories.

5.3.1 Cables

The first subclass within the electricity category is cables. Enexis is responsible for the construction, maintenance and management of about 142000 kilometres of electricity cable. Since not all cable fulfil the same purpose these is a distinction between three types of cables (1) Low voltage (LV) cables, (2) Medium voltage (MV) distribution cable and (3) Medium voltage (MV) transport cable. The distinction between these cable types is based on the time it takes to get the power supply up and running after an interruption. MV transport cables are $n-1$ redundant, which means that the power supply is ensured even if one cable fails. MV distribution cables are not redundant, but there is a possibility to restore the power supply by some manual switching, this means that the duration of the interruption equals the time it takes to perform the switching actions. In case of an interruption in a LV cable there is no backup to restore the power supply, so interruption of supply equals the time it takes to fix the cable. These differences in the duration of the interruption results in different risk profiles for each cable type. Table 5.1 gives a summary of the distinction between cables based on interruptions.

Cable category	Protection type	Duration interruption	Interruption (min per connection)
MV transport cable	$n-1$ redundant	No interruption in case of single failure	0
MV distribution cable	Linkable together with other cables	Interruption = time to link networks	<60
LV Cable	No backup	Interruption = repair time	>60

Table 5.1 Distinction between cable types based on duration of interruptions

5.3.2 Electricity stations

Beside 142000 kilometres of cables Enexis is also responsible for the construction, maintenance and management of almost 50000 electricity stations. As well as with cables there is a distinction between types of stations. Within the electricity station there are two types of stations: (1) High voltage (HV) Stations and (2) MV/LV stations. This distinction is based on the difference in power level and the severity of the interruption in case of a failure. The first distinction is based on the difference in power level at which the stations are operating. HV stations transform electricity from 150/110KV to 10KV and MV/LV stations on the other hand transform electricity from either 10KV to 10 KV or from 10KV to 0,4KV. Another reason to spits the class of electricity stations in two groups is based on the interruption of the power supply in case of a malfunction of a station. In case of a HV station thousands of people are cut off from power supply, resulting in a major loss of consumption minutes up to millions of minutes. In the case of MV/LV station malfunction the severity will be at least a factor ten smaller. This shows that HV and MV/LV stations cannot be compared and need separate categories. Table 5.2 summarizes the differences. Based on these two arguments it can be concluded that MV/LV stations have a different risk profile than HV Stations.

MV/LS Station	HV Stations
• Power level 10KV – 10 KV / 10KV – 0,4KV • In case of malfunction < 100.000 customer minutes lost	• Power level 150/110KV – 10KV • In case of malfunction possibly > 100.000 customer minutes lost

Table 5.2 Differences between HV and MV/LV stations

5.3.3 Public lightning

The public lightning is a non-regulated sector, however Enexis has to facilitate every one asks for a connection. Since the public lightning is non-regulated Enexis has limited influence on how people perform their work. This can result in undesired situation in the grids, and result in risks for Enexis. In contradiction to the public lightning the construction, maintenance and management is regulated and here Enexis has full control. The difference between full control and limited control forces the creation of a separate class for public lightning.

5.3.4 Legislation

Beside all technical orientated risks there is a large group of non-technical orientated risks. In its capacity of network operator, Enexis is accountable to the Office of Energy Regulation and is committed to the electricity law (Wet van 2 juli 1998, houdende regels met betrekking tot de productie, het transport en de levering van elektriciteit (Elektriciteitswet 1998)). The commitment to the electricity law brings several risks to Enexis, since breaking one of the requirements in the law results in a penalty. Because the risks related to legislation are different from the technical risks related to the other classes legislation is a separate class within electricity risks

6 Application of Bow Tie Analysis

Since the concept of Bow Tie Analysis is new to Enexis and the complete utility sector as far as it is concerned with the distribution of gas and electricity this chapter will start with an extensive clarification of the steps that have to be taken to perform a Bow Tie Analysis (6.1). To illustrate the steps the chapter will end with two examples of Bow Tie Analysis which are based on Enexis. The first example is a Bow Tie Analysis for gas mains (6.2) and the second example concerns a Bow Tie Analysis for LV Cables (6.3).

6.1 General

The exact starting point of the Bow Tie Analysis has been lost in time but it is believed that they were originally called "Butterfly diagrams" and evolved from the Cause Consequence Diagram of the 1970s. It is then thought that David Gill of ICI plc developed the methodology and called them Bow Ties in the late 70's. It is generally accepted that the earliest mention of the Bow Tie methodology appears in the ICI Hazan Course Notes 1979, presented by The University of Queensland, Australia. The technique was given a huge boost in the early to mid 90's when the Royal Dutch/Shell Group developed the technique as a result of the Piper Alpha disaster. In the late 90s the Royal Dutch/Shell Group started working to improve the quality and effectiveness of the bowties being developed and allow the company to get the most out of the technique. Shell is acknowledged as the first major company to integrate the whole bowtie methodology fully into its business practices but as the 1990's grew to an end the approach became a standard method within many other companies. The structured approach of the Bow Tie Analysis was particularly popular in risk analysis within safety cases where quantification is not possible or desirable. Nowadays Bow Tie Analysis are used for assessing any type of risk, e.g. environmental, safety, business, political, security, etc. and is currently used in a wide range of companies, industries, countries and regulators (CadMus Solutions Ltd, sd).

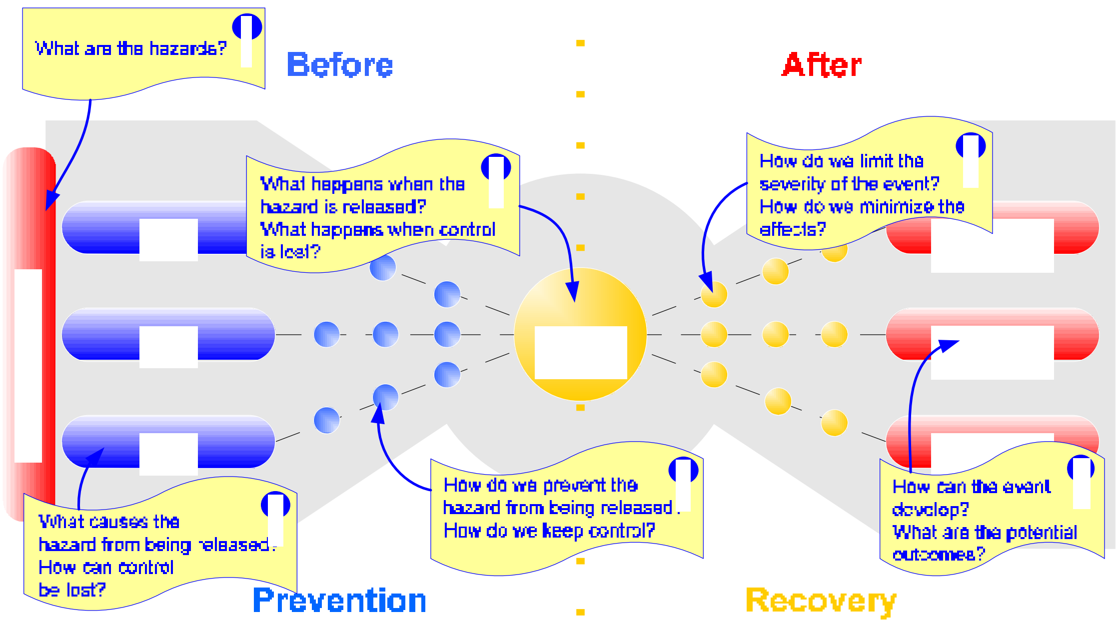
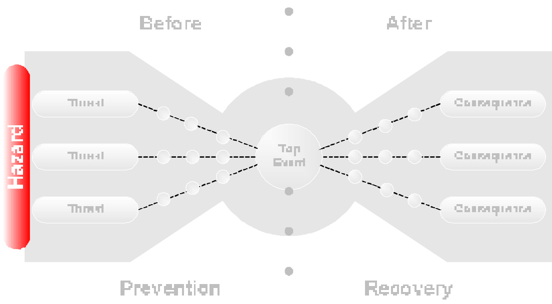


Figure 6.1 Steps to a Bow Tie Diagram (free from Governors B.V., 2004)

As mentioned above the Bow Tie Analysis is expanding across a wide variety of fields. Through its increasing popularity Enexis wants to know how it could benefit from the Bow Tie Analysis. However the Bow Tie Analysis is a proven concept it is still in its infancy within the utility industry. There are some initiatives to apply the Bow Tie Analysis for the transport of gas and electricity. However Enexis is active in the distribution of gas and electricity, a field which can not be compared with the transport of gas and electricity. Since the transport and distribution are to complete different fields there is noting known about the application of Bow Tie Analysis within the distribution and Enexis has to figure out whether or not it is applicable for distribution networks. Therefore the following paragraphs given a comprehensive guide to perform a Bow Tie Analysis. Figure 6.1 shows the process of a Bow Tie Analysis and the successive steps which have to be taken.

6.1.1 Identify the hazard

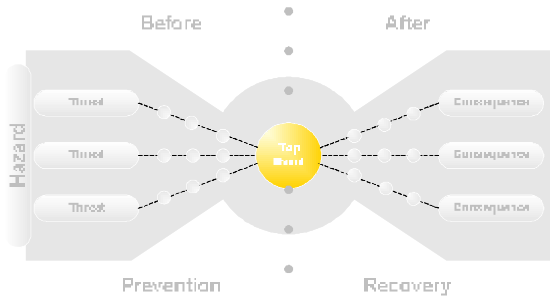
The starting point for Bow Tie Analysis is hazard identification. A hazard is a physical situation, condition or material property that has the potential to cause harm such as sickness, injury or death to people, damage to property and investments, environmental damage, business interruption and loss of reputation. A container with flammable material is a hazard because it has the potential to cause fire and/or explosion.



Hazard identification is done within a workgroup consisting of risk experts and depending on the subjects under consideration experts in the field of gas or electricity. To get some feeling for hazard identification the session can start with some simple examples of a situation with the related hazard to clarify the basic idea. With a clear understanding of hazard identification the workgroup can start with one of the defined risk classes, as defined in the previous chapter. In a group discussion the workgroup has to identify the hazard(s) for the specific risk category. The discussion has to result in one or more hazards which can be used in the next step.

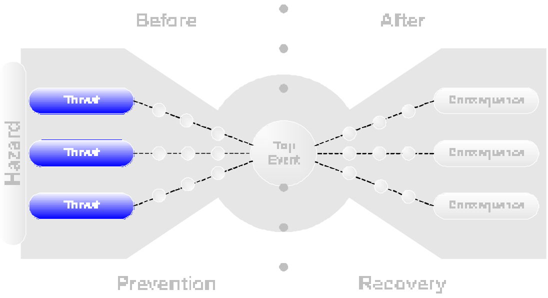
6.1.2 Define the top event

The second step in creating a Bow Tie diagram is defining the top event. The top event, in some literature also defined as critical event, describes the moment of loss of control, the moment were the hazard is released. The top event has to answer the question "What happens when the hazard is released?". If a container with flammable material is the hazard, as in the example above, then the top event is loss of containment because the first thing to happen after there is something wrong with the storage of the material it will flow out of the container. This formalization step is needed to come to a meaningful identification of threats, consequences and barriers.



Defining the top event can be done in the same session as the identification of the hazard. After identifying the hazard the workgroup consisting out of risk analysts and either gas or electricity experts has to brainstorm about what is the main event that happens if control over the hazard is lost. It is important that this step is done carefully, since the next steps are based on the choices made here. As a result of this step the hazard have to be mapped into a top event.

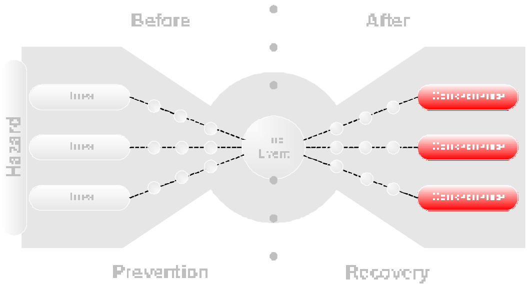
6.1.3 Identify the threats



After identifying the hazard and defining the top event, the threats have to be identified. A threat is an event which has the potential to release the hazard and produce the top event. Threats are identified to get a complete overview of all possible ways the control of a hazard can be lost. There are several types of threats: mechanical (e.g. wearing out), chemical (e.g. corrosion), physical (e.g. high pressure or temperature), natural circumstances (e.g. storm, rain, coldness) and human error

Before the workgroup meets for the identification of all threats the risk analysts have to check the risk register for relevant risks related to the hazard under consideration. Goal of this review is to identify the know threats within the risk register. The threats that are identified by the risk analysts have to be summarized in a list. This list can serve as a starting point of the brainstorm session of the work group. The work group with risk analysts and either gas or electricity experts have to discuss whether the list of risk analysts is exhaustive or if there are missing/redundant threats on the list. Redundant threats have to be deleted from the list and missing ones have to be added. The group discussion/brainstorm session has to result in a exhaustive and verified list of threats that could release the hazard.

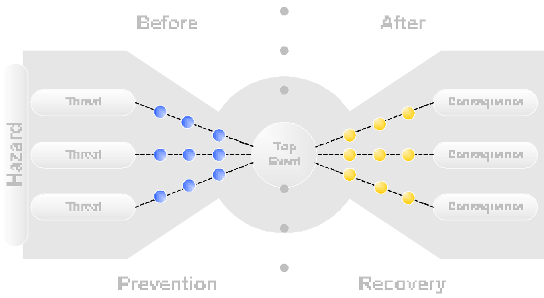
6.1.4 Identify the consequences



A consequence is an event or chain of events resulting from the hazard, its initiating event, failure of preventive control measures and failure or success of mitigative control measures. Sometimes consequences lead to other consequences. Within the Bow Tie methodology you can place them next to each other. You can also choose to just mention the final consequence. Sometimes a chain of events is too complex for one Bow Tie diagram. In that case it is better split the risk into several diagrams.

The identification of consequences has to start, as well as the identification of threats, with a review of the risk register by the risk analysts. They have to check the risk register for relevant risk related to the hazard under consideration. Based on these risks and the related risk analysis they can identify the known consequences and place them in the Bow Tie. All identified consequences have to be verified in a workgroup consisting of risk analysts and depending on the subjects under consideration experts in the field of gas or electricity. During this session the group has to check whether the list of identified consequences is exhaustive. In the case there are missing consequences they have to be added to the list. This step should result in an exhaustive list of possible consequences that could result from the hazard under consideration.

6.1.5 Identify Barriers



The last step is to identify the barriers at the left-hand side of the Top Event, which are the preventive measures and the barriers on the right-hand side of the Top Event, which are the mitigative or recovery controls. The preventive measures are put in place to prevent threats from releasing the hazard and the recovery measures try to reduce the probability of a consequence or reduce its severity. It has to be noted that some types of control are more effective than others in reducing risk.

According to Sklet (2006) there are various classifications of barriers. A widely used classification of barrier functions lists prevention, control and mitigation as the main functions (IEC:61508, 1998, IEC:61511, 2002, ISO 13702, 1999). Furthermore barriers are classified as physical and non-physical (ISO:17776, 2000), hard and soft defenses (Reason, 1998), technical or human factors-organizational systems (Svenson, 1991). Based on all these classifications Sklet (2006) proposed the classification as shown in figure 6.2

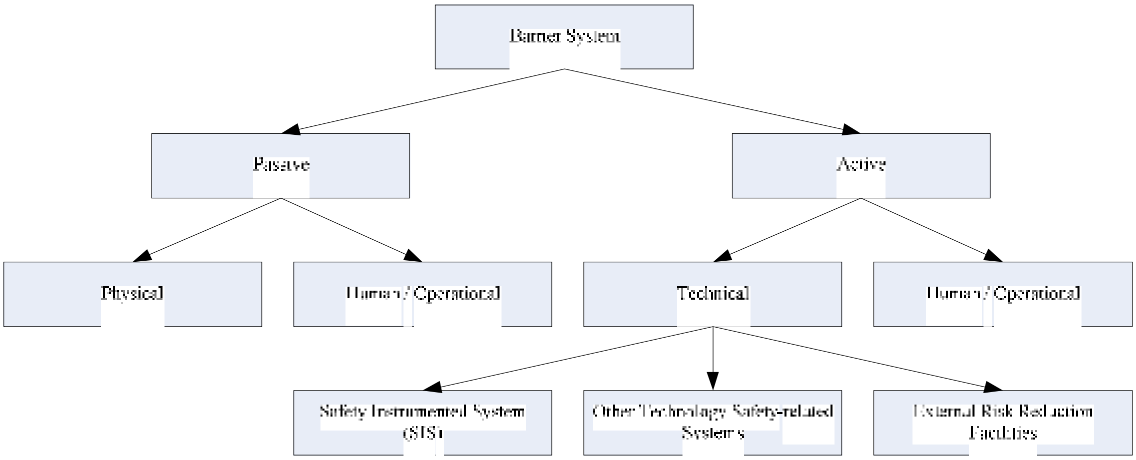


Figure 6.2 Classification of barriers (Sklet, 2006)

Hollnagel (1999) proposes another classification with four barrier categories (1) material barriers, (2) functional barriers, (3) symbolic barriers and (4) immaterial barriers. Material barriers physically prevent an action from being carried out or the consequences from spreading. A material barrier presents an actual physical barrier for the action or event in question and although it may not prevent it under all circumstances, it will at least slow it down or delay it. Furthermore, a material barrier does not have to be perceived or interpreted by the acting agent in order to serve its purpose. Functional barriers work by impeding the action to be carried out, for instance by establishing a logical or temporal interlock. A functional barrier effectively sets up one or more pre-conditions that have to be met before something can happen. These pre-conditions need not be interpreted by a human, but may be interrogated or sensed by the system itself. Symbolic barriers require an act of interpretation in order to achieve their purpose, hence an "intelligent" agent that can react or respond to the barrier. Whereas a functional barrier works by establishing an actual pre-condition that must be met by the system, or the user, before further actions can be carried out, a symbolic barrier indicates a limitation on performance that may be disregarded or neglected. Immaterial barriers are not physically present or represented in the situation, but depend on the knowledge of the user to achieve their purpose. Immaterial barriers are usually also represented in a physical form such as a book or a memorandum, but are normally not physically present when their use is mandated. Table 6.1 shows the classification proposed by Hollnagel (1999) with the four main classes and a more detailed use of the barriers

Barrier System	Barrier Function	Example
Material, physical	**Containing** or protecting. Physical obstacle, either to prevent transporting something from the present location (e.g. release) or into present location (penetration)	Walls, doors, buildings, restricted physical access, railings, fences, containers, tanks, valves, rectifiers, etc.
	Restraining or preventing movement or transportation	Safety belts, harnesses, fences, cages, restricted physical movements, spatial distance (gulfs, gaps), etc.
	Keeping together. Cohesion, resilience, indestructibility	Components that do not break or fracture easily, e.g. safety glass.
	Dissipating energy, protecting, quenching, extinguishing	Air bags, crumple zones, sprinklers, scrubbers, filters, etc.
Functional	**Preventing** movement or action (mechanical, hard)	Locks, equipment alignment, physical interlocking, equipment match, brakes, etc.
	Preventing movement or action (logical, soft)	Passwords, entry codes, action sequences, preconditions, physiological matching (iris, fingerprint, alcohol level), etc.
	Hindering or impeding actions (spatial-temporal)	Distance (too far for a single person to reach), persistence (dead-man-button), delays, synchronisation, etc.
Symbolic	**Countering**, preventing or thwarting actions (visual, tactile interface design)	Coding of functions (color, shape, spatial layout), demarcations, labels & warnings (static), etc.
	Regulating actions	Instructions, procedures, precautions / conditions, dialogues, etc.
	Indicating system status or condition (signs, signals and symbols)	Signs (e.g., traffic signs), signals (visual, auditory), warning, alarms, etc.
	Permission or authorization (or the lack thereof)	Work permit, work order.
	Communication, interpersonal dependency	Clearance, approval, (on-line or off-line), in the sense that the lack of clearance etc., is a barrier.
Immaterial	**Monitoring**, supervision	Check (by oneself or another aka visual inspection), checklists, alarms (dynamic), etc.
	Prescribing: rules, laws, guidelines, prohibitions	Rules, restrictions, laws (all either conditional or unconditional), ethics,

Table 6.1 Barrier systems and barrier functions (Holnagel, 1999)

For the purpose of this research barriers are classified according to their effectiveness in preventing a hazard form being released, reducing the probability of a consequence or reducing its severity. A three-point scale of efficiency is proposed based on the following types of barriers.

1 Technical barriers (high effectiveness) distinguish themselves from other barriers because do not need have to be perceived or interpreted by a human being. Within this group of barriers there are two subcategories:

- Technical active barriers perform their action on demand, if one or more pre-conditions are met the barrier starts working. These pre-conditions can be checked by the system itself. Technical active barriers can be illustrated by emergency shut-down systems.

- Technical passive barriers are barriers that are physical present to prevent a hazard form being released, reduce the probability of a consequence or reduce its severity. Examples are blast/fire walls containers.

2. Human/Organizational barriers (medium effectiveness) require an act of interpretation in order to achieve their purpose. This human interference includes the risk of neglecting of misjudging information resulting in the malfunction of the barrier.

3. Formal barriers (low effectiveness) are not physically present or represented in the situation, but depend on the knowledge of the user to achieve their purpose. Immaterial barriers are usually also represented in a physical form such as a book or a memorandum.

Before the identification of barriers can start it is important that all successive steps are finished. After the previous steps the risk analysts have to work out the result and start the identification of barriers in a new session. Since knowledge about possible measures and their effectiveness is often spread throughout the organization it is important that this session, as well as all other sessions is preformed in the workgroup. The risk analysts have to provide all group members a concept Bow Tie Analysis filled with the knowledge up till then (e.g. hazard, top event, threats and consequences have to be filled in). During the session their has to be successively brainstormed about barriers for each threat of consequence and their effectiveness in the three point scale. The session has to result in a completely filled Bow Tie Analysis with all know barriers assigned to the related threats or consequences. After the session the risk analysts have to link the elements form the Bow Tie Analysis to elements from the management systems (e.g. policies, procedures, guidelines, manuals, instruction, etc.) to show that the operation and quality of the barriers are secured.

6.2 Example Gas

As a result of the six steps the following Bow Tie Analysis is constructed.

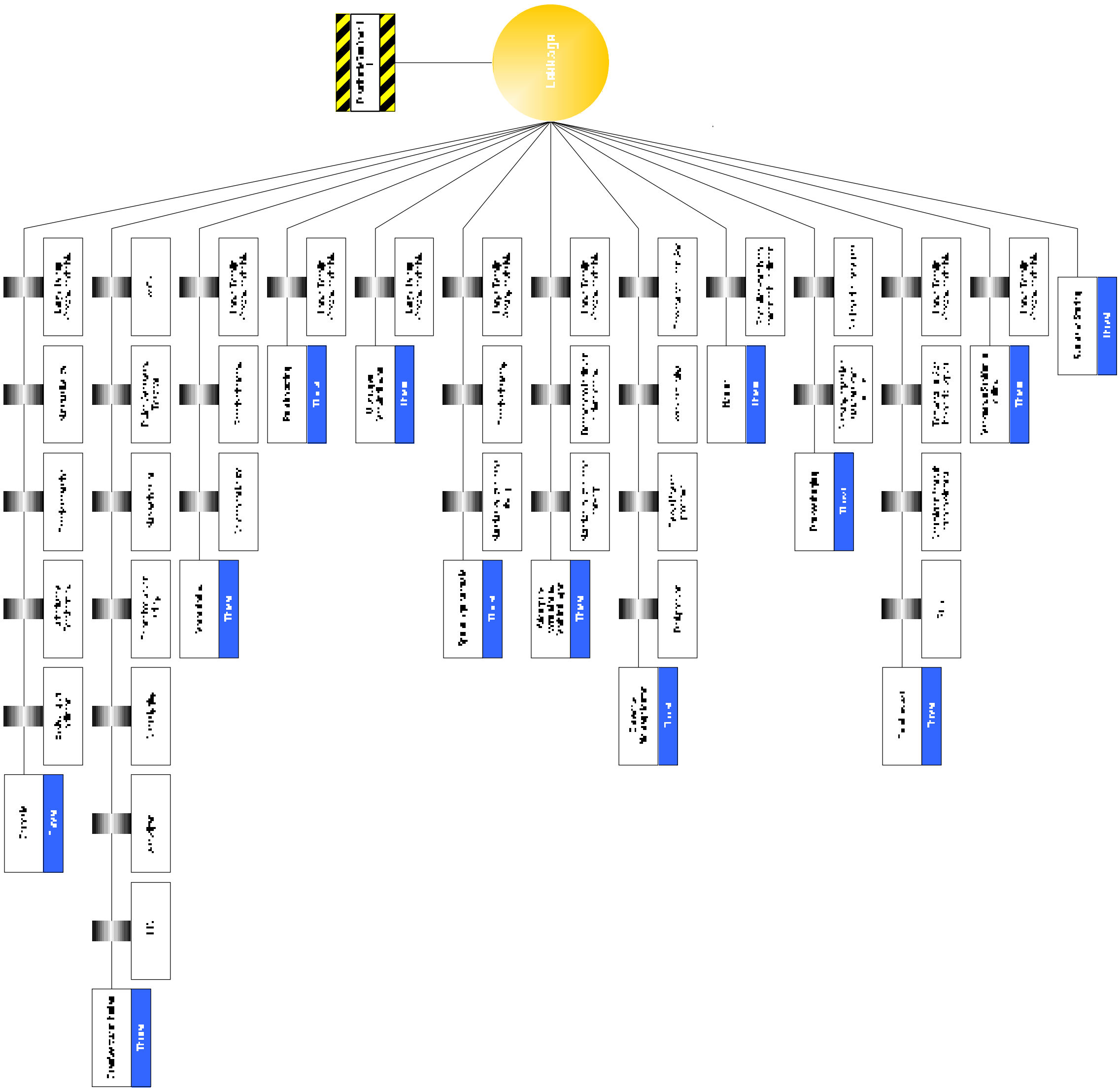


Figure 6.3 Left hand side Bow Tie Diagram gas mains

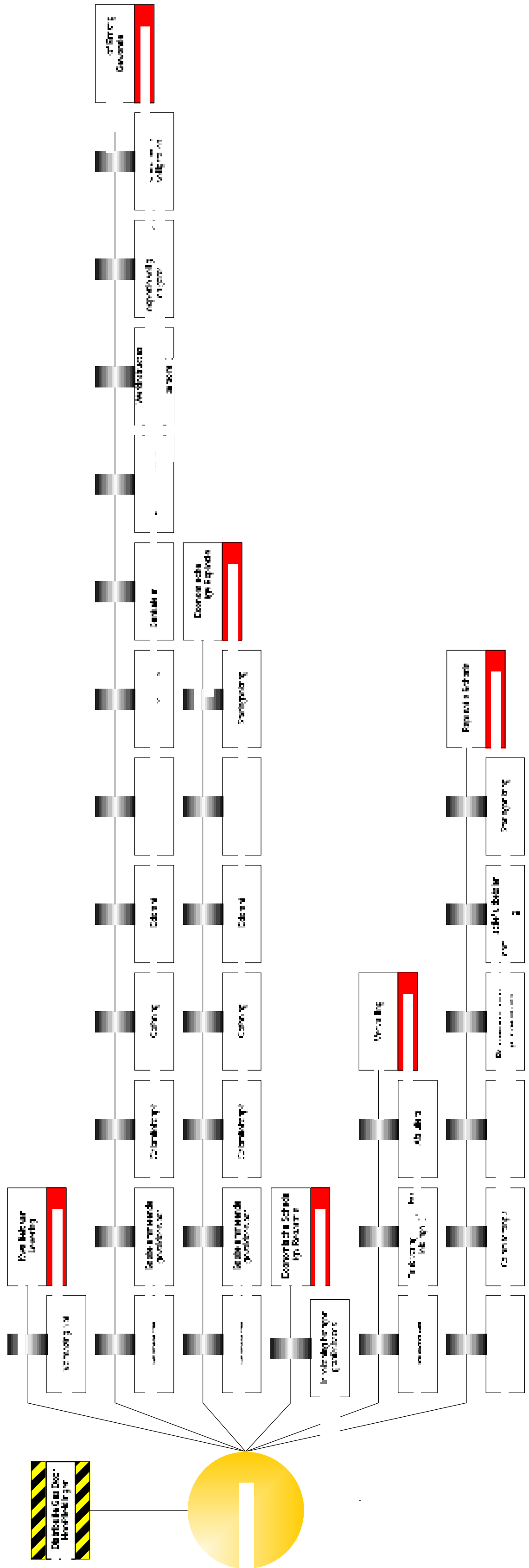


Figure 6.4 Right hand side Bow Tie Diagram gas mains

6.3 Example Electricity

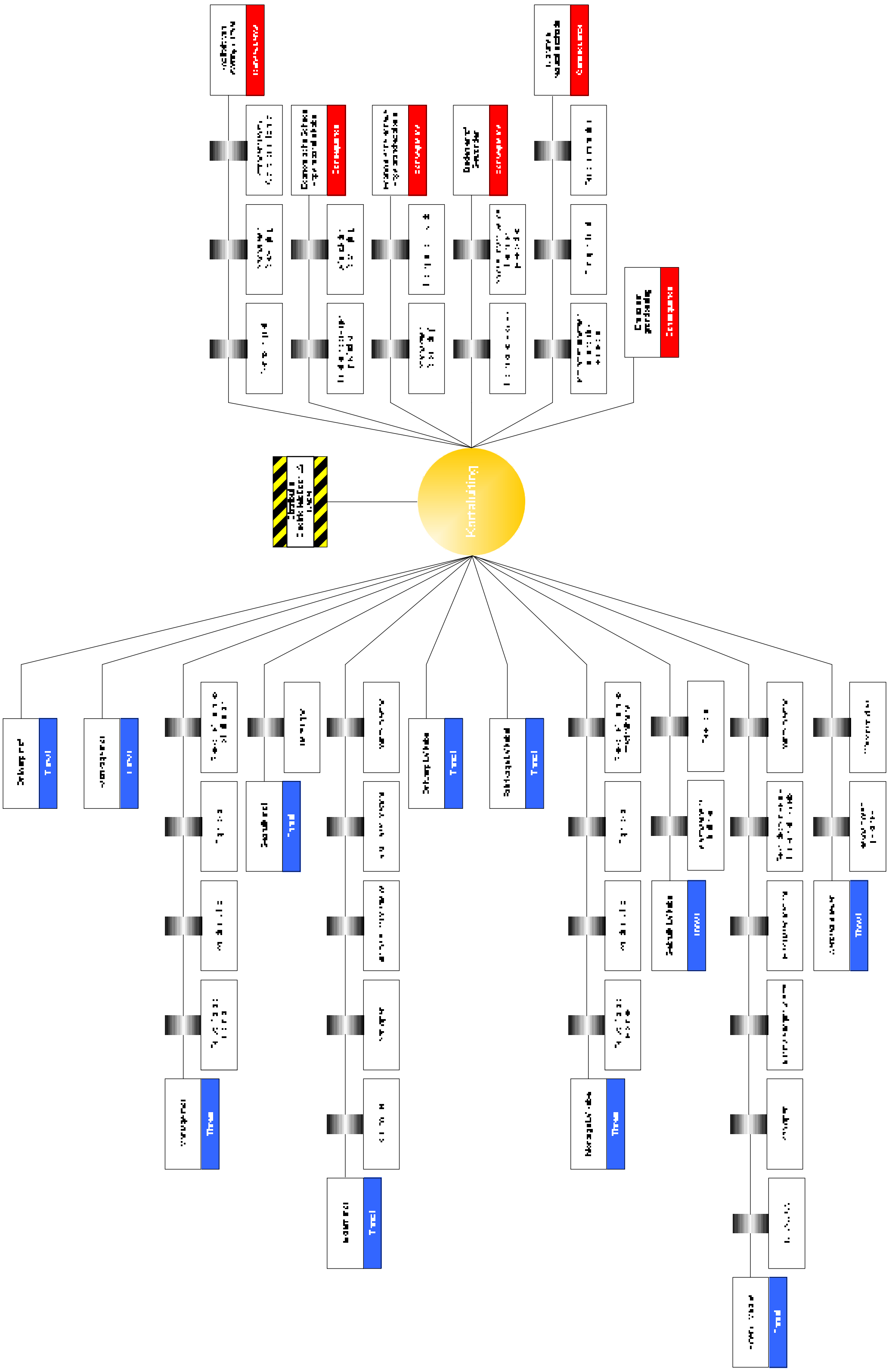


Figure 6.5 Bow Tie Diagram LV cables

6.4 Research findings during the application of Bow Tie Analysis

The first application of Bow Tie Analysis delivered interesting results which will be pointed out in this paragraph.

Overall result

The Bow Tie Analysis provided the desired insight in the relation between risks and the link between risks and policies. However during the process the quantification of Bow Tie Analysis appeared to be a complex matter. Literature about quantifying Bow Tie Analysis is rare and therefore there is limited knowledge how to do so. Based on the available literature it can be concluded that the quantification of Bow Tie Analysis is hard and requires a lot of information about the effectiveness of barriers. The quantification of barriers is complicated because there are factors involved which do not lend themselves for proper quantification, e.q. human functioning. Based on these complicating factors and the limited amount of knowledge about this effectiveness of barriers it can be concluded that Enexis is currently not able to quantify Bow Tie Analysis. This directly affects the ability to determine the effectiveness of the policies on the reduction of the risk position

Cover ratio

Bow Tie Analysis proved to be a powerful tool to provide the desired insight in the relation between risks and the link between risks and policies. About 75% of all risk in the risk register can be assigned to one of the eleven Bow Tie Analysis. The remaining 25% of the risks are relative insignificant risks compared to the ones assigned to the Bow Tie Analysis. These finding confirm that Bow Tie Analysis is particular suitable for large problems and that it is impossible to assign all risks to a Bow Tie Analysis. However the Bow Tie Diagrams allow Enexis to give a brief overview of all main risks and the policies in place to deal with these risks.

Place within the current risk management process

Bow Tie Analysis is an additional tool the current risk management process and has to be managed in the same way as the risk register. Each time the risk register is updated the Bow Tie Analysis have to be checked if it needs to be updated. Linking the Bow Tie Analysis to the risk register ensures that the Bow Tie Analysis is continually updated.

7 Monte Carlo Simulation

This chapter starts with the explanation on the importance of accurate data (7.1) and performs Monte Carlo simulations for the business values economy and quality of supply (7.3).

7.1 Data Quality

During the analysis of the risk register and the risk analysis it became apparent that the data quality used to simulate the expected risk position was not as accurate as it should be. This data serves as input data for the Monte Carlo Simulation this directly affects the reliability and accuracy of the simulation, since a prediction about the future cannot be more accurate than the data they are based on. This lack of accuracy became apparent in as well the input variables and the double counting of risks.

7.2.1 Input variables

Checking input variables is of major importance before running any simulation, since predictions cannot be more accurate than the values they are based on. Within the risk register there are maximum seven input values that have to be checked: (1) the lambda, which serves as input variable for the Poisson distribution, (2) economic impact, (3) quality of supply impact, (4) legislation impact, (5) safety impact, (6) customer satisfaction impact and (7) sustainability impact. It has to be noted that the check of the input variables is limited to verifying whether the data in the risk register equals the data in the risk analysis. In case there is an inconsistence between the two values the data in the risk register is adjusted to the data in the risk analysis. The review of all input variables resulted in some remarkable findings:

- The risk matrix as defined in paragraph 3.2 is not completely copied correctly into ARM. For the input variables economy, quality of supply and safety are correct, but the remaining variables are incorrect. Problem with this part of the risk matrix is that the range of each impact category is defined incorrectly. Instead of reflecting the ranges as defined in the risk matrix ARM still uses the default values of the program. To get all this data up to date and correct would require more time than is available to review the input variables. Therefore these three business values are kept out of the simulation.

- More than 50% of the values of the remaining input variables for the simulation do not correspond to the values described in the risk analysis. Most of them being higher in ARM then they are estimated in the risk analysis.

7.2.2 Double risks

Within the risk register there are risks that describe the same event, resulting in double counting of risks. The first reason for this is doubling of risks is the fact that not all risk are described at the same level, this can result in a main risk and for example two detail risks describing just a small part of the main risk are both added to the risk register. A second reason for doubling of risks is that there are some risks analysis initiated by the cause of the problem and some by its consequence. This combined approach can result is overlapping risks. To prevent double counting one of the double risks is either deleted or simply excluded from the simulation.

7.3 Simulations

This paragraph shows the result of the Monte Carlo simulations of the business values economy, quality of supply and safety.

7.3.1 Economy

Figure 7.1 shows the result of the Monte Carlo simulation for the business value Economy. As can be seen from the figure the sample mean equals 96 million Euro which is about 20% higher than the real economic risk. However it is a reduction of 270% of the initial risk position.

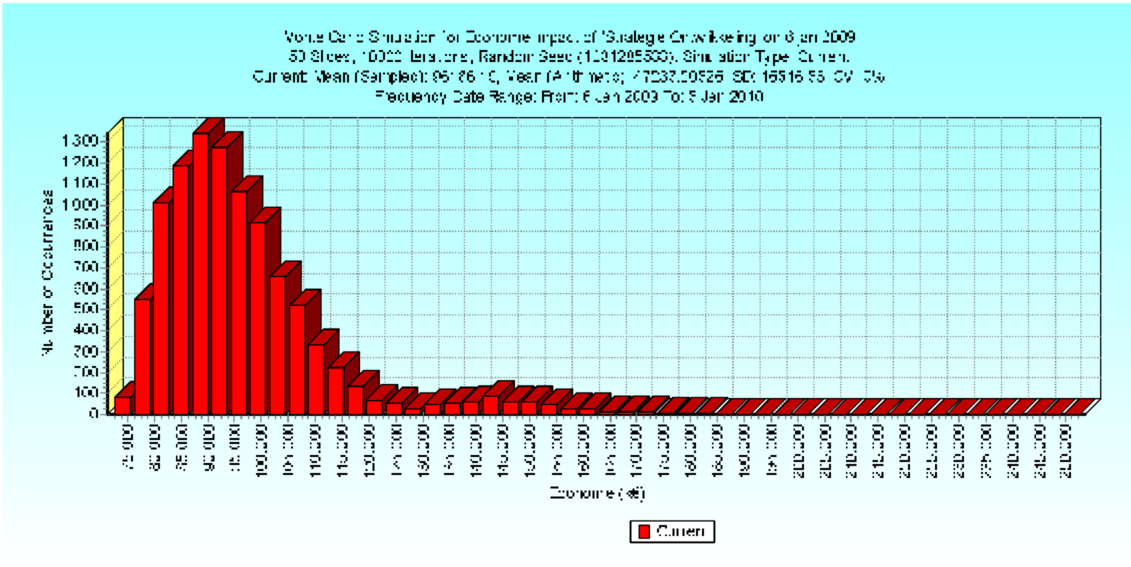


Figure 7.1 Monte Carlo simulation business value economy

7.3.2 Quality of supply

Figure 7.2 shows the result of the Monte Carlo simulation for the business value quality of supply. As can be seen from the figure the sample mean equals 105,000,000 minutes which is still 68% above real number of 65 000,000 minutes of lost customer minutes (Essent Network, 2007a), but an improvement of more than 100%.

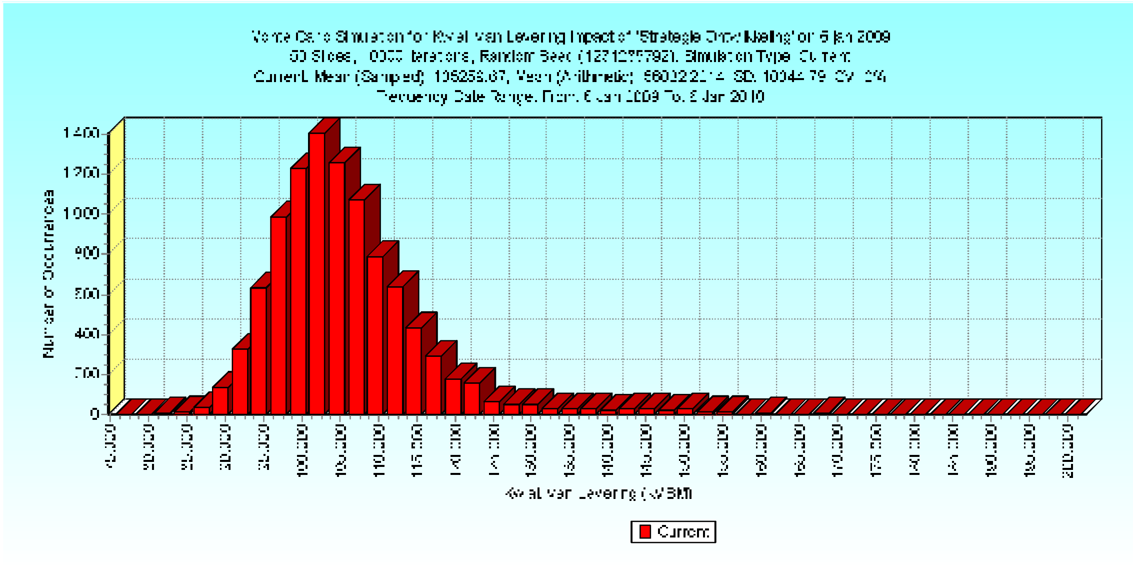


Figure 7.2 Monte Carlo simulation business value quality of supply

7.3.3 *Safety*

A simulation of the expected risk position on safety does not result in a usable outcome. A simulation results in expected value of let's say seven. Interpretation of this value is not possible since it is just the sum of the result of a simulation over 300 risks. A value of seven could be interpreted as seven accidents with dead each year, but in reality it a summation of many small accidents resulting in a number of seven. To get some reasonable outcome the results should be comparable to the DART score

8 Conclusions and Recommendations

This final chapter expounds to what extent the objective of this research is satisfied by formulating the main conclusions of this research (8.1). Subsequently recommendations are made for both application of the methods in practice and for the optimisation of the methods by further research (8.2). First of all the objective of this research is repeated:

Determine the risk position of Enexis and make the effectiveness of her policy on the risk position theoretically and practically provable.

8.1 Conclusions

Reason for this research formed the current risk management method of Enexis and the overestimated theoretical risk position. Enexis observed improvement potential the risk management process and the determination of the theoretical risk position. The use of this improvement potential leads to improved decision making.

Enexis implemented the Risk Based Asset Management (RBAM) methodology. This methodology has to guarantee an optimal risk reduction within the existing constraints of available funds and people. Therefore it is important that Enexis can calculate its risk position and the effectiveness of the policies on the reduction of this risk position. The current risk management process results in a over-estimated risk position. Due to problems with interrelations/overlap the calculated risk position of Enexis shows an over-estimation of the true position. A over-estimated risk position may trigger more actions and expenses than can be justified on the basis of the actual risks Enexis faces. Eventually this may lead to a culture of incorrect decision-making and overspending.

From risk management there are several methods en techniques available. In this study Bow Tie Analysis and Monte Carlo Simulation are subject of research. Bow Tie Analysis is a diagrammatic way of describing and analyzing the pathways of a risk from hazard to outcomes and reviewing controls. The Monte Carlo Simulation is a general method for representing and simulation of stochastic process by systematic drawing from probability density functions. In the current situation Enexis uses Monte Carlo Simulation to calculate its risk position. This research focuses on providing insight in the interrelations between risks and the relation between risk and risk management policies with Bow Tie Analysis and the improvement of the calculated risk position by assessing the accuracy of the input variables for the Monte Carlo simulation.

The research started with the categorization of all risks in manageable categories as suggested by Cvetkovich & Earle (1985). The main conclusions with respect to the categorization of risk are:

1. *Eleven risk categories for Enexis*
   The categorization of the 300 active risks resulted in eleven categories which meet the desired attributes for ideal risk categorization defined by Morgen *et al.* (2000). The categorization resulted in 25 till 30 risks per category which is assumed to be well manageable.

Next step in the research was the application of Bow Tie Analysis on each of the risk categories. Due to time constraints the Bow Tie Analysis is only applied on two of the eleven risk categories. The main conclusions with respect to the application of Bow Tie Analysis are:

1. *Bow Tie Analysis are applicable within the distribution networks*
   Bow Tie Analysis is a proven concept, however it is still in its infancy within the utility industry. There are some initiatives to apply the Bow Tie Analysis for the transport of gas and electricity. However Enexis is active in the distribution of gas and electricity, a field which can not be compared with the transport of gas and electricity. Since the transport and distribution are to complete different fields there is noting known about the application of Bow Tie Analysis within the distribution. This research has proven that the concept of Bow Tie Analysis is applicable for network operators within distribution networks. Furthermore it provides a comprehensive guide to apply Bow Tie Analysis.

2. *The Bow Tie Analysis provided the desired insight in the relation between risks and the link between risks and policies*
   Bow Tie Analysis proved to be a powerful tool to provide the desired insight in the relation between risks and the link between risks and policies About 75% of all risk in the risk register can be assigned to one of the eleven Bow Tie Analysis. The remaining 25% of the risks are relative insignificant risks compared to the ones assigned to the Bow Tie Analysis. These finding confirm that Bow Tie Analysis is particular suitable for large problems and that it is impossible to assign all risks to a Bow Tie Analysis. However the Bow Tie Diagrams allow Enexis to give a brief overview of all main risks and the policies in place to deal with these risks.

3. *Quantifying Bow Tie Analysis is a complex matter*
   Literature about quantifying Bow Tie Analysis is rare and therefore there is limited knowledge how to do so. Based on the available literature it can be concluded that the quantification of Bow Tie Analysis is hard and requires a lot of information about the effectiveness of barriers. The quantification of barriers is complicated because there are factors involved which do not lend themselves for proper quantification, e.q. human functioning. Based on these complicating factors and the limited amount of knowledge about this effectiveness of barriers it can be concluded that Enexis is currently not able to quantify Bow Tie Analysis. This directly affects the ability to determine the effectiveness of the policies on the reduction of the risk position

Finally this research studied the impact of data quality on the accuracy of the calculated risk position with a Monte Carlo Simulation. The main conclusions with respect to the impact of the data quality on the theoretical risk position are:

1. *Direct relation between accuracy data quality and accuracy theoretical risk position*
   The results of a Monte Carlo Simulation depend are based on the input variables. Since the results of a simulation cannot be more accurate than the data it is based on there is a direct relation between data quality and the accuracy of the risk position. This is perfectly illustrated by this research, as the improvement of the data quality resulted together with the exclusion of overlapping risks in an improved accuracy of the risk position between 100% and 270%.

2. *Overlapping risk contribute to the overestimation of the risk position*
   Due to interrelations between risks there are risks in the risk register that overlap each other. This overlapping of risks results in the double counting of these risks and directly influences the risk position. The Bow Tie Analysis visualized these interrelations and based on these findings double risks are excluded from the Monte Carlo Simulation

resulting together with the improved data accuracy in the above mentioned improvements of 100% up to 270% of the risk position.

8.2 Recommendations

The application of Bow Tie Analysis provided the desired insight in the relation between risks and the link between risks and policies and the improvement of the accuracy of the input variables resulted in an improved theoretical risk position. However this research resulted in the observation of a number of shortcomings. These are formulated in the next paragraph and directly followed by a recommendation to deal with it

8.2.1 Recommendations to optimize the use of Bow Tie Analysis

At this moment in time Enexis is not able to use the Bow Tie Analysis to its full content. Enexis is not able to quantify the Bow Tie Analysis, resulting in missing the opportunity to determine the effectiveness of the risk management policies with the use of Bow Tie Analysis.

1. *Determination effectiveness barriers*

   Quantification of Bow Tie Analysis require detailed information and knowledge about the effectively of barriers, since this information and knowledge is currently not available Enexis is at this moment in time not able to perform the final step of the Bow Tie Analysis and quantify the Bow Tie Analysis. Therefore it is recommended that Enexis performs further research to the effectiveness of barriers to be able to use Bow Tie Analysis to its full content

2. *Indicate effectiveness barriers*

   Until the effectiveness of each barrier is known it is recommended to indicate the effectiveness of each barrier according to the barrier classification defined in Chapter 6. The indication about the effectiveness of each barrier allows Enexis roughly estimate the effectiveness of their policies.

8.2.2 Recommendations to optimize accuracy of the risk position

Although the exclusion of overlapping risk and the improvement of data quality resulted in a spectacular improvement of the accuracy of the theoretical risk position it is still overestimated. This overestimation varies between 68% and 100%.

1. *Determination of correct input for the simulation*

The input for the simulation has to be determined even more accurate, since the reliability of the simulation depends in the exactness of the input variables. With this is aimed at the choice of the probability distribution and the parameters for the probability distribution

- This research assumed a Poisson distribution as probability distribution for all risk variables. It is recommended to set up an inquiry to possible other probability distributions for the risk variables.

- In case the Poisson distribution is chosen the parameter estimation of the Poisson distribution should be even more accurate, since this frequency of the occurrence of event has a large influence on the risk position.

2. Improve assessment of risk level

The severity of the consequences has a major influence on the risk position. As is concluded in the previous paragraph the severity of the individual risk is overestimated. Overestimation of these input variables result in an overestimation of the risk position. To solve this problem Enexis should consider several things.

- People tend to overestimate risk because people rather overestimate the risk then they underestimate the risk. It is recommended that Enexis set up an inquiry to find ways to let people set more realistic risk levels.

- In cases where risk levels are based on limited amount of data Enexis uses transition probabilities. However these transition probabilities are estimates without proper justification. Therefore it is recommended that Enexis map all transition probabilities with a proper justification. This will result in more realistic risk levels.

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Appendix A Risk management process Enexis

This appendix will give a general overview of the risk management process at Enexis (A.1). After that each individual part of the process will be discussed in detail. Starting with inventory and analyze of risks (A.2), followed by the development of strategies (A.3) and the development of tactics (A.4). After that the ranking of bottlenecks will be discussed (A.5) and finally there will be elaborated on the evaluation of tactics (A.6).

A.1 Managing Risks and Tactics

The risk management process (figure A.1) should provide and take care of an optimal risk position for Enexis. This risk position is optimized for the so called business values provided by the Asset Owner against minimal costs. As mentioned before the risk management process contains the following five steps: (1) inventory and analyze of risks, (2) development of strategies, (3) development of tactics, (4) ranking of bottlenecks and (5) evaluation of tactics.

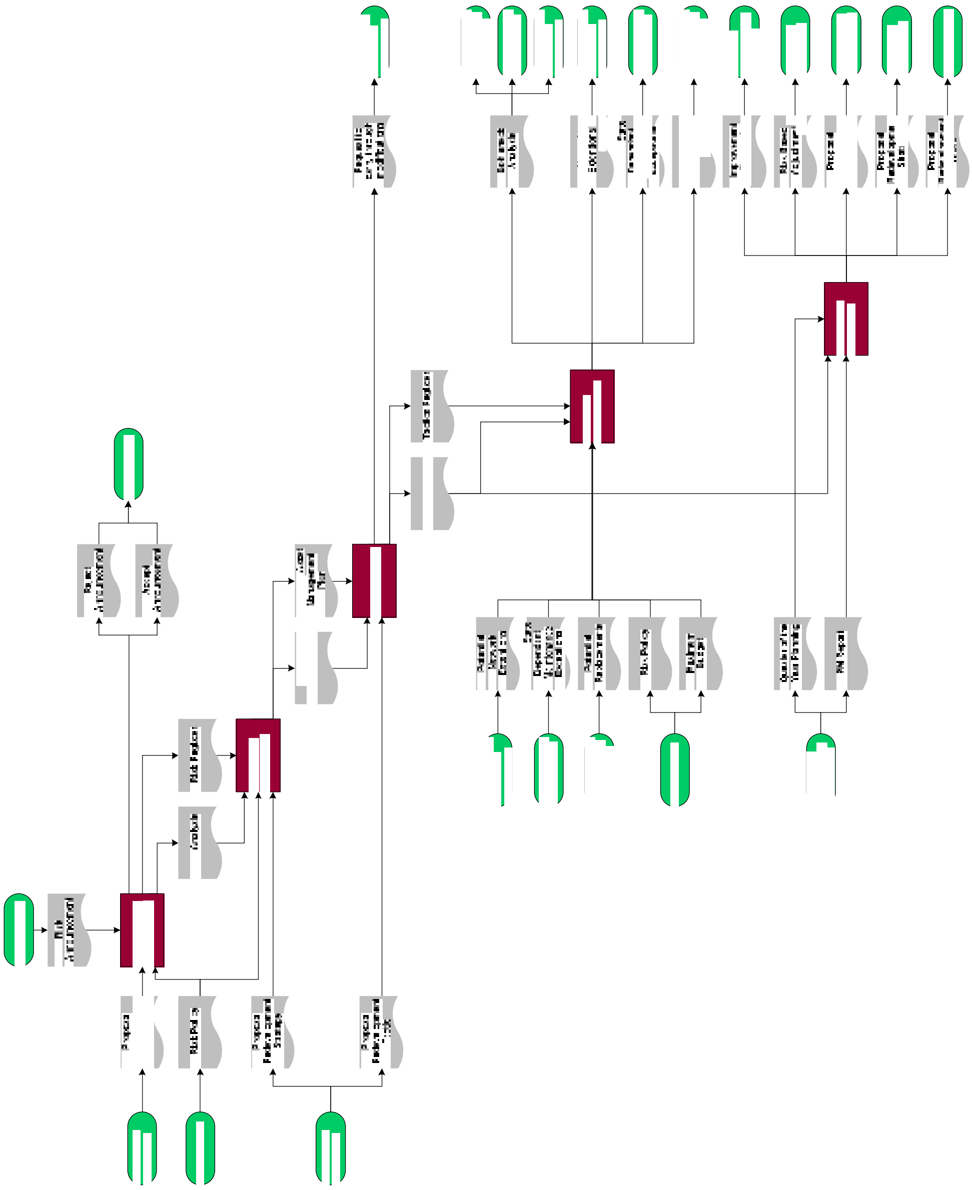

Figure A.1 Risk management process

A.2 Inventory and analyze of risks

The sub process of inventory and analyze risks (figure A.2) provides insight in the risks that Enexis faces with its assets. The process starts with a risk announcement with possibly need an extensive analysis. Each risk gets a rough assessment and if this assessment results is a risk level above a certain level it will be extensively analyzed. From the results of the analysis the risk position is consolidated. The process restricts its self to the business values defined by the Asset Owner and the technical assets.

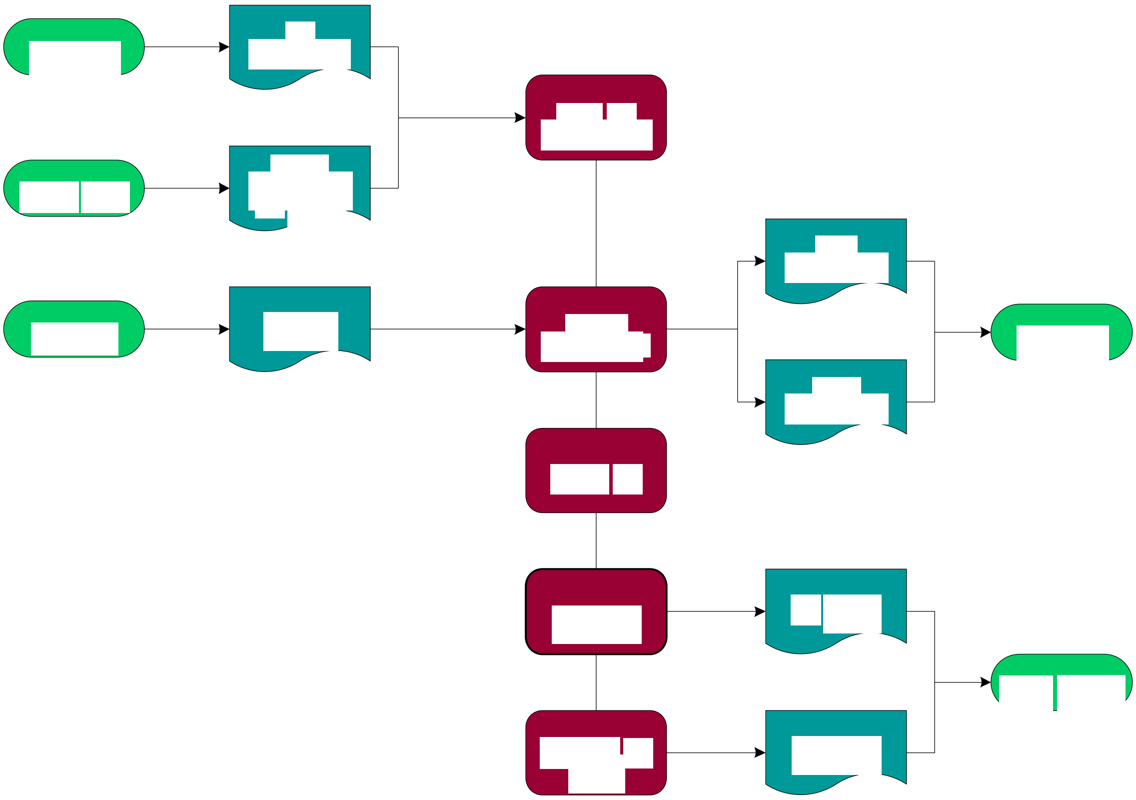

Figure A.2 Inventory and analyze risks

A.3 Development of strategies

In the sub process development of strategies (figure A.3) develops strategies for the selected risks which are the basis for the development of tactics. A strategy contains one or more solutions. For each solution the strategy contains a calculation for its return.

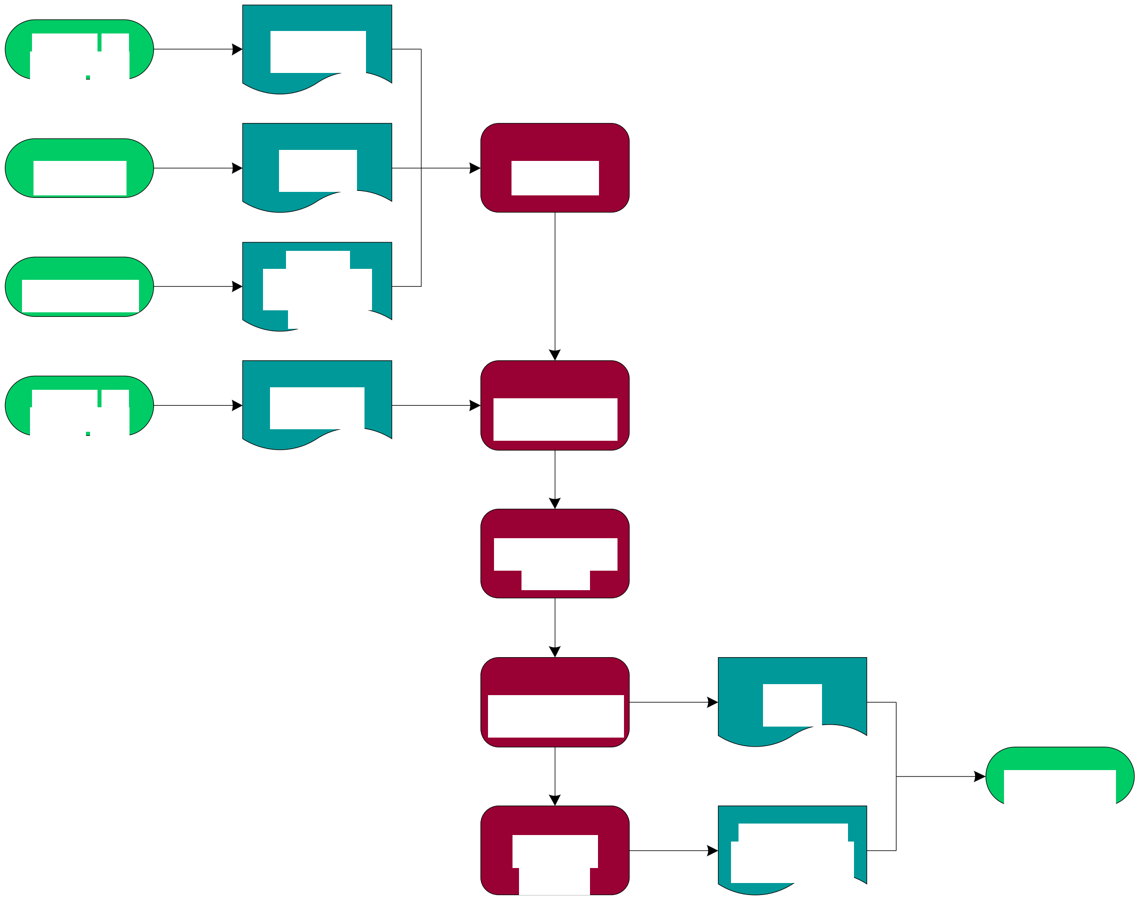

Figure A.3 Development of strategies

A.4 Development of tactics

During the development of tactics (figure A.4) strategies are translated into possible tactics. With the use of a assessment model the tactic with the highest return is chosen to be implemented.

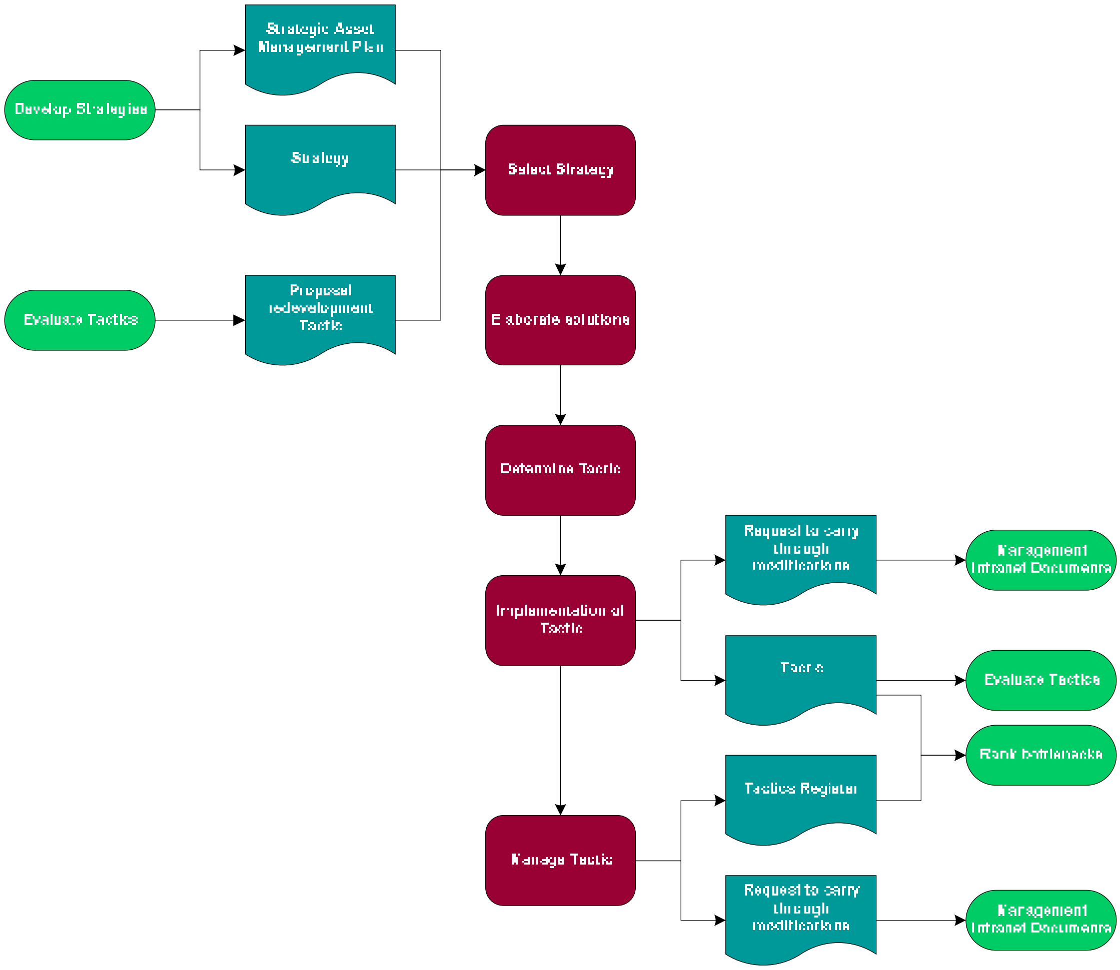

Figure A.4 Development of tactics

A.5 Ranking of bottlenecks

The process of ranking bottlenecks (figure A.5) looks after the optimal allocation of the total budget over the various tactics. Based on the desired performance of the network by the Asset Owner the Asset Manager proposes a budget allocation over the tactics. This proposal will be adjusted with the maximum budget available from the Asset Owner

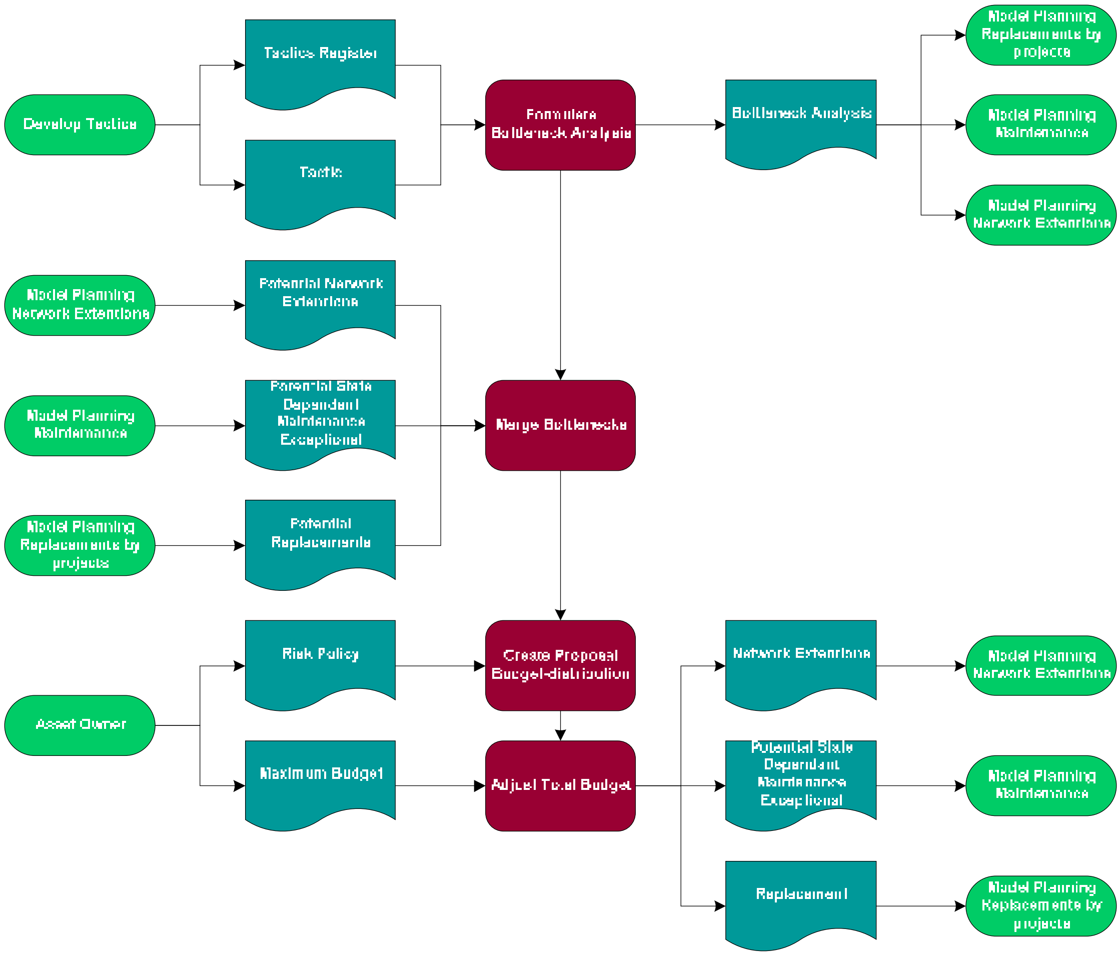

Figure A.5 Ranking of bottlenecks

A.6 Evaluation of tactics

The final step in the risk management process is the evaluation of risks, strategies and tactics. This evaluation determines whether: (1) the effectiveness of the strategies and tactics is sufficient, with other words whether the intended risk reduction is obtained, (2) the risk level should be adjusted as a result of the tactic, (3) the tactic is executed according to applying planning and appraisal and (4) the efficiency of the tactic can be optimized. Based on the determined effectiveness and efficiency of the tactic the corresponding risk level can be adjusted or there can follow a recommendation to redevelop the strategy or tactic.

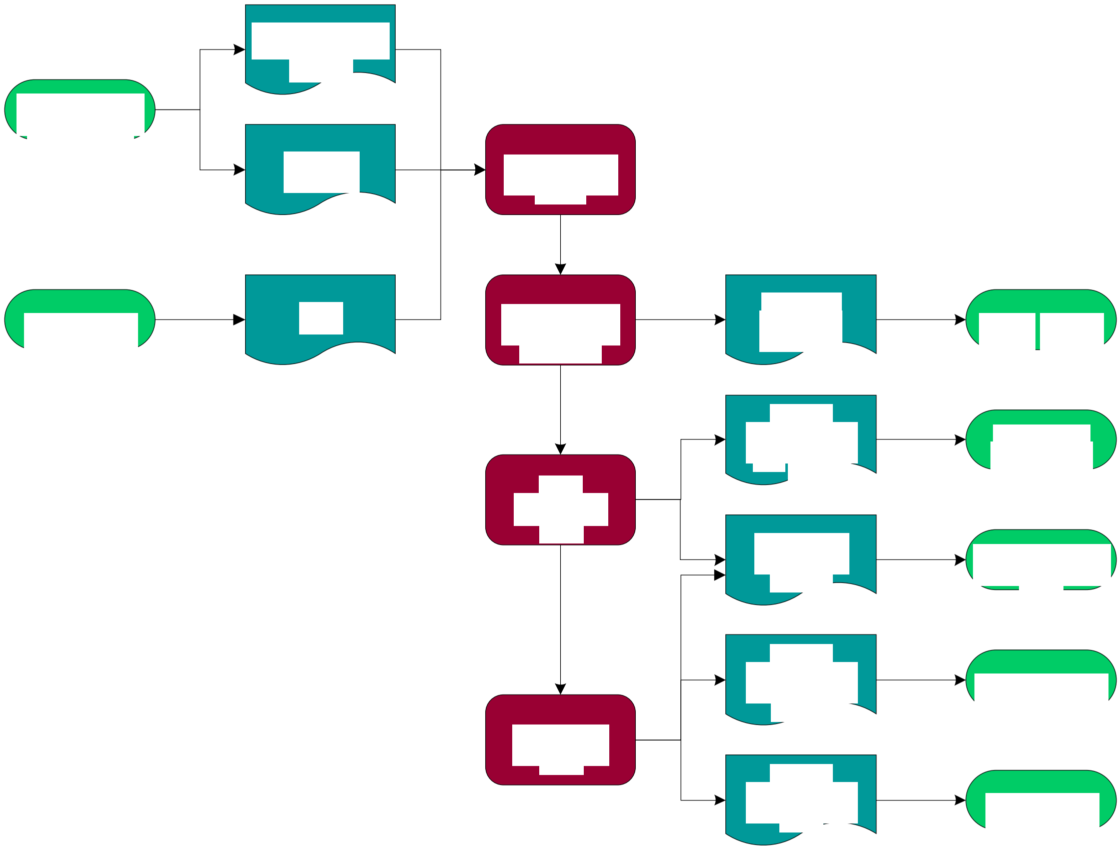

Figure A.6 Evaluation of tactics

Appendix B Risk Matrix Essent Netwerk 2008

Category	Quality of supply	Safety	Compliance	Final	Customer satisfaction	Sustainability	Almost impossible	Unlikely	Possible	Probable	Regularly	Yearly	Monthly	Daily	Permanent
							Ne[illegible]	Already seen in industry	Several times seen in industry	Already seen at Essent	Several times seen at Essent	[illegible]	[illegible]	[illegible]	Once till several times per day per region at Essent
							[illegible]	0,0001/a	0,001/a	0,01/a	0,1/a	1/a	10/a	100/a	1000/a
Disastrous	>20.000.000 consumption minutes (HS Deelnet 4 hours interruption)	Several dead persons	Loss of license [illegible]; Fine by anti-trust-body of [illegible] of turnover	Damage larger then 10M euro	International commotion 50.000 - 500.000 SC of 1.000 - 10.000 LC complaints	> [illegible] kt [illegible]	N	L	M						
Serious	2.000.000 tot 20.000.000 consumption minutes (HS Station 4 hours interruption)	Accident with very serious injuries or one dead person	Silent curator; Legal case against MD; Fine by anti-trust-body (NMa) < 1% of turnover	Damage from [illegible] till 10M euro	National commotion 5.000 [illegible] 100 - 1.000 LC complaints	[illegible] kt [illegible]	N	N	L	M					
Considerable	200.000 tot 2.000.000 consumption minutes (MS Verdeelstation 4 [illegible])	Accident with serious injuries with absence	Direction by court; Fine of the [illegible] category; Legal case by more then 5000 customers	Damage from 100k till 1M euro	Regional commotion, 500 - 5.000 SC of 10 - 100 LC complaints	10 [illegible] kt [illegible]	N	N	N	L	M				
Moderate	20.000 tot 200.000 consumption minutes (MS-D streng 4 hours interruption)	Accident with injuries with absence	Official direction; Fine of the 4th category; Legal case by more then 500 customers	Damage from [illegible] till 100k euro	Local commotion 50 - 500 SC of [illegible] 10 LC complaints	[illegible] kt [illegible]	N	N	N	N	L	M			
Small	2.000 tot 20.000 consumption minutes (Transformer housing 4 hours interruption)	Almost accidents, accidents with slight injuries, first aid without absence	Official warning; legal case by more then 50 customers	Damage from 1.000 till 10.000 euro	Not public commotion, 5 - 50 SC of 1 LC complaints	[illegible] kt [illegible]	N	N	N	N	N	L	M		
Neglectable	200 tot 2.000 consumption minutes (House > 2 hours till street < 4 hours interruption)	Dangers due to unsafe proceedings or situations	Fine of the 1st category; Legal case by a few customers	Damage less then 1.000 euro	Interna[illegible] [illegible] complaints	0,01 - 0,1 kt [illegible]	N	N	N	N	N	N	L	M	

ENEXIS

Appendix C Risk assessment techniques

Technique	Description
Failure mode and effect analysis	There are several types of FMEA: Design (or Product) FMEA which is used for components and products, System FMEA which is used for systems, Process FMEA which is used for manufacturing and assembly processes, Service FMEA and Software FMEA. In the case of Process FMEA, the Risk Priority number (a combination of severity of the failure, the failure cause occurrence and the detection effectiveness) is determined to prioritize the items for further action consideration. This analysis is usually semi-quantitative, but actual data for occurrence and detection can be used.
Failure mode, effect and criticality analysis	FMECA extends a Design FMEA so that each fault mode identified is ranked according to the combined influence of its likelihood of occurrence and the severity of its consequences. This analysis is usually qualitative or semi-quantitative but may be quantified using actual failure rates.
Fault tree analysis	A technique which starts with the undesired event (Top Event) and determines all the ways in which it could occur. These are displayed graphically in a logical tree diagram. Once the fault tree has been developed, consideration should be given to ways of reducing or eliminating potential causes / sources.
Hazard and operability studies (HAZOP)	HAZOP is a general process of risk identification to define possible deviations from the expected or intended performance. It uses a guideword based system.
Reliability centred maintenance	Reliability Centred Maintenance (RCM) is a method to identify the policies that should be implemented to manage failures so as to efficiently and effectively achieve the required safety, availability and economy of operation for all types of equipment
Markov analysis	Markov analysis, sometimes called State-Space analysis, is commonly used in the analysis of repairable complex systems that can exist in multiple states, including various degraded states.
Human reliability analysis	Human reliability assessment (HRA) deals with the impact of humans on system performance and can be used to evaluate human error influences on the system.
Preliminary hazard analysis (PHA)	PHA is a simple inductive method of analysis whose objective is to identify the hazards and, hazardous situations and events that can cause harm for a given activity, facility or system.
Event tree analysis	Using inductive reasoning to translate likelihood of different initiating events into possible outcomes.
Brainstorming	A means of collecting a broad set of ideas and evaluation, ranking them in a team. Brainstorming may be stimulated by prompts or by One-on-one and one-on-many interview techniques
Structured or Semi-Structured Interviews	A means of collecting a broad set of ideas and evaluation, ranking them in a team.
Delphi Techniques	A means of combining expert opinions that may support source and effects identification, likelihood and consequence estimation and risk evaluation. It is a collaborative technique for building consensus involving independent analysis and voting by experts.
Checklists	Check lists are lists of hazards, risks or control failures that have been developed usually from experience, either as a result of a previous risk assessment or as a result of past failures.
Consequence/Likelihood Matrix	The consequence likelihood matrix is a means of combining qualitative or semi-quantitative ratings of consequence and likelihood to produce a level of risk or risk rating.

LOPA	(May also be called barrier analysis). It allows controls and their effectiveness to be evaluated.
SWIFT	A system for prompting a team to identify risks. Normally used within a facilitated workshop. Normally linked to a risk analysis and evaluation technique.
Decision Tree	PHA is a simple inductive method of analysis whose objective is to identify the hazards and, hazardous situations and events that can cause harm for a given activity, facility or system.
Bow Tie Analysis	Bow tie analysis is a simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes and reviewing controls. It can be considered to be a combination of the thinking of a fault tree analyzing the cause of an event (represented by the knot of a bow tie) and an event tree analyzing the consequences
Monte Carlo	Monte Carlo simulation is used to establish the aggregate variation in a system of the resulting from the variations in for a number of inputs where each input has a defined distribution and the inputs are related to the output via defined relationships. The analysis can be used for a specific model where the interactions of the various inputs can mathematically defined. The inputs can be based upon a variety of distribution types according to the nature of the uncertainty they are intended to represent. For risk assessment, triangular distributions or beta distributions are commonly used.
Root Cause Analysis	A single loss that has occurred is analyzed in order to understand contributory causes and how the system or process can be improved to avoid such future losses. The analysis should consider what controls were in place at the time the loss occurred and how controls might be improved.
HACCP	The Hazard Analysis and Critical Control Point is a systematic, proactive, and preventive system for assuring product quality, reliability, and safety of processes by measuring and monitoring specific characteristics which are required to be within defined limits.
Environmental Risk Assessment	Hazards are identified and analyzed and possible pathways by which a specified target might be exposed to the hazard are identified. Information on the level of exposure and the nature of harm caused by a given level of exposure are combined to give a description of the nature of risk and its level.
Scenario Analysis	Possible future scenarios are identified through imagination or extrapolation from the present and different risks considered assuming each of these scenarios might occur. This can be done formally or informally qualitatively or quantitatively.
Business Impact Analysis	Provides an analysis of how key disruption risks could affect an organization's operations and identifies and quantifies the capabilities that would be required to manage it.
Cause & Consequence Analysis	A combination of fault and event tree analysis that allows inclusion of time delays. Both causes and consequences of an initiating event are considered.
Cause and effect analysis	An effect can have a number of contributory factors which may be grouped into different categories. Contributory factors are identified often through brainstorming and displayed in a tree structure or fishbone diagram.
Sneak Circuit Analysis	Sneak Analysis (SA) is a methodology for identifying design errors. A sneak condition is a latent hardware, software, or integrated condition that may cause an unwanted event to occur or may inhibit a desired event and is not caused by component failure. These conditions are characterized by their random nature and ability to escape detection during the most rigorous of

	standardized system tests. Sneak conditions can cause improper operation, loss of system availability, program delays, or even death or injury to personnel.
Bayesian Analysis	Bayesian analysis is a statistical procedure which utilizes prior distribution data to assess the likelihood of the result. Bayesian analysis depends upon the accuracy of the prior distribution to deduce an accurate result. Bayesian belief networks model cause and effect in a variety of domains by capturing probabilistic relationships of variable inputs to derive a result.

Table C.1 Risk Assessment Techniques (ISO/IEC, 2008)

Appendix D Applicability risk assessment methods

Table D.1 shows for each step of the risk assessment process the application of the method described as being either strongly applicable (SA), applicable (A) or not applicable (NA).

Tools & Techniques	Risk Assessment				
		Risk Analysis			Risk Evaluation
	Risk Identification	Consequence	Likelihood	Level of risk	
Failure mode and effect analysis	SA	NA	NA	NA	NA
Failure mode, effect and criticality analysis	SA	SA	SA	SA	SA
Fault tree analysis	NA	A	A	A	A
Hazard and operability studies (HAZOP)	SA	SA	NA	NA	SA
Reliability centered maintenance	SA	SA	SA	SA	SA
Markov analysis	A	NA	SA	NA	NA
Human reliability analysis	SA	SA	SA	SA	A
Preliminary hazard analysis	SA	NA	NA	NA	NA
Event tree analysis	NA	SA	SA	A	NA
Brain storming	SA	NA	NA	NA	NA
Structured or Semi-Structured Interviews	SA	NA	NA	NA	NA
Delphi Techniques	SA	NA	NA	NA	NA
Checklists	SA	NA	NA	NA	NA
Consequence/Likelihood Matrix	SA	SA	SA	SA	A
LOPA	SA	NA	NA	NA	NA
SWIFT	SA	SA	SA	SA	SA
Decision Tree	NA	SA	SA	A	A
Bow Tie Analysis	NA	A	SA	SA	A
Monte Carlo	NA	SA	SA	SA	SA
Root Cause Analysis	A	NA	SA	SA	NA
HACCP	SA	SA	NA	NA	SA
Environmental Risk Assessment	SA	SA	SA	SA	SA
Scenario Analysis	SA	SA	A	A	A
Business Impact Analysis	A	SA	A	A	A
Cause & Consequence Analysis	A	SA	NA	A	A
Cause and effect analysis	SA	SA	NA	NA	NA
Sneak Circuit Analysis	A	NA	NA	NA	NA
Bayesian Analysis	NA	NA	SA	NA	SA

Table D.1 Applicability of risk assessment tools for risk assessment (ISO/IEC, 2008)

Appendix E Example Monte Carlo Simulation

Simple examples of Monte Carlo simulation are almost embarrassingly simple. Suppose we want to find out the probability that, out of a group of thirty people, two people share a birthday. It is a classic problem in probability, with a surprisingly large answer.

Classically, you approach it like this. Pick people (and their birthdays) randomly, one at a time. We will keep track of the probability that there are no shared birthdays.

- The first person can have any birthday, and there is still a 100% chance of no shared birthdays.
- The second person has one chance of overlapping with the first person, so there is a 364/365 of placing him/her without an overlap. The probability of no shared birthdays is 364/365.
- The third person has two chances of overlapping with the first two people, so there is a 363/365 chance of placing him/her without overlaps (two days are taken). The probability of no shared birthdays is now (364/365) × (363/365).
- The fourth person has three chances of overlapping with the first three people, so there is a 362/365 chance of placing him/her without overlaps. The probability of no shared birthdays is now (364/365) × (363/365) × (362/365).
- ...
- The thirtieth person has 29 chances of overlapping with the first three people, so there is a 336/365 chance of placing him/her without overlaps. The probability of having no shared birthdays is now (364/365) × (363/365) × (362/365) × ... × (336/365)

The overall probability of no overlapping birthdays is then 0,294, giving a 71% chance that at least one pair of people has overlapping birthdays. It's not too complex if you see the trick of keeping track of the probability of zero overlaps, rather than trying to add up the probability of one or more overlaps. It also takes some thought to realize that the probabilities are conditioned properly, so that multiplying together all the various $P\left(N^{th}\ person\ doesn't\ overlap \middle| first\ N-1\ people\ don't\ overlap\right)$ factors.

With a Monte Carlo Simulation the solution is conceptually very simple:

1. Pick 30 random numbers in the range [1,365], each number represents one day of the year.
2. Check to see if any of the thirty are equal.
3. Go back to step 1 and repeat 10,000 times.
4. Report the fraction of trials that have matching birthdays

Appendix F Law of Large Numbers

The Law of Large Numbers (LLN) is a theorem in probability that describes the long-term stability of the mean of a random variable. Given a random variable with a finite expected value, if its values are repeatedly sampled, as the number of these observations increases, their mean will tend to approach and stay close to the expected value.

To prove this LLN another important inequality called the Chebyshev Inequality is needed.

Theorem Chebyshev Inequality: Let X be a discrete random variable with expected value $\mu = E(X)$, and let $\varepsilon > 0$ be any positive real number. Then

$$P(|X - \mu| \geq \varepsilon) \leq \frac{V(X)}{\varepsilon^2}$$

Proof Let $m(x)$ denote the distribution function of X. Then the probability that X differs from μ by at least ε is given by

$$P(|X - \mu| \geq \varepsilon) = \sum_{|x - \mu| \geq \varepsilon} m(x).$$

We know that

$$V(X) = \sum_x (x - \mu)^2 m(x),$$

and this is clearly at least as large as

$$\sum_{|x - \mu| \geq \varepsilon} (x - \mu)^2 m(x),$$

since all the summands are positive and we have restricted the range of summation in the second sum. But this last sum is at least

$$\sum_{|x - \mu| \geq \varepsilon} \varepsilon^2 m(x) = \varepsilon^2 \sum_{|x - \mu| \geq \varepsilon} m(x) = \varepsilon^2 P(|X - \mu| \geq \varepsilon)$$

So,

$$P(|X - \mu| \geq \varepsilon) \leq \frac{V(X)}{\varepsilon^2}$$

Note that X in the above theorem can be any discrete random variable, and ε any positive number.

With use of the above stated Chebyshev Inequality it is possible to prove the LLN

Theorem Law of Large Numbers (discrete probability distributions) Let $X_1, X_2, \ldots, X_n$ be an independent trials process, with finite expected value $\mu = E(X_j)$ and finite variance $\sigma^2 = V(X_j)$. Let $S_n = X_1 + X_2 + \cdots + X_n$. Then for any $\varepsilon > 0$,

$$P\left(\left|\frac{S_n}{n} - \mu\right| \geq \varepsilon\right) \to 0$$

as $n \to \infty$. Equivalently,

$$P\left(\left|\frac{S_n}{n} - \mu\right| < \varepsilon\right) \to 1$$

as $n \to \infty$

Proof Since $X_1, X_2, \ldots, X_n$ are independent and have the same distributions, we can apply the general properties of variance. We obtain

$$V(S_n) = n\sigma^2,$$

And

$$V\left(\frac{S_n}{n}\right) = \frac{\sigma^2}{n}$$

Also we know that

$$E\left(\frac{S_n}{n}\right) = \mu$$

By Chebyshev's Inequality, for any $\varepsilon > 0$,

$$P\left(\left|\frac{S_n}{n} - \mu\right| \geq \varepsilon\right) \leq \frac{\sigma^2}{n\varepsilon^2}$$

Thus, for fixed ε,

$$P\left(\left|\frac{S_n}{n} - \mu\right| \geq \varepsilon\right) \to 0$$

as $n \to \infty$, or equivalently,

$$P\left(\left|\frac{S_n}{n} - \mu\right| < \varepsilon\right) \to 1$$

as $n \to \infty$.

The LLN can easily be illustrated using the rolls of a die. A die is multinomial distributed, so the values 1, 2, 3, 4, 5 and 6 are all equally likely to be rolled. The expected value of a roll with a die is the sum of the probability of each outcome times the outcomes. $E = \sum_{1}^{6} p_i x_i = \frac{1}{6}\times 1 + \frac{1}{6}\times 2 + \frac{1}{6}\times 3 + \frac{1}{6}\times 4 + \frac{1}{6}\times 5 + \frac{1}{6}\times 6 = 3{,}5$. Figure F.1 shows the results of ten runs of the experiment of rolls of a die. The experiment calculates the average of the die rolls after each trial minus the expected value. Figure F.1 shows that this values deviates wildly around zero at first and stabilizes around the expected value of 0 as the number of observations becomes large, as is proposed by the LLN.

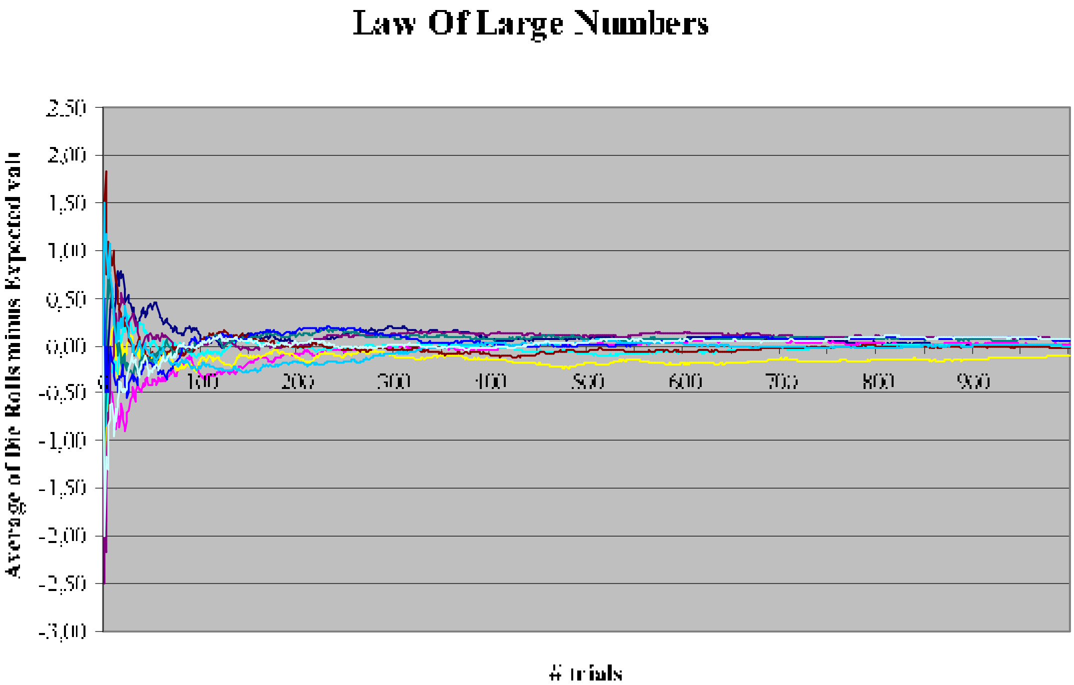

Figure F.1 Average of Die Rolls minus Expected value

Another example of the LLN is flip of a coin. Since the probability of heads is equal to the probability of tails, both have a probability of 50%. The expected difference between the number of heads is 0, or the expected excess of heads over tails (or the other way around) is 0%. Figure F.2 shows the results of ten runs of the experiment of 1000 flips with a coin. The graph shows that the excess of heads over tails deviates wildly at first and stabilizes around the expected value of 0% as the number of observations becomes large

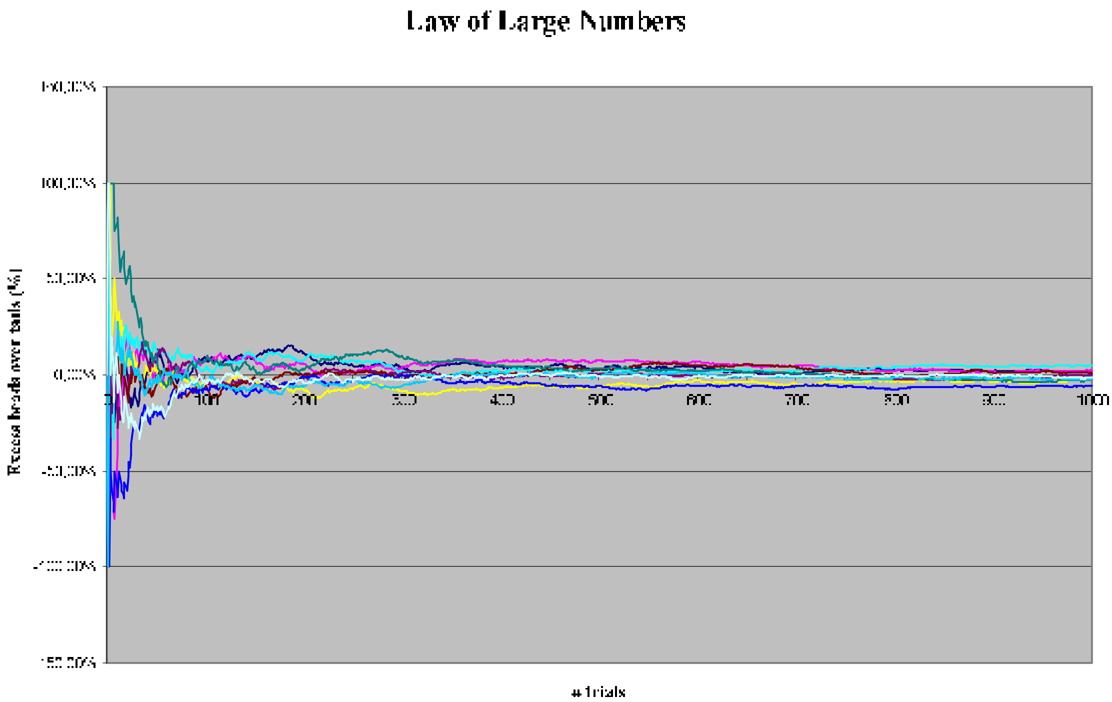

Figure E.2 Excess heads over tails

the previous section discussed the LLN for discrete probability distributions. This law has a natural analogue for continuous probability distributions.

Theorem Law of Large Numbers (continuous probability distributions) Let $X_1, X_2, \ldots, X_n$ be an independent trials process with a continuous density function f, finite expected value μ and finite variance σ^2. Let $S_n = X_1 + X_2 + \cdots + X_n$ be the sum of the X_i. Then for any real number $\varepsilon > 0$,

$$\lim_{n \to \infty} P\left(\left| \frac{S_n}{n} - \mu \right| > \varepsilon \right) = 0,$$

or equivalently,

$$\lim_{n \to \infty} P\left(\left| \frac{S_n}{n} - \mu \right| < \varepsilon \right) = 1$$

Since the prove in completely analogous to the prove in the discrete case it is not discussed here