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A risk register based on the  $(A, C, U)$  risk  
perspective

Anders Jensen

June 14, 2012

## **Preface**

This thesis completes my Master's degree in risk management (ERM) at the University of Stavanger. A final thesis project is mandatory for all students participating in the risk management program, and it has been conducted during my last spring semester (Jan-Jun, 2012). Specializing in enterprise risk management, it felt natural to further investigate the risk of which an entire enterprise is exposed to, and thus how risk registers can be used to describe this risk.

I would like to thank Dag Carlsen for good discussions. I would also like to thank my thesis adviser Roger Flage for excellent guidance, rich discussions, interesting debates and good inspiration. Thanks!

Anders Jensen, June 2012

## **Abstract**

A risk register is simply a collection of risk descriptions. However, most risk registers do not sufficiently capture the background knowledge which the contained risk descriptions are based on. To account for this, the method laid out in Flage and Aven (2009) is further developed. It is extended to a suitable method for evaluating uncertainty factors in the background knowledge of risk descriptions contained in risk registers, constructed in light of the  $(A, C, U)$  perspective of risk.

The method provides a “measure” of the background knowledge’s consistency with the phenomena, and it is argued that including the evaluation of uncertainty factors and constructing the risk register in light of the  $(A, C, U)$  risk perspective allows for, using the risk register as a description of enterprise risk.

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# 1 Introduction

## 1.1 Background

As outlined in Aven (2011b) risk is often described differently in the various areas covering the industry. This is, among other things, because of its historical origin and because of the practical concerns regarding how to actually describe risk. More general overall risk frameworks are being developed and gradually acknowledged. Frameworks which separates between risk as a concept and how it is described, opens up for new ways to actually describe risk without disagreeing on what risk actually means (Aven, 2011b). Seeing risk conceptually as an event  $A$ , a consequence  $C$  and some associated uncertainty  $U$  allows an analyst to choose how to describe the risk. Risk is thus seen in light of the  $(A, C, U)$  perspective of risk, and how to describe this concept, is more or less up to the analyst (Aven, 2011c).

In an enterprise there are often subdivisions, all belonging to different schools of risk (different definitions of risk), meaning the analyst dealing with the overall risk of the enterprise must somehow process all the information on risk from all of the subdivisions. The analyst will have to deal with various types of risk descriptions, all describing possibly different concepts of risk. This might be a difficult task when the descriptions are not based on the same concept. The analyst must then try to describe the various risk-contributions from the subdivisions so that the analyst can establish an enterprise risk picture.

Depending on what industry the enterprise operates in, the size of the enterprise, culture, technical practicalities and so on, numerous suggestions on how to accommodate a multitude of risk descriptions exist. However, there seems to be consensus among large enterprises to aggregate their risk descriptions in a *risk register*. The risk register allows to collect all the risk descriptions and organize them according to severity, probability, cost, and what like. The enterprises are free to organize and design their register in whatever structure they like, and building it can be done in specialized software, through a spreadsheet model, or simply on paper.

Herein, lies some of the problem with risk registers. Different enterprises have different risk registers, and risk register readers may therefore expect different types of infor-

mation from the various kinds of risk registers.

Nevertheless, there are still some commonalities in the various risk registers throughout the industry. Usually an entry in a risk register contains a probability, a predicted consequence and an initiating event of some sort. This understanding on how to construct a risk register might not be as fortunate, and this thesis seeks to explain why and provide a method on how to construct a proper risk register.

Aven (2009) defines risk management as: All the measures and activities carried out to manage risk so that one is able to balance conflicts inherent in exploring opportunities on the one hand and avoiding losses, accidents and disasters on the other. A part of risk management must then be decision making, and to be able to do reasonable decisions one needs information about the phenomena at hand, which implies a need for information about the risk at hand. Risk analysis is among other things, very much about obtaining information regarding the phenomena and thus a basis for decision making. Too much emphasis on probabilities and predicted consequences, without seeing them in light of the current knowledge seems to have a narrowing effect on the basis for decision making, thus making risk registers poorly equipped for decision making and other risk management tasks.

## **1.2 Problem**

Various definitions of enterprise risk exists. However, most of them are only variations of “a specific set of consequences”, “level of achievement” or “uncertainty related to achievement of goals” (ISO, 2009a, COSO, 2004b). For example being in compliance with regulations might be one of the enterprise goals, and the risk associated with not being in compliance is thus considered enterprise risk. Or for example, the risk associated with only selling half the units produced in a production company, could be considered enterprise risk. Another variant could be the the probability of achieving a specific goal<sup>1</sup>. This might not, due to the massive disparities in business areas and/or general indeterminate enterprise objectives, be suitable to all enterprises (Aven and Aven, 2011). It is therefore

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<sup>1</sup>See Aven and Aven (2011) for a more in depth discussion regarding the ISO standard definition of enterprise risk

a need for a definition of enterprise risk which allows for a wider extent of business areas and indeterminate enterprise objectives. Aven and Aven (2011) suggests seeing enterprise risk as any other risk, and enterprise risk is therefore seen in light of the  $(A, C, U)$  risk perspective. Then, a practical way to describe enterprise risk is by using the enterprise's risk register.

Probabilities and expected values are often used in risk registers, but usually, no notification on how to interpret these assignments are provided for. Nor, is the basis on which the assignments are based on, properly highlighted. As a result, all probability- and expected value - assessments in the risk register are treated similar and hence weighted as such in a decision making process based on a risk register. This might be unfortunate, because clearly some assignments are treated less thoroughly in the assessment process than others, and this should be accounted for when doing decisions. Therefore it is desirable with a risk register which somehow distinguish between more thoroughly treated assignments and less thoroughly treated assignments.

The main mission of this thesis is thus to construct a risk register:

1. Which is consistent with the  $(A, C, U)$  risk perspective, and describes the enterprise risk.

Also it is preferable to construct a risk register that:

2. Allows for a distinction between the various risk assignments contained in the register, based on the background knowledge in which the risk assignments are based on.

### **1.3 Outline of thesis**

This thesis is organized as follows. A general framework of risk is outlined in Section 2 and 3 and an introduction on how risk is defined as a concept with a corresponding risk description is given. It is also in Section 3 outlined a method (Flage and Aven, 2009) on how to assess uncertainty factors in the background knowledge. Section 4 goes on describing how typical risk registers are designed and build in some typical industries and suggests to divide the purpose of a risk register into 4 main categories.

Section 5 suggests how to build and construct a risk register based on the foundations laid in Section 2-4. An extension of Flage and Aven (2009) is developed to deal with the uncertainty factors in the background knowledge of a risk register and implemented in the proposed risk register.

In Section 6 the proposed theory is illustrated with two cases so that the theory gets a little easier to grasp. Finally, Section 7 and 8 ends the thesis with a discussion and a conclusion, respectively.

## 2 Risk as a concept

There seems to be little consensus on how to define risk, and there has been many attempts to define risk throughout history. However, most definitions of risk seems tailored to the area which they are being used, and designed to return some value of interest, thus not sufficiently satisfy an overall definition of risk.

### 2.1 Different perspectives of risk

The origin of the word risk is not fully known. Bernstein (1996) says the word may originate from the early Italian word *risicare*, which means *to dare*. Giddens (2003) argues that the word came from the Portuguese or the Spanish language and that it refer to *sailing in uncharted water*. The British Medical association suggests that the word risk originate from *rizha*, meaning *sailing too near the cliffs*. In Aven (2011b), a more detailed list of possible origins is presented.

From these early “definitions” it seems that the meaning of risk has evolved, not as a general concept, but rather into definitions suitable for some specific situation or activity. This, of course, has led us to describe risk in a vast amount of ways, simply because there are so many different situations which contain elements of risk.

Aven (2011b) has from a historical point of view proposed to partition the different schools of risk into six different categories. These categorizations evolves from how risk has been defined through out history. Aven (2011b) suggests:

1. *E* - Expected value
2. *C&P* - Consequence and Probability.
3. *C&U* - Consequence and Uncertainty.
4. *U* - Uncertainty.
5. *OU* - Objective probability, Uncertainty otherwise.
6. (*C*, *C&U*, and *ISO*)

The above definitions are how risk usually is defined through out the various industries. However, not all of these definitions are suitable as a risk definition, which has been thoroughly discussed in Aven (2010a). Nevertheless, based on Aven (2011c), the most suitable definition seems to be number 3, *risk defined as consequences and associated uncertainty*. and throughout this thesis, risk will be seen as the concept  $(C, U)$ .

## 2.2 The $(A, C, U)$ risk concept

Regardless of what school of risk one belongs to, or what industry one might relate to, there are in risk some basic elements which seem to yield some fundamental underlying concept. E.g. think of the risk associated with an assembling of a crane. Something might go wrong and an accident might occur.

Now, if one think of the risk associated with a stockbroker's aggressiveness towards trading, one would agree that, also in this situation, there exist elements of risk. It might not immediately seem comparable to a crane-assembly accident, however, it seems like there are some fundamental elements in a crane-assembly accident *and* a loss due to aggressive trading that is alike. They both indeed carry some level of risk, irrespectively of how one choose to define risk, meaning that most people would agree that there is some risk associated with both aggressive trading and assembling of a crane.

Comparing these two scenarios and their corresponding risk to a third one, *dying of a disease*, is not very meaningful, but the point still stands, there is something fundamental in all these scenarios that seems to make a perception of something "alike". The three scenarios are however all different and they do not really compare that easily.

Nevertheless, there are some essential similarities. All of the the scenarios above are concerned with something that might go wrong, namely some initiating event  $A$ . The crane assembler could for example loose a wrench causing it to fall. The aggressive trader, however, could act to hard upon his trading strategy and a arbitrary backpacker might travel to subtropical ares in Asia and catch Dengu fever. The similarities between these events, other then the fact that they are events that might cause a consequence, are almost non-existing. The events are only similar from a more abstract point of view - namely they are all some form of event that initiates a consequence  $C$ .

There is also uncertainty regarding each scenario. The crane assembly may go smoothly or might end with a fatality or somewhere in between. The trader may act too hard upon his strategy and obtain a substantial profit or he might for example end up bankrupt. The backpacker might not catch Dengu fever at all, or he might end up dying of Dengu fever or maybe he just gets a little sick. There are still no notable similarities in the events or the corresponding consequences, other than the fact that they are events which might happen, and these events might induce some consequence. To each of these scenarios there is associated uncertainty, and this uncertainty induces risk.

Based on the examples above uncertainty seems to be a big part of the risk picture, but not the entire part. Risk cannot be seen solely as uncertainty. Eg. the main purpose of risk analysis is to provide a ground for decision making, that is obtaining sufficient information on risk so that decision makers can use this information in the decision making process. If one were to define risk solely as uncertainty this might impair the decision making because now the decision does not account for any potential consequence. An uncertainty with an extremely severe consequence might get the same treatment as an uncertainty with an ignorable consequence, because risk now solely focus on the uncertainty and ignores the corresponding consequences.

It seems like, also the consequence,  $C$  of an initiating event  $A$ , should be a part of the risk picture, and risk as concept is thus defined as  $(A, C, U)$ .

However, now only the concept of risk is defined. Only what seems logical to include in risk is incorporated and hence the risk concept is only an idea that seems to fit how we perceive risk.

Surely, this is not enough for an analyst, which needs to provide a foundation for decision making. Therefor a description of the concept is needed.



### 3 Describing risk

Seeing risk as a concept with a corresponding risk description, allows for a choice on how to assess and describe the risk, and thereby not restrict the risk analysis to specific methods. For example, a consequence may be described in whatever way that seems practical for the phenomena at hand. Likewise with uncertainty, the analyst may choose according to her own preferences, a method on how to describe the uncertainty, for example probability.

A risk description is in essence a risk assessment output. One always start out with some concept of risk. It is defined as  $(A, C, U)$  in Section 2. Some assessment is done resulting in a risk description. The assessment method is chosen according to how much information that is needed for decision support and the analyst's preferences. For example, say if one defines risk as the uncertainty regarding the event  $A$ , and choose to describe this with the probability of  $A$ , the assessment will simply be the process of assigning the probability  $P(A)$ .

On the basis of  $(A, C, U)$ , by letting  $Q$  be the measure used to represent  $U$ , an intuitive description of the risk concept is  $(A', C', Q)$  where  $A'$  and  $C'$  are descriptions of respectively the initiating  $A$  event and the consequence  $C$  (Aven, 2011c). However, one can not obtain  $Q$ ,  $A'$  or  $C'$  without background knowledge  $K$ . Hence, background knowledge should also be a part of the description. The risk-description is then  $(A', C', Q, K)$  (Aven, 2011c).

#### 3.1 Describing initiating events and consequences.

The initiating event  $A$  is often described as a list of incidents, but may really be described in whatever way that suits the purpose of the analysis and the risk analyst. The description of  $A$  is  $A'$  and provides informative details about the initiating event.

The initiating event  $A$  leads to a consequence  $C$  which usually causes some sort of harm. However, the consequence can also be of benefit, and the situation at hand is then often referred to as an opportunity. Management of opportunities is often referred to as opportunity management, however this thesis will mainly focus on risk management.

How to describe  $C$ , is often determined by the situation at hand and really depends on the system involved in the assessment. The consequence  $C$  is often described in terms

which are easy to understand and allows further analysis, so using numerical values such as number of fatalities or for example predicted monetary losses are very common. Nevertheless,  $C$  is a consequence of  $A$  and may take on several values, thus being uncertain. The description of  $C$  is  $C'$  and it is typically distributed over some range of consequences, however in a risk analysis setting it might be too comprehensive to include all possible consequences so a prediction of  $C'$ , denoted  $C^*$  is practical and often used. The actual prediction may be whatever predictive measure that fits the purpose and style of the analysis. Such a measure may be expected value, prediction intervals or simply a shared opinion among a group of experts. For example, an initiating event  $A' = \text{"fire in a tunnel"}$  may result in a multitude of consequences, 2 persons might get killed, 5 persons might get killed, maybe the tunnel collapses or maybe no one gets hurt. Therefore, to simplify, one uses a prediction  $C^*$  which through some assessment is identified to be, 2 persons are killed.

### **3.2 Describing uncertainties.**

Uncertainties are described as  $Q$ , which serves as a measure of uncertainty (Aven, 2011c). By making a distinction between risk as a concept, and the description of this concept, one allows for an inclusion of alternative approaches for assessing, representing and describing the uncertainties involved (Aven, 2011c). This way, the risk analyst is provided with an opportunity to choose how to describe the uncertainties, using  $Q$ , and she is thus not tied to one assessment method. A major part of risk is, as mentioned above, uncertainty, and a poor uncertainty description could therefore be crucial on how the risk is managed in the enterprise. Therefore, some basic components should be a part of  $Q$ . First, one does not know whether or not the initiating event  $A$  will actually happen, this causes uncertainty. Now, consider  $A$  evolving into  $C$  through some chain of events, that is, an event turning into some consequence(s). This chain of events might evolve rather arbitrary. One might not know, due to lack of knowledge, how this process is governed, and there is thus uncertainty regarding what value  $C$  might take. Based on this,  $Q$  should at least contain some description of the uncertainty about  $A$  and some description of the uncertainty associated with  $A$  evolving into  $C$ .

Determining  $Q$ , and thereby determining a major part of the risk description, is thus an

assessment of the uncertainties involved and the output is often some type of probability. So,  $Q$  may then be represented in various ways, for example probability intervals  $Q = [P_{lower}, P_{upper}]$ . The most common is however a probability  $Q = P$ , where  $P$  is a probability interpreted as either subjective or relative frequency (Aven, 2011a)

Regardless of how  $Q$  is described, when assigning  $Q$ , knowledge is necessary, and this knowledge is referred to as background knowledge  $K$ . Often one establishes a collection of conditions and provides some assumptions in which the uncertainty-assessment can be based on. A coupling between the assumptions, and the description of uncertainty is implied, because the confidence in the measure of uncertainty will depend on the credibility of the assumptions being made. These assumptions, regarding the phenomena involved, are therefore vital when assessing uncertainties, and in the subsequent chapters, a screening process will be introduced.

A way to describe the uncertainty is in terms of subjective probabilities (also referred to as knowledge - based and judgmental, (North, 2010, Aven, 2010b)), thus letting  $Q = P_s$ , where  $P_s$  is a subjective probability. Then the uncertainty will be purely epistemic, which means that the probability is an expression of the uncertainties as seen in by the assessor. Then there exist no uncertainty related to the actual value of the probability, only probabilities seen in light of current knowledge (Aven, 2009). If one assigns a subjective probability  $P_s(A) = 0.2$ , one simply compares the uncertainty of  $A$  to occur with drawing a specific ball out of a urn containing 5 balls (Lindley, 1985).

The current state of knowledge should therefore also be reflected, due to “confounding factors” that are hidden from view (Schofield, 1998). These factors are related to inadequate information, suitability of assumptions, and difficulties of modelling complex phenomena.

### **3.3 Background knowledge and the effect on the risk description.**

It is important to recognize that the description of risk is more than just initiating, events, consequences and evaluated uncertainties. All assessment of events, consequences and uncertainties are affected by the background knowledge. For example if one choose to describe the uncertainty regarding the occurrence of  $A$ , with the probability  $P_s(A)$ , as de-

scribed in 3, the probability  $P_s(A)$ , must be based on some background knowledge  $K$ . The probability is regarded as a subjective probability, and is thus a reflection of the assigner's degree of belief and is therefore a result of an assessment based on the analyst's background knowledge  $K$ . The probability is then reflecting the uncertainty as seen by the analyst. In other words it is regarded as the analyst's degree of belief. If the background knowledge is changed then the probability also might change, thereby making the background knowledge the basis of which subjective probabilities are assigned. Surprises, relative to assigned probabilities might occur when the background knowledge, of which the probabilities are conditioned, turns out to be wrong. However, if the background knowledge is consistent with the characteristics of the actual phenomena at hand, then the probabilities reflect the current state of the phenomena at a greater level.

Assumptions are part of the background knowledge, and since there is uncertainty related to whether or not these assumptions reflect the characteristics of the actual phenomena, there may be inherent uncertainties hidden in the background knowledge.

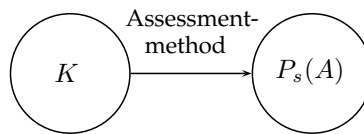


Figure 3.1: Background knowledge  $K$  inducing subjective probability  $P_s(A)$

Based on the background knowledge, one is able to do analysis, and hence obtaining risk descriptions. The problem then, is not entirely the assessment method used to obtain the risk description, but also what the background knowledge it is based on. The assumptions contained in the background knowledge may to a greater or lesser degree constitute uncertainty factors in the sense that the assumptions might not be valid (Flage and Aven, 2009, Aven and Heide, 2009).

Consider for example a risk assessment of an oil spill from a tanker accident. A simple oil spill index which specifies expected oil - contamination per tanker accident is to be considered. It is difficult to predict how spilled oil will disperse spatially into the water, and also difficult to predict how spilled oil will disintegrate temporally into the water, however it is necessary to evaluate these factors because they will stand as input when

calculating the oil spill index.

The dynamics of disintegration and dispersion are not fully known, so assumptions will have to be made. Since the oil spill index then is based on assumptions and therefore does to a lesser degree reflect the reality, it is obvious that these factors in the background knowledge induce uncertainty. This is because the oil spill index now is reflecting the phenomena in light of the assumptions being made, and not according to the actual phenomena at hand. There is no uncertainty in the oil spill index per se, however the oil spill index is based on assumptions (background knowledge) which does not encapsulates the actual phenomena, and this induces uncertainty.

Regardless of this, the uncertainty in the assumptions, regarding the factors, disintegration and dispersion does not really have an impact on risk unless the oil spill index is sufficiently sensitive to any changes in the assumptions regarding disintegration and dispersion. That is, it is uncertainty related to whether or not the assumptions being made actually reflect the reality, however if the oil spill index is insensitive to changes in any assumed values it does not really matter. The effect is therefore dependent on two dimensions (Flage and Aven, 2009):

- Degree of uncertainty
- Sensitivity of the relevant risk and/or vulnerability indices to changes in the uncertain quantities.

If for example the assumed value of oil disintegrating time carries a high degree of uncertainty and the oil spill index is highly sensitive for changes in disintegrating time, the effect on risk will be substantial. On the other hand, if the assumption of oil disintegrating time only suffers low degree of uncertainty and the oil spill index is insensitive to changes in disintegrating time the effect on risk will be minimal.

These factors are called uncertainty factors and naturally, some framework on how to assess uncertainty factors in the background knowledge is required. A semi quantitative categorization scheme is presented in Flage and Aven (2009) and it is stated beneath:

*Significant uncertainty:* One or more of the following conditions are met:

- The phenomena involved are not well understood; models are nonexistent or known/believed to give poor predictions.
- The assumptions made represent strong simplifications.
- Data are not available or are unavailable.
- There is a lack of agreement/consensus among experts.

*Minor uncertainty:* All of the following conditions are met:

- The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.
- The assumptions made are seen as very reasonable.
- Much reliable data are available.
- There is a broad agreement among experts.

*Moderate uncertainty:* Conditions between those characterized significant and minor uncertainty.

- The phenomena involved are well understood, but the models used are considered simple/crude.
- Some reliable data are available.

*Significant sensitivity:* relatively small changes in base case values result in altered conclusions (eg. exceeded risk acceptance criterion)

*Moderate sensitivity:* relatively large changes in base case values needed to bring about altered conclusions.

*Minor sensitivity:* Unrealistically large changes in base case values needed to bring about altered conclusions.

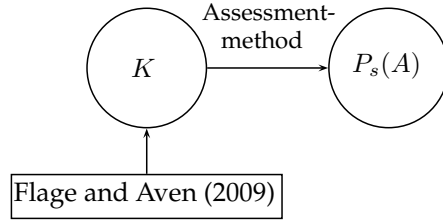


Figure 3.2: Background knowledge  $K$  inducing a subjective probability and assessment of uncertainty factors in  $K$

The categories above serves as a set of guidelines for classification of uncertainty factors in the background knowledge. The scheme is subject to judgment by the analyst, that is an analyst could be overly optimistic and categorize sensitivity and uncertainty as both minor. Or the analyst could be overly pessimistic and categorize sensitivity and uncertainty as both significant.

Its also serves as a practical way of screening uncertainty factors, and thereby identify which factors that are subject to more thorough treatment in the analysis (Flage and Aven, 2009). The result of the screening process can then easily be plotted in a  $3 \times 3$  matrix, providing the analyst or decision-maker with an intuitive picture of the uncertainty factors. The matrix can be seen in relation to risk reducing measures and consequences in the system and then give an indication on where to implement risk reducing measures.

The uncertainty factors, oil dispersion and oil disintegration are assessed through the scheme described above, and plotted in a matrix. “Oil dispersion” is evaluated to be the combination (significant sensitivity, minor uncertainty) by an analyst. This means that the analyst consider oil dispersion pattern to be relatively certain because the assumption made is seen as reasonable and there is much data available. However, any potential changes in the assumption significantly change the oil spill index.

Oil disintegration on the other hand, is classified to be the combination (significant sensitivity, moderate uncertainty), which means that the analyst consider the assumption to be moderately uncertain. This is because the assumption seems reasonable by the experts, however at the same time, there is little data which confirms the assumption. The analyst regard changes in the assumption to significantly influence the oil spill index.

Naturally, for complex processes and systems one must screen a vast amount of factors,

and not only two as in the example above. The scheme might then be very comprehensive, and this is discussed further in Section 7.

Sensitivity, S	Significant	Oil dispersion	Oil disintegration time	
	Moderate			
	Minor			
		Minor	Moderate Uncertainty, U	Significant

Figure 3.3: Example of classification matrix with the two plotted factors. The effect on risk increases as one “move” closer to the upper left

Screening uncertainty factors this way also provides the analyst with a clearer view of where special considerations should be taken. Critical uncertainty factors in the background knowledge can through this categorization methodology be identified in a relatively quick and easy way, so that measures and special considerations may be implemented on the most critical factors (uncertainty factor reducing measures). Screening the background knowledge for uncertainty factors like this will therefore not only serve as a tool for enhancing the risk picture, but also have a depleting effect on the uncertainty related to the background knowledge because one now has the opportunity to deal with these factors in the background knowledge.



## **4 Typical risk registers**

### **4.1 The purpose of a typical risk register**

Different enterprises tend to have different reasons for having a risk registers. Registers are often specifically designed for each enterprise, both with respect to their risk concept, and more management related items. Therefore constructing a risk register which encompasses all the preferred attributes of all the associated enterprises may be a little too excessive. However some general lines related to goals, objectives and the targets can be drawn when studying the various types of risk registers. Four general purposes of a risk register are suggested in the following sections and these are the main risk register purposes on which the register introduced in Section 5 is based on.

#### **4.1.1 Risk database**

A risk register serves as a risk description repository. Its purpose is, among other things, to list the risk descriptions associated with events  $A_i$  for  $i = 1, \dots, n$  where  $n$  is the number of identified events which might result in a harmful consequence. It serves as a source of information and allow people to easily look up events, which may cause harm to the enterprise. Risk analysts can easily add or delete events in the repository. Risk registers are usually build up by numbered events, that may cause harm to the company, and its associated data. Typical events can be an oil spill, falling cargo, falling oil prices, or whatever event that may through a consequence cause harmful consequences. Often these events are divided in groups such as HSE, Financial, Reputation, Credit, Operational, Strategic or whatever suits the companies management strategy.

#### **4.1.2 Risk ranking**

An important feature of the risk register is ranking. The risk register enables the enterprise to list its risk descriptions according to some criteria. This could for example be likelihood, severity of the consequence, impact, or a weighted combination of risk attributes. By listing risk descriptions the enterprise obtains a feel of the risk the enterprise is running, and may initiate risk reducing measures accordingly.

### **4.1.3 Monitoring of enterprise risk**

A risk register should be dynamic, meaning that new entries are added frequently and old ones are replaced, deleted or updated. The risk register aims at reflecting the risk that an enterprise is facing at that particular moment. This being because risk management is a continuous process, and risk management is done according to the state of the risk register. Specialized software could be useful.

### **4.1.4 The risk picture**

Besides serving as a repository and a summary for the various “risks” in the enterprise, a risk register should also provide an overview of the total risk in the enterprise. The register gives the opportunity to compare different alternatives and solutions in terms of risk. The risk analyst should through the risk register have the ability to identify factors, conditions, activities, components etc. that are critical with respect to risk. This means that one should be able to form a risk picture based on the content in the register. The risk register should provide the manager with an accurate and informative feel of what risk the enterprise is running.

As mentioned earlier, risk management is defined as all measures and activities carried out manage risk. Risk management deals with balancing the conflict inherent in exploring opportunities on the one hand and avoiding losses, accidents and disasters on the other Aven (2009). To be able to do these measures and activities one needs a sufficient body of knowledge regarding the enterprise risk. The decision-maker must obtain info on relevant risk, without actually doing any of the analysis, so she can manage according to enterprise - targets and -goals. She needs a solid understanding of what risk the enterprise face at a given moment so she can make reasonable decisions. The risk picture seeks to give this understanding of enterprise risk. In any setting, regardless of what kind of system one is managing, one needs a solid foundation of knowledge to support decisions. The enterprise risk picture, based on the information in the risk register should provide the decision-maker with a sufficient base of knowledge so she can make decisions accordingly.

## 4.2 Contents of a typical risk register.

Besides listing risk descriptions of events in a risk register one usually lists other risk-associated data in typical risk registers. The main associated data are often expected value  $E(C|A)$  and the probability of the event  $A$  namely  $P(A)$ .  $P(A)$  is often interpreted according to ISO (2009b): A probability is a measure of the chance of occurrence expressed as a number between 0 and 1. Nevertheless, there seems to be no adopted standard or consensus regarding what a chance means, and this is further discussed in Aven and Aven (2011).

$E(C|A)$  is the expected consequence of  $C$  given  $A$ , where  $C$  could be any consequence of interest. The product of the expected consequence and the probability,  $P(A) \cdot E(C|A)$ , is often referred to as a risk score. And often serves as a measure that allows one to rank the events relative to each other. Apart from the mentioned items above, risk registers often contains more management related items, such as risk-owner, risk mitigation strategy and so on. A typical risk register is thus build as follows:

$$[i, A'_i, P(A_i), E(C_i|A_i), P(A_i) \cdot E(C_i|A_i), \text{Management related items}], \text{ for } i = 1, \dots, n$$

where  $n$  is the total number of identified risk inducing scenarios entered in the risk register and  $A'$  is an description of the event  $A$ . A typical risk table is shown in table 1.

#	Event	Expected consequence	Probability	Risk score	Management
1	$A'_1$	$E(C_1 A_1)$	$P(A_1)$	$P(A_1) \cdot E(C_1 A_1)$	$[\ ]_1$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$n$	$A'_n$	$E(C_n A_n)$	$P(A_n)$	$P(A_n) \cdot E(C_n A_n)$	$[\ ]_n$

Table 1: Typical risk register

For each entry in the table there is typically some additional documentation seeking to give extra information on how each value in each entry is determined. This can typically be information on how the probabilities are assigned, results from risk assessments, or some other information of practical importance. In bigger enterprises risk registers are

frequently build in spreadsheets or in specialized software designed for registration of risk.

## **5 A risk register based on the $(A, C, U)$ risk perspective**

As shown (through table 1) in Section 4, typical risk registers tend to partially exclude uncertainties in the background knowledge. As argued, this way of describing risk is not totally adequate. A risk register should, if its intent is to fully describe the total risk picture, also contain uncertainties related to the background knowledge. A risk register that emphasizes this, is therefore introduced in this section. A method, much based on Aven and Aven (2011), Flage and Aven (2009), is introduced and then implemented in the risk register. This method seeks to give an evaluation of the background knowledge and thereby some understanding of the uncertainties in the background knowledge which the risk register is based on.

Also, much based on the thoughts laid out in Aven and Aven (2011), and the explanations provided in Section 3, this section explains how the risk register may be used as a description of the enterprise risk.

### **5.1 A definition of enterprise risk**

The  $(A, C, U)$  risk perspective does not make any conceptual distinction between different kinds of risk. All risk, regardless of origin, is conceptually seen as similar when following the framework laid out in Section 2 and 3.

Using the same argumentation as in Section 2, enterprise risk also seems through out various industries, to consist of something conceptually alike: An event might occur which may cause a harmful consequence, and to this, it is related uncertainty. Enterprise risk is therefore conceptually as any other risk and should hence be seen in light of the  $(A, C, U)$  risk perspective.

Using the  $(A, C, U)$  concept allows for a more overall definition of enterprise risk. After all, enterprises are indeed different so specifying the enterprise risk definition to certain objectives or a specific set of consequences (COSO, 2004a, ISO, 2009a) might not be sufficient as a definition of enterprise risk. For example, if company A identifies a set of consequences completely different from company B's consequences - then there exist two definitions of enterprise risk? Or as asked in Aven and Aven (2011), what if the enterprise

has no objectives, then there is no risk? Clearly it seems like enterprise risk should not be limited to specific consequences or achievement of objectives.

Using the risk framework presented in Section 1.1, 2 and 3 and thereby regard enterprise risk as a concept with a corresponding risk description, allows each enterprise to specify their own enterprise risk, using their risk register, and thereby coping with the issues mentioned above. The enterprise will through its collection of risk descriptions, namely the risk register, specify their own enterprise risk independently from other enterprises. The only “alike” is how enterprise risk is seen as a concept, namely as any other risk.

It is questionable how two completely different enterprises can share a common enterprise risk definition when they both function in completely distinct business - areas. It seems like the definition of enterprise risk needs to possess an overall generality in order to allow enterprises operating in distinct business - areas to use a common enterprise risk definition. Using a risk register to describe the enterprise risk allows for such overall generality.

Using a risk register in such a way as described above, utilizes the distinction made between risk as a concept and how it is described (see Section 2 and 3). Enterprise risk as a concept is therefore conceptually seen as any other risk, some event causing some consequence and to this there is some related uncertainties. The next sections will explain how to design a risk register in light of  $(A, C, U)$  perspective.

## **5.2 A risk register**

A risk register is in essence a grouping of  $n$  similar risk descriptions entered in a repository. As described in 4.1 the register should cover the following aspects:

1. *Serve as a risk database*
2. *Rank each risk*
3. *Provide the reader info regarding the total current risk exposure*
4. *Provide a risk picture*

It is desirable to organize and structure the enterprise's risk descriptions so that it covers aspect (1-4) to the highest degree. Also, it is desirable to design the risk register in light of the risk concept  $(A, C, U)$  (see Section 5.1) so that sufficiently describes the enterprise risk.

The risk register is made up of various entries which each contain some amount of information. The entries should be listed, so that the reader easily can screen through the risk descriptions. Through a risk description database system the register is searchable and accessing details such as initial risk assessment or more details on the risk description is possible. It should be easy to add new risk descriptions, and modification of old ones should for the risk register administrator be fairly easy.

The descriptions should also be organized in such a manner that the risk register reader is able to rank the contained risk descriptions without much trouble. Ranking of risk descriptions is not necessarily an easy task when different phenomena and situations often causes different risk descriptions. Therefore all risk descriptions entered in the risk register are entered as similar and it is therefore important to choose a risk description which to a high degree describes the  $(A, C, U)$  perspective (outlined in Section 3, 2 and in 5.1).

An important attribute of the risk register is its ability to inform the risk register reader about the total current risk exposure and risk contributors in the enterprise. A risk register should therefore intuitively provide a fulfilling enterprise risk picture and distinguish between the contained risk descriptions.

Therefore the purposed way of listing risk descriptions, and thus constructing the risk register, is to only use similar risk descriptions and choose the description which provides the most information about the the risk when seen in light of the  $(A, C, U)$  risk perspective. The description is chosen as in Section 3 and consists of a predicted consequence  $C^*$  if an initiating event  $A$  were to happen, and the probability of that initiating event  $A$  to occur, that is the subjective probability,  $P_s(A)$ . These are both defined on a some background knowledge  $K$  which might, depending on phenomena and the situation at hand, be of varying quality. Therefore an evaluation of the background knowledge is also necessary. How to evaluate the background knowledge is outlined in Section 5.3. The structure of the register is shown in table 2.

ID	Event	Consequence	Probability	Background knowledge	Management
...	$A'_1$	$(C_1^* A_1, K_1)$	$P_s(A_1 K_1)$	$[]_1$	$[]_1$
...	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
...	$A'_n$	$(C_n^* A_n, K_n)$	$P_s(A_n K_n)$	$[]_n$	$[]_n$

Table 2: Proposed risk register. Each entry are entered similar and according to Section 5.3 and aspects (1-4).

### 5.3 More on uncertainty factors in the background knowledge

Each entered risk description in the risk register is based on background knowledge  $K$ . Depending on the situation,  $K$  will only to some extent reflect the actual phenomena at hand and this might induce uncertainty. Therefore it would be useful to evaluate each entry's background knowledge using the method introduced in Flage and Aven (2009). The method however, along with uncertainty, focus on how changes in base values alter the conclusions. The evaluation method is typically used in QRA settings where some risk index ( $IR$ ,  $PLL$  or for example  $FAR$ ) is calculated. The risk index is then compared to an acceptance criteria and a conclusion is reached. Eg. a calculated  $IR$  level is compared to an accepted  $IR$  level, so if  $IR_{calculated} < IR_{acceptance}$  it is concluded that the individual risk is acceptable. If, on the other hand  $IR_{calculated} \geq IR_{acceptance}$ , it is concluded that the individual risk is unacceptable. An  $IR_{acceptance} = 10^{-4}$  is suggested as a boundary for members of the public who have a risk imposed on them "in the wider interest of society" by (HSE, 2001). Uncertainty factors in the background knowledge in which the  $IR$  calculations are based on, are then identified and evaluated according to the scheme in Section 3.3. The sensitivity of  $IR$  is evaluated with respect to changes in associated uncertainty factors, and in addition, the uncertainty factors' associated uncertainty is evaluated, thus giving two evaluations (uncertainty in factor and sensitivity with respect to changes in that factor).

Nevertheless, it can be problematic, when doing analysis on uncertainty factors in the background knowledge of risk registers, to use the term "conclusion" because providing conclusions does not directly comply with the purposes of the risk register described in Section 4. There is no comparable risk index in the risk register defined in Section 5.2, table 2, only descriptions in line of  $[A', P_s(A), C^*]$ . Therefore, implementing the method



(Flage and Aven, 2009) directly in the risk register could be problematic. The conclusion part of the assessment is not done in the risk register per se, but separately from it, because a risk register, as defined here, only serves premises and information which conclusions can be made upon, not the conclusions itself. Therefore the method (Flage and Aven, 2009) can not, without adjustments be directly integrated in a risk register. This is because of how the risk register is defined (see Section 5.2).

Each entry in the risk register is a risk description in line of  $[A, P_s(A), C^*]$ . By rather focusing the sensitivity analysis on  $C^*$  (predicted consequence) and  $P_s(A)$  (subjective probability) the issues, as described above, can be resolved. Letting  $S_{f,C^*}$  be the evaluated sensitivity of  $C^*$  with respect to changes in an observable uncertainty factor  $f$ , and letting  $S_{f,P_s(A)}$  be the evaluated sensitivity of  $P_s(A)$  with respect to changes in the same observable uncertainty factor  $f$ , one obtains an evaluation of the factor  $f$  which is in accordance with the descriptions contained in the risk register.

Based on Flage and Aven (2009) a categorization scheme is suggested. This scheme is used on every identified uncertainty factor in each risk description's background knowledge  $K$  in the risk register:

*Significant sensitivity:* Relatively small changes in base values alter  $P_s(A)$  or  $C^*$  in the risk register entry. (e.g. substantially different probabilities or e.g substantially different predicted probability)

*Moderate sensitivity:* Relatively large changes in base values needed to bring about altered  $P_s(A)$  or  $C^*$  in the risk register entry.

*Minor sensitivity:* Unrealistically large changes in base values needed to bring about altered  $P_s(A)$  or  $C^*$  in the risk register entry.

These sensitivity measures must then be seen in relationship to how uncertain the factors are, and this is done exactly as in Flage and Aven (2009). The scheme is written in Section 3.3. This gives for each factor, an evaluation in line of  $(U_f, S_{f,C^*}, S_{f,P_s(A)})$ , which

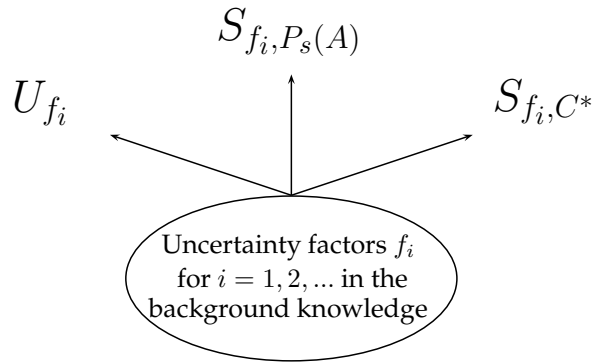


Figure 5.1: Uncertainty factors  $f_i$  inducing evaluations  $U_{f_i}$ ,  $S_{f_i, C^*}$ ,  $S_{f_i, P_s(A)}$

altogether serves as information on how each factor  $f$  affects the risk.

Summarized, all uncertainty factors  $f_i$  are evaluated with respect to the corresponding risk description's sensitivity and the uncertainty factor's corresponding uncertainty. This results in a list of uncertainty factor evaluations for each contained risk description in the risk register.

### 5.3.1 Visualization of factors and background knowledge

Screening uncertainty factors in the background knowledge of each risk description in the risk register will obviously result in several uncertainty factor descriptions. A collection consisting of a multitude of uncertainty factor descriptions is obtained through the screening process outlined in Section 5.3. This collection of uncertainty factor evaluations might however be very comprehensive, especially if such a collection is obtained for each risk description in the register. Say for example that 10 factors are identified for each of the 250 risk descriptions in company X's risk register. The enterprise risk manager is then dealing with  $10 \cdot 250 = 2500$  factors which might be problematic. This may also cause the analyst to focus to excessively on details, thus impairing her impression of how credible the background knowledge is.

To overcome this, it is suggested that for each risk description in the risk register, all of the corresponding factors are plotted in a diagram as in figure 5.2. The diagram works as follows. The diagram allocates sensitivity and uncertainty. Uncertainties are visualized

horizontally, while the sensitivities are visualized perpendicularly to the uncertainty. This diagram consists of two sensitivity parts divided by the horizontal dashed line. One upper part, representing the sensitivity of the predicted value  $C^*$ , and one lower part, representing sensitivity of the subjective probability  $P_s(A)$ . The upper and lower part are subdivided into the categorizations introduced in above, namely minor, moderate and significant. Uncertainty is visualized along the horizontal axis and, as sensitivity, categorized as minor, moderate or significant.

For example, an uncertainty factor ( $f_8$ ) is, through the scheme described above, categorized as:

$$f_8 \Rightarrow (U_f = \text{MINOR}, S_{f,C^*} = \text{SIGNIFICANT}, S_{f,P_s(A)} = \text{MODERATE})$$

and thereby with the rest of the factors corresponding to an arbitrary risk description, plotted in figure 5.2.

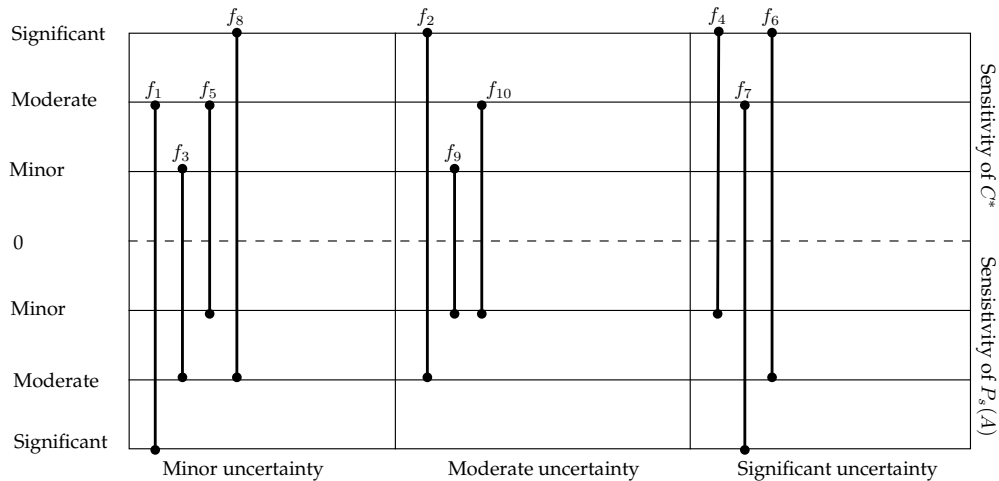


Figure 5.2: 10 plotted uncertainty factors for an arbitrary risk description in the register.

Each factor is plotted in the diagram so that the analyst gets a “feel” and visual picture over of the uncertainty factors “hidden” in the background knowledge and thereby a sense of the credibility of the risk description.

The uncertainty factor evaluation can be subdivided into pairs, which each is an evaluation of the uncertainty factor's effect on a component in the risk description. The pair  $(S_{f,C^*}, U_f)$  describes uncertainty factor  $f$ 's effect on the consequence. The pair  $(S_{f,P_s(A)}, U_f)$ , on the other hand describes uncertainty factor  $f$ 's effect on the probability. The pairs  $(S_{f,C^*}, U_f)$  and  $(S_{f,P_s(A)}, U_f)$  are visualized in respectively the upper and lower part of figure 5.2.

Besides illustrating the severity of each identified uncertainty factor, the diagram also provides a visualization of how many identified uncertainty factors there is. The number of identified uncertainty factors also have an effect on risk, since clearly it is unfortunate to base a risk description on background knowledge containing a multitude of uncertainty factors.

## 5.4 A risk register and uncertainty factors

An entry in a risk register may, as mentioned above, possess a multitude of uncertainty factors. Entering them all in a diagram as in figure 5.2 is fairly easy, practical and illustrative, however for each risk description entered in the register, there is typically a multitude of identified uncertainty factors. Since a risk register per definition (see Section 5) does not contain the full extent of the risk assessment, it is suggested to summarize each risk description's uncertainty factors into a single triplet which can be included in the risk register.

Using for example ordinary averages one can calculate the average sensitivity  $\overline{S_{f,C^*}}$  of the predicted consequences  $C^*$  with respect to changes in the uncertainty factor, the average sensitivity  $\overline{S_{f,P_s(A)}}$  of the subjective probability  $P_s(A)$  with respect to changes in the uncertainty factor and the average uncertainty  $\overline{U_f}$  for each factor  $f$  in each risk description. This is done by assigning the values 1, 2, 3 to minor, moderate and significant, respectively. Calculation is simply done by averaging over all the evaluations  $S_{f_i,C^*}, i = 1, \dots, S_{f_i,P_s(A)}, i = 1, \dots$  and  $U_{f_i}, i = 1, \dots$  for each risk description in the risk register. For example, the diagram in figure 5.2 has an average sensitivity, with respect to the predicted consequence  $C^*$ , of 2.1 which is slightly above moderate

Including  $(\overline{S_{f,C^*}}, \overline{S_{f,P_s(A)}}, \overline{U_f})$  in the register will provide the risk register reader with a

sense of the uncertainty “hidden” in the background knowledge of each risk description. Nevertheless, the average does not take into account the number of uncertainty factors in the background knowledge of each risk description. There might be risk descriptions with only 1 identified uncertainty factor, while others might have for example 15 identified uncertainty factors. An average does not make any distinction between such cases, so using an average clearly has its weak points and might be misleading. Therefore it should be acknowledged that  $(\overline{S_{f,C^*}}, \overline{S_{f,P_s(A)}}, \overline{U_f})$  is a very crude measure, and that it only should be considered a rough description of the uncertainties “hidden” in the background knowledge.

If a more in depth understanding of the uncertainties “hidden” in the background knowledge is desired it is recommended to study the sensitivity uncertainty diagram presented in figure 5.2. The proposed register is thus as in table 3.

ID	Event	Consequence	Probability	$\overline{S_{f,C^*}}$	$\overline{S_{f,P_s(A)}}$	$\overline{U_f}$	Management
...	$A'_1$	$(C_1^* A_1, K_1)$	$P_s(A_1 K_1)$	$(\overline{S_{f,C^*}})_1$	$(\overline{S_{f,P_s(A)}})_1$	$(\overline{U_f})_1$	$[\ ]_1$
...	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
...	$A'_n$	$(C_n^* A_n, K_n)$	$P_s(A_n K_n)$	$(\overline{S_{f,C^*}})_n$	$(\overline{S_{f,P_s(A)}})_n$	$(\overline{U_f})_n$	$[\ ]_n$

Table 3: Proposed risk register with included uncertainty factors.

## 5.5 Enterprise risk - a risk register.

By using the risk framework laid out in earlier Sections, a risk register can be used as a tool to describe the enterprise risk. This causes the enterprise risk definition to no longer be tied to a specific set of consequences/events, nor is it some “degree of achievement - measure” (ISO, 2009a, COSO, 2004b). This could be valuable for an enterprise, management-wise, because enterprise risk is now seen, not as a single-measured risk description, but in a portfolio perspective, thus allowing management to more efficiently identify risk reducing measures.

However, most of the descriptions in the risk register are based on some assumptions, so the background knowledge is therefore not completely consistent with the phenomena at hand, and there are thus uncertainty factors (see Section 5.3). This should if the register

is used as a description of enterprise risk be properly highlighted (see Section 5.3 and 5.4). Then, one could initiate actions to eliminate uncertainty factors, and thus decrease the discrepancies between background knowledge and the actual phenomena.

For example if an enterprise has listed all its risk - descriptions in a risk register, the risk register will describe the enterprise risk. Nevertheless, the listed risk descriptions' background knowledge are not completely in accordance with the actual phenomenons at hand and the enterprise can highlight these deviations with an evaluation of the uncertainty factors as done in the previous sections.

Assumptions and unknown knowledge are what gives rise to uncertainty factors and by continuously assessing these, as in Section 5.3 and Section 5.4, and implementing uncertainty-factor reducing measures, the enterprise risk register will subsequently describe the risk associated with the actual phenomena.

The description of enterprise risk is simply reflected by the descriptions contained in the risk register. Also, the risk register does not not contain all possible risk scenarios so important aspects of the enterprise risk may have been left out if the risk register is incomprehensive. It is therefore important for the enterprise to:

- Implement uncertainty-factor reducing measures

and

- Obtaining a comprehensive risk register in terms of “number of risks included”

Then, the risk register will sufficiently describe the enterprise risk.

## 6 Case examples

This section contains 2 illustrating cases, and seeks to demonstrate the explanations and methods presented in previous Sections. The illustrating cases are based on a virtual enterprise, but it could just as easily been an actual one. The enterprise is mainly delivering products, services and various oil related solutions to oil operators in the northern sea. For the company, the challenge for the risk management is to strike the right balance between exploring opportunities on the one hand, and avoiding losses, accidents and disasters on the other (Aven and Aven, 2011).

The first case, *Assessment of uncertainty factors*, will illustrate how to use the categorization scheme presented in Section 5.3. The second case, *Total risk in an enterprise*, illustrates how to develop a risk register which allows for a distinction between the various risk descriptions based the background knowledge in which they are based on. At the end of case 2, it will be demonstrated that the risk register will describe the enterprise risk.

### 6.1 Assessment of uncertainty factors

#### 6.1.1 Introduction

Someone in management begins to grow concern regarding the type of risk register the enterprise is using. They inform the board of directors of their concerns, and the board of directors agree to arrange for some of the employees to form a team. The team consists of a number of carefully chosen persons which will try to review, and if necessary, reconstruct the risk register so that it provides a more detailed and complete risk picture for the management. This is done so the management will get more insight into the enterprise risk and so that the risk register can support decisions to a larger extent than before. The team then need a proper way to assess the situation and subsequently enterprise risk.

The enterprise is an oil service company delivering products, services and various oil related solutions to oil operators in the northern sea. The enterprise designs, builds and assemble various module based solutions such as pump systems, power systems, drilling equipment, pipe systems, control systems, and other oil related solutions.

The risk register should not only be a tool for measuring enterprise risk, but also pro-

vide a basis for supporting decisions on risk reducing measures and investments (Aven, 2009). The risk is divided in 3 categories, *strategic, operational and financial*.

The enterprise’s risk register is investigated in order to establish an overall riskpicture of the enterprise. The investigation is meant as a review of all the risk descriptions and their credibility.

Each entry in the risk register is numbered and consist of an initiating event, a predicted consequence and a probability. Probabilities are interpreted as subjective and regarded as the assessors degree of belief. The register also consists of management related items. Management related items include items of more practical concerns such as risk owner, mitigation, contingency, category, name, what-if-actions and so on. Table 4 shows the basic structure of the risk register in the enterprise.

#	Event	Consequence	Probability	Management

Table 4: Existing risk register in the enterprise

Each entry in the register is a result of an earlier risk analysis, but only an initiating event, a probability and predicted consequence are given in the register, thereby making the underlying uncertainties in the background knowledge more or less hidden. The assessments are based on different types of analysis: *model-based, standard and simplified* (Aven, 2009). Therefore, there is little consensus, within the enterprise, regarding the assumptions made and how these assumptions affect the final result. For example: If the assumptions were to be flawed, how would that affect the total risk description? How would improper and inadequate background knowledge affect their view on the enterprise risk? Does one obtain a fulfilling riskpicture by just looking at the entries in the register? How does background knowledge affect the risk descriptions? And how credible are the risk descriptions regarding the actual phenomena at hand?

Therefore it is preferable to evaluate uncertainty factors “hidden” in the background knowledge of each risk description entered in the register, so that one is able to address the problem, inadequate background knowledge.



### 6.1.2 Analysis

Probabilities and predicted consequences are indeed useful, however they must be seen in light of the background knowledge they are based on. Therefore it is desirable to do some assessment of the background knowledge which the predicted consequences and probabilities are based on.

An assessment of the background knowledge is conducted, however this is a major and difficult job, and it would therefore be desirable with a method which allows one to do this effectively.

Using the framework laid out in 5 one is able to expose uncertainty factors in the background knowledge that might have an effect on risk. The effect, from the uncertainty factors, on risk, will be a combination of the factors' uncertainty and how sensitive the predicted consequences and subjective probabilities are to potential changes in the relevant uncertainty factors.

### 6.1.3 Assessment of uncertainty factors

Each entry's background knowledge should be assessed with focus on uncertainty factors in the background knowledge that may induce additional risk. For each risk description a list of factors in the background knowledge is identified. Each one of these factors are then assessed using the categorization scheme mentioned in Section 5.

Each uncertainty factor is categorized with a qualitative measure of uncertainty as described in Flage and Aven (2009). However, when categorizing the sensitivity, the method (Flage and Aven, 2009) mainly focus on how changes in base values alter the conclusions, which might not be in direct compliance with a risk register as defined in Section 5.2. The sensitivity - dimension is therefore evaluated over the information in the risk description instead, here being the subjective probability and the predicted consequence (see Section 5.3) .

To see how changes in uncertainty factors alter the predicted consequence and how it alters the subjective probabilities one needs to evaluate each uncertainty factor  $f$  according to the scheme outlined in Section 5.3 and thus obtaining two sensitivity evaluations with respect to changes in the background knowledge:  $S_{f,C^*}$  and  $S_{f,P_s(A)}$ . Along with the

sensitivity evaluations, the uncertainty in each factor is also evaluated according to the categorization scheme introduced in Flage and Aven (2009). Each uncertainty factor's associated uncertainty is written as  $U_f$ . Each factor  $f$  is then evaluated.

The description of risk 34 -*fire in the production area* - seems, before conducting any analysis, to be the least credible description, because it is considered that the actual phenomena at hand is poorly reflected by the background knowledge.

Fire in production area is a typical operational risk and it is considered as critical. The consequence might be severe injuries and/or people getting killed. The background knowledge of the risk description is through a structured and organized review, analyzed, and 8 uncertainty factors are identified and listed in table 5. Each of the 8 factors are then evaluated using the scheme mentioned in Section 5. Uncertainty factor number 7 is considered to be the most critical. The enterprise does its assembling of new systems and modules onshore. A temporary power supply is typically needed in the assembly process, and due to the variety in each system being build, large variations in power usage, installation method, voltage, and so on, the power is supplied rather differently on each project, meaning that electrical wiring is only installed on a temporary basis, since final installation is done offshore. The time between electrical failures are assumed in the risk analysis to follow a Exponential distribution, meaning that arrival of failures is a Poisson process with constant rate parameter (homogeneous). However, due to the variety in each system being build, this is a rather strong simplification and it is likely that the rate parameter is dependent on the system or module being build, however one does not actually know this, so the phenomena involved are not well understood. Therefore,  $U_{f_7}$  is evaluated to be significant. The probability and the consequence are both dependent on the time between each electrical failure and thus regarded as highly sensitive with respect to changes in this assumption. Therefore  $S_{f,C^*}$  and  $S_{f,P_s(A)}$  are evaluated as both, significant. Uncertainty factor 1-6 are evaluated in the same manner.

Each factor is plotted in an uncertainty - sensitivity diagram as in figure 6.1 to illustrate and provide a visual picture of the uncertainties hidden in the background knowledge. Risk 34 -*fire in production area* was at first suspected to be of weak background knowledge and thereby inducing some uncertainty. Diagram 6.1 seems to possess some highly sensitive factors with both moderate and significant uncertainty and thereby support the suspicion.

ID	Name	$S_{f,C^*}$	$S_{f,P_3(A)}$	$U_f$
$f_1$	Time between welding accident	Significant	Significant	Minor
$f_2$	Smoking in PA never occurs	Minor	Moderate	Minor
$f_3$	Expert knowledge considered reliable	Significant	Significant	Moderate
$f_4$	Constant routine violation frequency	Significant	Significant	Moderate
$f_5$	Sufficient gas concentration for ignition	Significant	Significant	Moderate
$f_6$	Amount of spilled diesel	Moderate	Significant	Significant
$f_7$	Time between electrical failures is $exp(\lambda)$	Significant	Significant	Significant
$f_8$	Diesel comes in contact with ignitable source	Moderate	Significant	Significant

Table 5: Identified uncertainty factors in the background knowledge  $K$  risk 34, Fire in production area (PA)

Each uncertainty factor evaluation as a whole is an evaluation of the uncertainty factor's effect on the risk description as a whole. The uncertainty factor evaluation can be subdivided into pairs, which each is an evaluation of the uncertainty factor's effect on a component in the risk description. Eg. the pair  $(S_{f_1,C^*}, U_{f_1}) = (Significant, Minor)$  describes the effect of uncertainty factor number 1 on the predicted consequence.

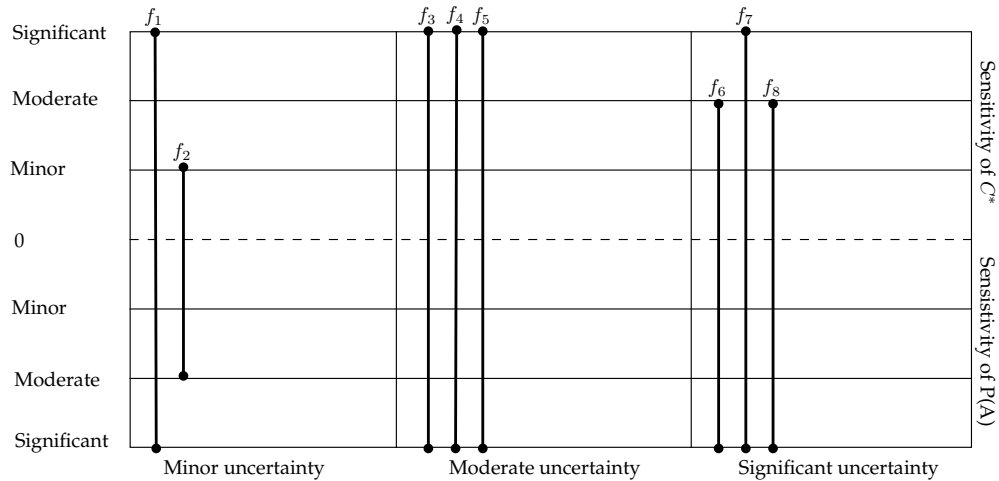


Figure 6.1: Uncertainty-sensitivity diagram with 8 plotted uncertainty factors.

#### 6.1.4 The risk register and uncertainty factors.

Obviously each risk description entails a multitude of associated uncertainty factors. As shown in table 5 and figure 6.1 there are 8 identified uncertainty factors for risk number 34 - *fire in production area*. Several factors per risk will of course result in a vast amount of factors in the risk register and therefore it is desirable to obtain a combined evaluation of the uncertainty factors involved, if the risk description were to be entered in the risk register.

This “combined” measure of the uncertainty factors involved is here simply denoted  $(\overline{S_{f,C^*}}, \overline{S_{f,P_s(A)}}, \overline{U_f})$ . The “combined” measure of the uncertainty factors is a compiling of all the uncertainty factors in the background knowledge of risk description 34 - *fire in the production area*. It is preferable to include  $(\overline{S_{f,C^*}}, \overline{S_{f,P_s(A)}}, \overline{U_f})$  in the risk register, and hence let it be a part of the risk description, so that it provides the decision maker with more information.

Obtaining the combined measure of all the uncertainty factors is here done by averaging the uncertainties and the sensitivities for each risk description in the register, thus obtaining an overall evaluation of the uncertainties hidden in the background knowledge of each entry. Other combining methods are of course possible. To calculate the average uncertainty, each level of uncertainty, *minor*, *moderate*, *significant*, is assigned the value 1, 2 and 3 respectively. Then the average of the uncertainty assignments are calculated. The average level of sensitivity is calculated using the same procedure namely assigning integer values, 1, 2 and 3, to the categorization categories, *minor*, *moderate*, *significant* respectively. Then, the average is calculated.

Components	Calculation	Average
$\overline{S_{f,C^*}}$	$\frac{3+1+3+3+3+2+3+2}{8}$	2.5
$\overline{S_{f,P_s(A)}}$	$\frac{3+2+3+3+3+3+3+3}{8}$	2.875
$\overline{U_f}$	$\frac{1+1+2+2+2+3+3+3}{8}$	2.125

Table 6: Calculations

Considering the calculations done in table 6 it seems like the assumptions done represent relatively strong simplifications and the background knowledge in risk description 34 - *fire in production area* is thus quite weak. The predicted consequence and the subjective

probability seems to be of little credibility and a discussion on whether or not the risk description should be considered as valid (Aven and Heide, 2009) should be carried out.

Risk number 34 was at first considered manageable and tolerable, however after taking into consideration the background knowledge on which it's predicted consequence and subjective probability is based on, namely the background knowledge, most people will agree upon an alteration in risk perception. However, uncertainty factors are identified and this does not change the risk itself, however it changes the risk description into a more informative measure and thereby our perception of risk number 34 - *fire in production area*.

The combined measure of the uncertainty factors for risk 34- fire in production area is (2.5, 2.875, 2.125) which is added to the risk register entry in table 7

#	Event	Consequence	Probability	$\overline{S_{f,C^*}}$	$\overline{S_{f,P_s(A)}}$	$\overline{U_f}$	Management
34	Production area fire	Severe injury/death	0.034	2.5	2.875	2.125	□

Table 7: Proposed risk register with additional information on the background knowledge

However, the combined measure of uncertainty factors consists of only three averages in a triple, and averages can be misleading, so a comparison of the combined measure of uncertainty factors with its corresponding sensitivity - uncertainty diagram (see figure 6.1) might be wise. This will ensure some consistency between the combined measure of all uncertainty factors and the visual picture of the uncertainty factors, and alert the team of skewed values (which might need special attention). Also, an average does not take into consideration how many uncertainty factors there are. It may exist risk descriptions which has the exact same combined measure of uncertainty factors (2.5, 2.875, 2.125), however with a different total amount of uncertainty factors. Even tough, the calculated combined measures of uncertainty factors are the same, there are still a different amount of uncertainty factor present in each risk description and this affect risk differently. Therefore the number of uncertainty factors should be noticed, and this can be done using the sensitivity uncertainty diagram in figure 6.1.

As seen in table 7, each risk description's associated  $(\overline{S_{f,C^*}}, \overline{S_{f,P_s(A)}}, \overline{U_f})$  is appended to the risk register so that one, by inspecting the risk register, obtains more insight about the background knowledge in which the risk description is based on. A more detailed

view of each risk description's associated uncertainty factors "hidden" in the background knowledge is obtainable by inspecting each risk description's corresponding uncertainty sensitivity diagram (see figure 6.1)

## **6.2 Total risk in an enterprise**

Consider the same company as in Case 1. Critical events such as power failures, software related problems, accidents, monetary losses due to currency fluctuations, reputational issues and so on seems to be happening more frequently than before, and this concerns the management as well as the shareholders. The management therefore ask the risk department for a risk review of the enterprise. The risk department designates a team consisting of people from each department and some risk analysts to do an overall assessment of the enterprise risk.

Typically an oil operator post a tender, leaving the enterprise and it's competitors to bid on it. If the tender is won, a project aiming at delivering the product is initiated. The enterprise is therefore considered to have a very project driven way of operating, meaning that if a solution is to be provided, a project is initiated.

The team, as in Aven (2009), decides to make a distinction between the following types of risk:

- Financial and commercial risk, including risk related to foreign exchange rates, interest rates, credit and prices.
- Operational risk, which includes risk associated with the uncertainty of the unavailability of the production system and ICT<sup>2</sup> security.
- Strategic risks, including risk associated with political decisions and reputation.

Each of the above mentioned types of risk should be evaluated according to the various parties involved. Furthermore, a distinction is made among the various parties (Aven, 2009):

- The enterprise

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<sup>2</sup>Information and communications technology

- Important partners, for example suppliers, banks and financial services.
- Others, for example the regulators and public opinion.

In the following sections, 9 scenarios are evaluated and analyzed. For each of the 9 identified scenarios, some corresponding uncertainty factors are identified. At the end of the case they are summarized in a risk register, thus providing a risk description of the enterprise risk. Throughout the case more information about the enterprise is provided.

### 6.2.1 Financial risk

**Increased cost of purchasing** The company is a supplier of oil related industry solutions. Such manufacturings are usually dependent on large quantities of steel and copper. Steel and copper prices are fluctuating, tend to correlate, and are subject to uncertainties. Based on historical data, a simple Monte Carlo model is constructed<sup>3</sup>.

The enterprise is on the buy side, and if the sum of the steel price  $D_t$  and copper price  $F_t$  rise above a threshold value  $J_{threshold}$  the enterprise will loose money selling their product because they can not afford to pay more then a total of  $J_{threshold}$  for materials. A simulation is carried out and the probability  $P(D_t + F_t \geq J_{threshold})$  is determined as 0.12. The predicted loss if  $D_t + F_t$  rise above the threshold value  $J_{threshold}$  is  $C^* \geq 350000000$

However, the probability model is based on background knowledge that might not be completely consistent with the actual phenomena at hand. The background knowledge thus induces uncertainty and a set of factors are identified as described in Section 5.3. The list is presented in table 8. First there is assumed that the underlying distribution follows an Geometric Brownian motion, which implies that returns are normally distributed. This assumption seems, when comparing past historical data, to be a moderate simplification and this induces uncertainty. The model also assume that the standard deviation (volatility) is invariant to time shifts, that is constant standard deviation (volatility) is assumed. By visually inspecting figure 6.2 the simulated returns and the realized combined returns seems to deviate, presumably due to ARCH effects<sup>4</sup>. There is little use of expert knowl-

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<sup>3</sup>For an introduction to Monte Carlo methods in Financial Engineering see for example Glasserman (2003)

<sup>4</sup>There exist tests for detection of ARCH effects. See Tsay (2010)

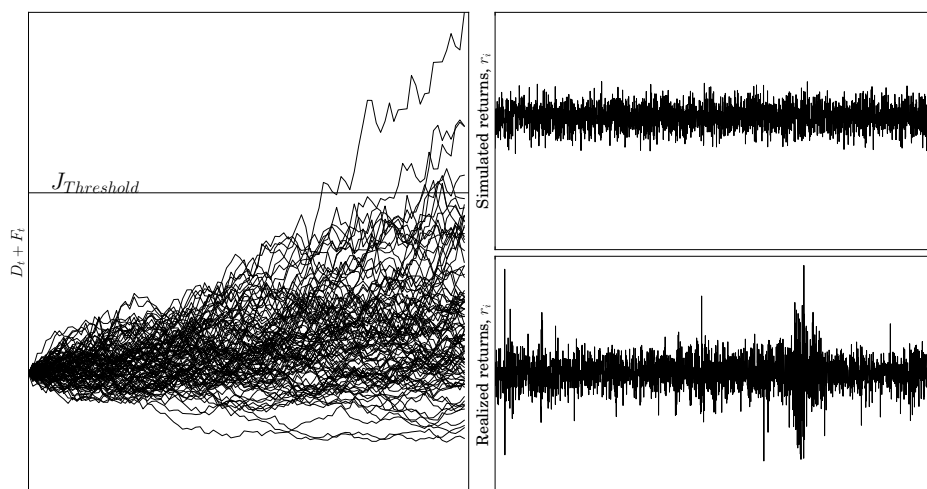


Figure 6.2: Schematic plot of the simulation described vs. the realized returns. Observe that simulated returns and realized returns deviates, presumably due to ARCH effects (Tsay, 2010) in observed data.

edge, and steel and copper returns are assumed to have constant correlation throughout the periods. Based on this, the 4 uncertainty factors are evaluated according to the scheme in Section 5.3, and tabulated in table 8. The model is believed to moderately reflect the actual phenomena, and the uncertainty factors are evaluated accordingly.

**Unfortunate fluctuations in currency** The enterprise is positioned in such a way that it is vulnerable to fluctuations in the currency markets. The enterprise buys various parts and components which often are paid in some foreign currency. The financial department has carried out a risk assessment to investigate how much the enterprise might lose due to unfortunate fluctuations in currency.

The enterprise is mainly exposed to fluctuations in the  $NOK/USD$  and  $NOK/EUR$  currency pairs. To reduce potential losses due to these currency fluctuations, the enterprise hedge their currency exposures using futures. Nevertheless, there are some inconsistencies between the duration, the cost of each project carried out by the enterprise, the futures' price and time to maturity which causes some concerns within the enterprise.

Since there are some durational and price related issues regarding the hedge, the en-



Risk: Increased cost of purchasing				
Category		Probability	Consequence	
Market risk		0.12	350 000 000 NOK	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P(S_t+K_t>A_{threshold})}$	$U_f$
$f_1$	Normally distributed returns	Moderate	Moderate	Significant
$f_2$	Constant variance	Significant	Moderate	Moderate
$f_3$	Expert knowledge	Minor	Minor	Moderate
$f_4$	Constant correlation in returns	Minor	Moderate	Minor
$f$	<i>Combined</i>	<i>1.75</i>	<i>1.75</i>	<i>2</i>

Table 8: Identified uncertainty factors in the background knowledge  $K$  of the financial risk, copper and steel decline

terprise is still exposed to some currency risk. The financial department estimate that a total loss related to currency fluctuations grater then 300 000 000 NOK will destroy their profit margin. Thus, if the sum of the currency pairs  $NOK/USD$  and  $NOK/EUR$ , simply denoted  $B$ , grows above a threshold value  $B_{threshold}$  within the duration of a project, the predicted loss is  $C^* \geq 300 000 000$  NOK. The probability of this to happen is believed to be  $P(B \geq B_{threshold}) = 0.0032$ .

Regarding this, there are some uncertainty factors, first of all, the enterprise carries out a multitude of projects and currency related losses are above assumed to be equal in every project, this is a simplification which might induce uncertainty, and it is believed that since the project size varies, this will significantly affect the predicted loss. Also when estimating one project's value, assumptions are done regarding future value of various parts of the project. Hence, there is uncertainty regarding the future value of the project and therefore an uncertainty how much potential currency fluctuations will affect the value of the project. It is believed that changes in these assumptions significantly affects the consequence and that the model thereby produces moderately sensitive predictions.

As in the risk *Increased cost of purchasing* the sum of the currency pairs are assumed to follow a Geometric Brownian motion, but with different parameters. Currency risk is therefore subject to the same type of uncertainty factors as the risk *increased cost of purchasing*. The assumed property regarding volatility being invariant to time shifts, is

believed to significantly affect the predicted loss.

Risk: Currency fluctuations				
Category		Probability	Consequence	
Market risk		0.0032	3 · 10 <sup>6</sup> NOK	
Uncertainty factors				
ID	Name	$S_{f,C^* \geq 300000000}$	$S_{f,P(B \geq B_{threshold})}$	$U_f$
$f_1$	Equal projects	Significant	Minor	Moderate
$f_2$	Future value of project	Significant	Moderate	Moderate
$f_3$	Normally distributed returns	Moderate	Moderate	Significant
$f_4$	Constant variance	Significant	Moderate	Moderate
$f_5$	Expert knowledge	Minor	Minor	Moderate
$f_6$	Constant correlation in returns	Minor	Moderate	Minor
$f$	<i>Combined</i>	<i>2.16</i>	<i>1.67</i>	<i>2</i>

Table 9: Identified uncertainty factors in the background knowledge  $K$  of the currency risk

### Credit risk.

**Customer default** The oil company sells various oil related solutions to customers. Customer defaults might occur and the enterprise may not be provided its eligible cash. The enterprise may therefore in a worst case scenario loose all capital spend on the project. The enterprise has therefore in its financial department developed a mathematical credit rating model which enables the enterprise to evaluate its customers according to credit risk. The credit rating model is based on input parameters which allows the enterprise to score its customers.

If a default occurs the enterprise will loose money, but not necessarily all the money invested in the project. This is because various parts can be resold to other oil companies. Agreements, real options and various types of insurances are used to secure the enterprise against customer defaults, but there is still risk involved and this risk is assessed and given in their risk register. Through their in-house credit rating system and other types of analysis the enterprise evaluates an arbitrary customer's probability of a default to  $P(\text{default}) = 0.094$ . The predicted consequence if a default occurred is a loss of  $C^* = 150\,000\,000$  NOK.

However there are factors in the background knowledge which are suspected to induce uncertainty. For example, not all customers order the same solution and the cost of building the solutions are therefore subject to variations. Since there is an variability in order size there are obviously different costs of each project. Therefore the uncertainty factor *different orders from different customers* is considered to significantly affect the the predicted loss.

There is also assumed that all customers are similar, meaning that their credit rating is the same. The probability for default is assigned as follows, all previous customers who suffered default are divided by the total amount of previous customers. Letting this fraction represent the probability of a default implicitly assumes that all customers have equal probability of default, this might induce uncertainty, and there is believed that this affect the probability of default significantly

The in-house credit rating system also assumes a constant economic activity, that is the general economy does not affect customer's credit ratings. This implies that a potential economic downturn would not affect the customers ability to pay for their products, this is an assumption and induce uncertainty.

The in-house credit rating system is much based on statistics and different models. The credit rating system relies much on past historical data which might not reflect the future accurately. There is through the credit rating system assumed that the past will repeat it self, and this might be some what of a simplification. There are in general little data, so it is considered uncertain that the data available accurately reflects the actual phenomena at hand.

### **6.2.2 Operational risk**

**Construction accident - Fire** The enterprise designs, construct and delivers module based systems which are ready for installation on oil rigs. The use of steel and copper is, as mentioned above, an important aspect of the construction process, so naturally welding is necessary. Due to high temperatures during welding, some minor fires has occurred, but because of nearby fire-extinguishers and quick-witted personnel, severe consequences has been prevented. Still, explosive fires (> 20 MW) might happen in the construction area

Risk: Customer default				
Category		Probability	Consequence	
Credit risk		0.094	1.5 · 10 <sup>6</sup> NOK	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P(\text{default})}$	$U_f$
$f_1$	Different orders from different customers	Significant	Minor	Moderate
$f_2$	Different credit score on customers	Minor	Significant	Moderate
$f_3$	Economic influence on credit rating	Minor	Minor	Significant
$f_4$	Rating based on historical data.	Minor	Moderate	Significant
$f$	<i>Combined</i>	1.5	1.75	2.5

Table 10: Identified uncertainty factors in the background knowledge  $K$  of the Risk: Customer default

and severe consequences might occur. The event  $A = \text{“explosive fire in construction area”}$  is assessed and the predicted consequence is evaluated to be  $C^* = 2$  fatalities. The HSE section in the enterprise has with a Bayesian network<sup>5</sup> modeled the intricate relationships between the different variables, and with specialized software done fire simulations (CFD - modeling) and thereby determined the probability of an “explosive fire in construction area” to be  $P_s(A)=0.00014$ , and obtained a model of smoke dispersion.

Related to the background knowledge in which the probability and predicted consequence are based on there are uncertainty factors. Through an assessment 4 uncertainty factors are identified. First, there is assumed that there are 2 persons in the working area at any given time, however this number is determined using a simple average. There are in reality not always 2 people in the working area, sometimes it is 10-15 persons for some amount of time, and sometimes, there are 0 persons in the working area for some amount of time. A simplification is done, and this induces some uncertainty. The predicted number of people killed is in direct relationship with the expected number of persons being in the working area, and it is therefore believed that this will significantly affect the predicted consequence.

The spread of the smoke is modeled, however depending on the geometry of the construction being build, the spatial smoke dispersion varies. Depending on sales orders, in

<sup>5</sup>For an introduction to Bayesian networks see Koski and Noble (2009)

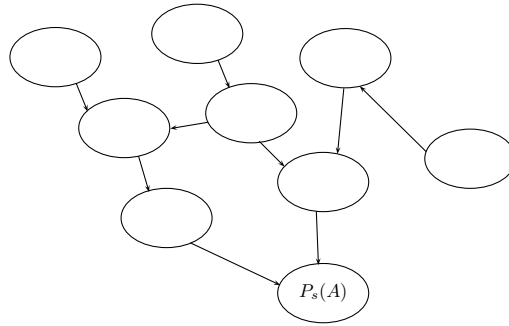


Figure 6.3: Schematic Bayesian network resulting in  $P_s(A)$

some periods smaller and less geometrically complicated projects are constructed, while in other periods larger and more geometrically complicated projects are being build. Depending on this the smoke dispersion varies. Nevertheless, when the smoke dispersion were modeled some simplifications were done, regarding the geometry of the construction, thus not giving a completely accurate smoke dispersion pattern, This is considered an uncertainty factor. Changes in the assumption regarding the smoke dispersion is believed to significantly affect the consequence, however the phenomenon is believed to be well understood and the uncertainty in the factor is thus evaluated to be only minor.

To obtain the subjective probability of the event  $A = \text{“explosive fire in construction area”}$  a Bayesian network is designed and used. However little and unreliable data forces the analyst to almost explicitly base the Bayesian network on expert knowledge. The expert feels reluctant to give precise probabilities and says that her knowledge might be insufficient, and that these phenomena are hard to predict. However, being the only alternative, the expert assigns probabilities with the best of intentions, and the experts credibility is therefore considered an uncertainty factor in the background knowledge.

Several scenarios might lead to the undesirable event  $A = \text{“explosive fire in construction area”}$ , nevertheless the analysis has only considered a minority of these scenarios because an evaluation of all possible scenarios would probably be very extensive and extremely detail oriented. Little data on both details and possible scenarios has led the analyst to only consider the 5 most likely scenarios. This is a simplification and might be considered an uncertainty factor.

Risk: Workshop fire				
Category		Probability	Consequence	
Operational		$1.4 \cdot 10^{-4}$	2 fatalities	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P(A)}$	$U_f$
$f_1$	Expected people in working area	Significant	Minor	Moderate
$f_2$	Smoke dispersion	Significant	Minor	Minor
$f_3$	Expert credibility in Bayesian network	Minor	Significant	Moderate
$f_4$	Only 5 scenarios	Minor	Moderate	Moderate
$f$	<i>Combined</i>	2	1.75	1.75

Table 11: Identified uncertainty factors in the background knowledge  $K$  of the risk, Workshop fire

**Construction accident - Cargo loading** After necessary assembly and construction on - shore, new systems and modules are shipped out to off - shore oil rigs and installed. Such an installation process could be very comprehensive if a major system were to be installed. If only a smaller system will be installed, the off shore assembly process might not be as extensive. Nevertheless, loading the modules from a platform supply vessel on to an oil platform is associated with some risk, and a risk assessment of the loading process is conducted.

A Bayesian network is designed specifically for the loading process. The loading procedure has been done many times before and no accidents or noteworthy situations has occurred, so historical data seems to imply a very low rate of accidents. The Bayesian network is based on historical data and expert knowledge, and seems to imply that the crane operator is the main risk driver. Docking of new modules usually demands a high level of lifting - accuracy and therefore require a high level of expertise from the crane operator. The operator of the crane may accidentally load the module incorrect, and an accident may occur. Thus identifying  $A = \text{"incorrect loading of module"}$  as an initiating event. The probability of the undesirable event is from the Bayesian network determined to be  $P_s(A) = 0.003$ . The predicted consequence  $C^*$  is determined to be  $C^* = \text{potentially fatal injury}$ .

A screening of the uncertainty factors involved is done, and 3 factors are identified.

Expert knowledge might not be as credible as presumed, expert knowledge is difficult to define and experts might not possess all necessary information required to define all branches in the Bayesian network. It is therefore acknowledged that it is uncertain how much information the expert possess.

There is also assumed in the Bayesian network that all module loadings are more or less similar which may result in an inadequate description of the loading procedure. This is a significant simplification, which to a high degree is expected to affect the probability of the initiating event, and the predicted consequence. Also, the predicted consequence does not necessarily have to be a potentially fatal injury. Entrapment due to inaccurate module loading could be deadly, however there is high uncertainty regarding whether or not this actually could happen. There is assumed in their models that a certain amount of workers are involved in each module loading, thus not accurately reflecting the phenomena and hence evaluated as a significantly uncertain factor.

Risk: Cargo loading				
Category		Probability	Consequence	
Operational		$3 \cdot 10^{-3}$	Potentially fatal injury	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P_3(A)}$	$U_f$
$f_1$	Expert knowledge	Minor	Moderate	Significant
$f_2$	All loaded modules are similar.	significant	Significant	Moderate
$f_3$	Number of workers involved in loading	Significant	Minor	Significant
$f$	<i>Combined</i>	2.33	2	2.67

Table 12: Identified uncertainty factors in the background knowledge  $K$  of the operational risk, cargo loading

**Installation accident** After loading the new systems and modules on to the oil rig, a final assembly is necessary. The assembly consists of final stage tasks such as electrical installations, securing of components and final stage welding. Many of the components used in the systems and modules installed are electrical components and connecting these might be dangerous if not done in a proper manner. There is thus some risk involved, regarding final installation of electrical components. To raise awareness among the tech-

nicians regarding the hazards involved in such installations they are obligated to carry out a *job safety analysis* (Aven, 2009). Even though, the associated risk is not completely eliminated. An expert with much experience in this field of operations considers the probability of the undesirable event  $A =$  "Worker is electrocuted" to be very low. The expert hesitates with providing a point probability, but believe it is something in line of 0.0001. The consequence of an electrocution could be severe burn injuries and/or death, thus  $C^* =$  "severe burn injuries and/or death"

The assigned probability is purely based on the expert's beliefs and his experience. The expert's belief and experience might not be consistent with the actual phenomena, and therefore it should be conducted an assessment of the background knowledge.

The predicted consequence is based on some assumed voltage, however both higher and lower voltages occur, so the predicted consequence might not be as accurate as desired. An alteration in this assumption could be of great significance regarding the consequence because a higher voltage might instantly kill the worker or burn the worker more severely. The expert speculates whether an increase in the voltage would cause the worker to be more careful, take more precautions, and hence reduce the probability of electrocution. Therefore an increase in voltage is considered to have a minor effect on the probability. Current might also vary, and this is considered to affect the consequence and probability the same as an alternation in voltage. However, regulatory demands requires the power supply on offshore installations to follow standards and is therefore considered to have an minor uncertain effect, thus evaluated as minor.

**Loss of key personal** As mentioned above the enterprise delivers highly specialized solutions to various oil operators. To always ensure that the enterprise can deliver excellent solutions, the enterprise must retain proficient and competent employees. Highly skilled and trained people must be at hand and losing them might be very unfortunate for their business. The event  $A =$  *loss of key personnel* is considered to be an initiating and undesirable event. It is predicted that if event  $A =$  *loss of key personnel* were to happen it will eventually lead in an economic loss. To evaluate the situation a very crude discussion is carried out, and a probability of losing a valuable employee is agreed to be in line of 0.002. Hence it is subjective. Regarding the consequence, it is predicted by the group



Risk: Installation accident				
Category		Probability	Consequence	
Operational		$10^{-4}$	Severe burn injuries and/or death	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P_s(A)}$	$U_f$
$f_1$	Expert belief	Minor	Significant	Significant
$f_2$	Voltage Assumption	Significant	Minor	Minor
$f_3$	Current assumption	Significant	Minor	Minor
$f$	<i>Combined</i>	<i>2.33</i>	<i>1.67</i>	<i>1.67</i>

Table 13: Identified uncertainty factors in the background knowledge  $K$  of the operational risk, Installation accident

that if a valuable person is lost to competitors they will loose valuable contracts and hence money. The predicted loss of money if a valuable person is lost, is  $C^* = 1000000$ , while the probability of  $A$  is  $P(A) = 0.002$ .

The review of the predicted consequence and subjective probability are however subject to uncertainties because of the numerous assumptions done by the group. First, the group has a lesser understanding of how attractive they are to their employees relative to other companies. The group assume a certain level of “attractiveness” and then based on this assumption a discussion is carried out. An alternation in the initial assumption is belied to significantly affect the probability. Also, the team acknowledges that the awareness of their own attractiveness is rather low. Hence, the uncertainty factor is considered significantly uncertain.

Also, it is assumed a similarity between all workers, which seems to be a strong simplification. This induces uncertainty since the assumption only to a lesser degree reflect the actual phenomena. Consequences obviously depend a high degree on the importance of the employee being lost, and since the enterprise consists of people with different characteristics, (mechanics, engineers, economists, human resources and so on) and it is assumed that all the employees are people with equal characteristics, changes in this assumption is believed to have a significant effect on the predicted consequence. Also, the phenomena involved are not well understood, and the assumption made makes strong simplifications, there is a lack of data, and there seems to be some knowledge-deficiencies within the

group. Therefore the uncertainty is considered significant.

When predicting the consequence it was also more or less assumed that all of the enterprise's projects was alike, meaning that no distinction were done between projects. This assumption simplifies the assessment and thereby exclude important aspects of the actual phenomena.

Also, there were asked whether or not the group of experts were competent enough to evaluate this issue, without actually asking any of the employees, and regarding this there is a lack of agreement/consensus whether they are competent or not, thus evaluated as uncertain.

Risk: Installation accident				
Category		Probability	Consequence	
Operational		$2 \cdot 10^{-3}$	1 000 000NOK	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P_s(A)}$	$U_f$
$f_1$	Relative to other companies	Minor	Significant	Significant
$f_2$	Similarity between employees	Significant	moderate	Significant
$f_3$	Equal projects	Significant	Minor	Significant
$f_4$	Competent experts	Moderate	Moderate	Significant
$f$	<i>Combined</i>	2.25	2	3

Table 14: Identified uncertainty factors in the background knowledge  $K$  of the operational risk, Installation accident

**Regulatory compliance** Extensive projects often require compliance with regulatory demands and law. If not in compliance, sanctions could be issued by government, some supervisory agency and/or some ministry corresponding to the infringement made. This gives rise to legal risk. Also, legislative concerns regarding, terms of delivery, terms of payment, use of time and so on must be sorted out before any potential commencement of plans. Contracts allows the enterprise to divide the various liabilities and responsibilities out over the parties involved, thus allowing the enterprise to disclaim some of the liabilities and responsibilities inducing risk.

In collaboration with the legal department, the risk management has identified  $A = \text{''High}$

*level of inconsistency with the Working Environment Act*<sup>6</sup>, to be very undesirable in terms of legal risk. The consequence could be from minor fines to imprisonment, however the predicted consequence is predicted to be  $C^* = \text{“imprisonment of responsible board member(s)”}$

In Norway, where the enterprise mainly assembles and constructs its projects, regulatory demands and law are very well defined and misconceptions regarding the working environment act rarely occur. Therefore, in collaboration with the legal department, the risk management group considers the probability of  $A$  to be very low,  $P(A) = 0.0000001 \approx 0$ .

Nevertheless, some uncertainty factors are identified and the screening process mentioned in Section 5 is conducted. For example the subjective probability above is assumed to only hold in Norway, meaning that for a Norwegian enterprise, there will, due to lack of knowledge in foreign law, be more challenging to be in compliance with laws and regulations in countries other than Norway. Also, due to lack of knowledge in foreign penal law, the consequence of a potential offense in countries other than Norway is uncertain. This uncertainty factor is seen as less critical, since literature on foreign law is highly available and the legal department will quite easily obtain the acquired knowledge. Nevertheless, the enterprise seeks to expand and this issue must be dealt with.

Another uncertainty factor is the level of competence of the legal department, it is assumed that the department has sufficient knowledge regarding the regulatory demands and the law. This is assumed with confidence and when assessed, there is no reason for any immediate concern. No other uncertainty factors seem to be of any importance. Therefore the assessment of the regulatory compliance is based on background knowledge which contains few uncertainty factors of any immediate concern. Therefore the background knowledge seems to reflect the actual phenomena at hand.

### 6.2.3 Strategic risk

**Competition and technology** The enterprise has some national and international competition. Competitors are considered a source of risk. To reduce the associated risk, the enterprise seeks to always stay ahead when it comes to technology, price and in terms

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<sup>6</sup>This is what is called *Arbeidsmiljøloven* in Norway

Risk: Regulatory compliance				
Category		Probability	Consequence	
Operational		0	Imprisonment	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P_s(A)}$	$U_f$
$f_1$	All construction are done in Norway	Significant	Minor	Minor
$f_2$	Competent legal department	Minor	Minor	Minor
$f$	<i>Combined</i>	2	1	1

Table 15: Identified uncertainty factors in the background knowledge  $K$  of the financial risk, copper and steel decline

of delivery. Being able to do this requires high level of competence among employees and therefore a well-functioning educational program within the enterprise. If the enterprise fails to further educate their employees, they are likely not to deliver as good products as their competitors, and thereby loose customers. If this were to happen the enterprise could become bankrupt which of course is very undesirable.

The risk management department, together with management and some members of the board therefore conduct a discussion where they try to obtain a risk picture. They define  $A$  = "Loosing customers due to competition" as the initiating event. The associated consequence is by the group considered to be  $C^*$  = "Deficit greater then  $450 \cdot 10^6$ ".

Usually, getting customers are done through a bidding process on contracts, meaning that an oil operator post various tenders, and different companies provide a bid for that particular contract. If too many contracts are lost, a customer is considered lost. The company delivering the best product for the lowest price wins the contract and hence the customer. Losing too many contracts, will result in a decline in income and eventually decline in customers and over time it will most likely result in bankruptcy.

The problem then, is deciding how much or little to bid for the various contracts. A very low bid will more or less ensure the enterprise the contract, however a low bid will minimize profit margins, and in a worst case scenario result in a loss. Obviously, an evaluation of what competitors are likely to bid is necessary, and for decision problems like this, the enterprise typically build a decision tree (Albright and Winston, 2012). For the decision tree the *expected monetary value*  $EMV$  is calculated and the bid which provides

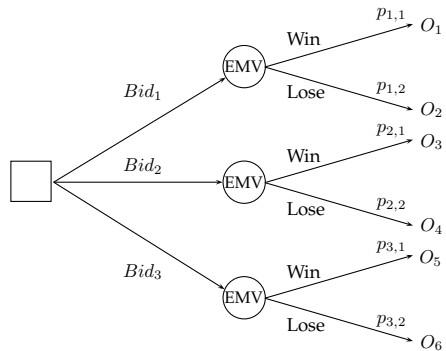


Figure 6.4: Example of decision tree with 3 alternative bids. For each bidding scenario the EMV is calculated.

the most satisfying *EMV* is then chosen. The decision tree does not try to describe the risk per se, but it tries to provide a framework for decision-making under the uncertainty which is induced by the unknown behavior of their competitors. These uncertainties are described using probability distributions (subjective or relative frequency).

From earlier, the enterprise has been involved with similar decision problems and, based on gathered data from previous bidding processes, it seems that  $P(A) = 0.00004$ . However, screening for uncertainty factors reveals that this probability is of poor validity and should be paid extra attention.

A decision tree assumes that competitive bids follows some relative frequency probability distribution, Nevertheless, a subjective probability distribution is used to describe the distribution of bids. It may not be that the subjective probability distribution actually describes the assumed true probability distribution, and this induces uncertainty. Changes to the assumed distribution is considered to only have an minor effect on the consequence, however the probability of loosing customers is significantly sensitive to changes in the distribution of bids.

Also the subjective probability,  $P(A)$  is highly based on historical numbers which might not represent the future, and this is considered an uncertainty factor. The probability of loosing customers seems through the screening process suggested, to be of significant sensitivity if the past were to not reflect the future. A constantly changing economic climate seems to make this assumption significantly uncertain.

To solve the decision tree, manufacturing costs must be taken into account. Manufacturing costs are estimated. The cost is a variable affecting the EMV, and uncertainties regarding the estimate are hence influential on the EMV. Decisions are made directly on the basis of EMV, hence, manufacturing cost is an uncertainty factor.

In general, there is lack of consensus among the considered experts, regarding the uncertainty factors. The assumptions represent strong simplifications and the phenomena involved are not well understood. Also, little data is available and considered more or less unreliable. All of the uncertainty factors are therefore regarded as significantly uncertain.

Risk: Competition and technology				
Category		Probability	Consequence	
Strategic		$4 \cdot 10^{-5}$	$450 \cdot 10^6$ NOK	
Uncertainty factors				
ID	Name	$S_{f,C^*}$	$S_{f,P_i(A)}$	$U_f$
$f_1$	The distribution of bids	Minor	Significant	Significant
$f_2$	Past equals future	Minor	Significant	Significant
$f_3$	Estimated costs	Minor	Significant	Significant
$f$	<i>Combined</i>	<i>1</i>	<i>3</i>	<i>3</i>

Table 16: Identified uncertainty factors in the background knowledge  $K$  of the strategic risk, Competition and technology

#### 6.2.4 Overall risk picture

The enterprise described above are exposed to risk. Various sources has been shown to influence the risk exposure, and in table 17, the risk register is presented. In general, the enterprise risk is conceptually defined as a  $(A,C,U)$  (Aven and Aven, 2011). Following (Aven and Aven, 2011) and using the  $(A,C,U)$  perspective allows the enterprise to choose how they will describe the enterprise risk. Here, the enterprise has described the enterprise risk using a risk register.

The enterprise is dependent on some crucial aspects (stable prices, a low number of accidents, minor competition and so on) to operate in its usual intended way. For all these aspects, a corresponding risk is identified and described accordingly. The collection of

	#	Name	Predicted consequence	Probability	$\overline{S_{f,C^*}}$	$\overline{S_{f,P_s(A)}}$	$\overline{U_f}$
Financial	1	Increased cost of purchasing	$\geq 350 \cdot 10^6$ NOK	0.12	1.75	1.75	2
	2	Unfortunate currency fluctuations	$\geq 300 \cdot 10^6$ NOK	0.032	2.16	1.67	2
	3	Customer default	$150 \cdot 10^6$ NOK	0.0094	1.5	1.75	2.5
Operational	4	Construction accident - Fire	2 fatalities	0.00014	2	1.75	1.75
	5	Construction accident - Cargo loading	Potential fatal injury	0.003	2.33	2	2.67
	6	Installation accident	Severe burn injuries and/or death	0.0001	2.33	1.67	1.67
	7	Loss of key personel	$1 \cdot 10^6$ NOK	0.002	2.25	2	3
	8	Regulatory compliance	Imprisonment of board member(s)	$10^6$	2	1	1
Other	9	Loosing customers due to competition	Deficit greater then $450 \cdot 10^6$ NOK	0.00004	1	3	3

Table 17: Enterprise risk register.

these risk descriptions are then summarized in the risk register. The risk register, as a whole, will then reflect the enterprise risk (see Section5.5).

The problem then, is that the enterprise above does not know all possible “risks”, so the enterprise risk description reflected by the resulting risk register is probably not coherent with all of reality. There are off course more than a total of nine scenarios and events associated with risk in the company described above, and therefore it is likely that the risk register does not sufficiently reflect the reality as a whole, but only a part of it.

There are also identified uncertainty factors in in each of the nine risks. Therefore, it is questionable how well each risk description describes the risk involved and thus questionable how well the the collection of these risk descriptions describe the enterprise risk.

The risk register and thus the enterprise risk description is based on assumptions made from part of the background knowledge and the risk register and hence the enterprise risk must be seen in light of this basis. To cope with this, the enterprise has plotted every of its nine risk description's combined measures of uncertainty factors the same way as in diagram 5.2<sup>7</sup>, thus reflecting the assumptions on which each risk description's background knowledge is based on.

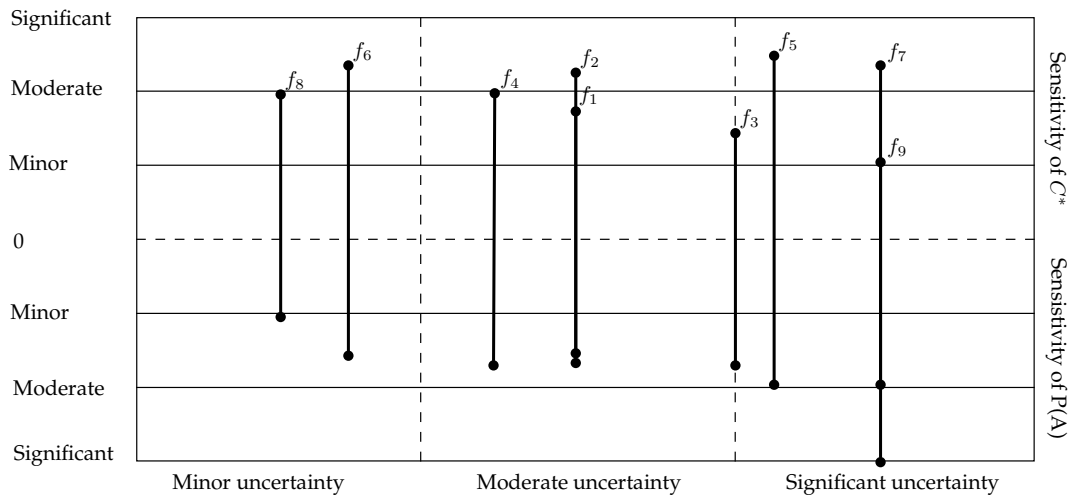


Figure 6.5: Identified q-qualities for risk 1-9

As a final conclusion, the description of enterprise risk in this enterprise is simply reflected by the descriptions contained in the risk register (see table 17). Each risk description is however based on background knowledge that might not be consistent with the actual phenomena at hand (Normally distributed returns, voltage assumption, all projects are equal, distribution of bids and so on), and this is reflected in figure 6.5. The risk register therefore needs to be seen in light of the figure 6.5, so that the enterprise risk description is seen in light of the current state of knowledge.

If one regard the uncertainty factor evaluations as a measure of how well the background knowledge reflects the phenomena at hand, risk description five, seven and nine seems to be based on the poorest background knowledge among the nine risk descriptions.

<sup>7</sup>Though, only the combined measures of uncertainty factors.



Uncertainty factor reducing measures should be implemented to reduce the uncertainty factor effect on the corresponding risk descriptions.

A risk score, as in typical risk registers (see Section 4), is possible to calculate among each consequence category (cost, fatalities, injury and years in prison) and thereby obtain a crude risk ranking. Nevertheless, since each risk score is based on background knowledge  $K$  the sensitivity uncertainty diagram (figure 6.5) should be taken into consideration. The obtained ranking, together with the sensitivity uncertainty diagram (figure 6.5) can be used as further indication on where to implement risk reducing measures.

Also, the risk register does not contain all possible risk scenarios in an enterprise of this magnitude, so important aspects of the enterprise risk may have been left out. It is therefore important for the enterprise to:

- Minimize/remove the uncertainty factors (Normally distributed returns, voltage assumption, all projects are equal, distribution of bids and so on) and thereby increase the validity of the risk register (fig 17)

and:

- Obtaining a comprehensive risk register. Include more than nine risk descriptions in the register. If possible all.

Then the risk register will describe the enterprise in light of the risk concept  $(A, C, U)$

## 7 Discussion

Restricting enterprise risk to a specific definition concerning a specific set of consequences or achievement of goals might have an unfortunate effect on risk management. Using a risk register to describe the enterprise risk, scenarios which represent the most risk, naturally gets the most attention in terms of risk reducing measures, because they are properly highlighted in the risk register. Describing the enterprise risk with a risk register therefore promotes the enterprise to focus on the scenarios that represent the most risk rather than a specific set of consequences or achievement of goals. This way, the description of enterprise risk is left out to each enterprise, and instead of focusing on how to define it, it is focused on how to reduce it, regardless of what kind of industry the enterprise operates in. Each enterprise then holds a unique portfolio of risk descriptions, which as a whole describes the enterprise risk for that particular enterprise. This portfolio will then, if the enterprise follows the points laid out in Section 5.5 reflect the risk which the enterprise are exposed to and not some constructed definition of enterprise risk (COSO, 2004b, ISO, 2009a). By describing the enterprise risk in light of the  $(A, C, U)$  risk perspective the enterprise risk picture will, if done properly through a risk register, reflect a very enriched picture of risk. This will in terms serve as a very solid foundation for decisions, thus promoting healthy risk management. This is a very strong incentive for an enterprise to describe their enterprise risk in terms of a risk register constructed in light of the  $(A, C, U)$  perspective.

At the same time, including an evaluation of the uncertainty factors “hidden” in each risk description’s background knowledge allows the analysts and decision makers to evaluate each risk description, not only in terms of the associated risk per se, but also in terms of current knowledge, thereby gaining insights regarding the descriptions validity and credibility<sup>8</sup>. Descriptions in the risk register are subjective and therefore it is important to see each risk description in light of the current state of knowledge. It is therefore useful to include an evaluation of the uncertainty factors in the background knowledge, as described in 5.3. Including this uncertainty factor description indicates where further analysis and assessment must be done, by simply screening through every uncertainty fac-

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<sup>8</sup>For an in depth discussion of validity see (Aven and Heide, 2009).

tor in the risk register. By continuously improving each risk description in the risk register by reducing the uncertainty factors, the register quality will improve and eventually be a description based on background knowledge which encapsulates actual phenomena. That being said, it is important to recognize that the proposed evaluating scheme only serves as a set of guidelines which can be used for evaluation of uncertainty factors. The scheme is a semi quantitative method, which heavily relies on the evaluators subjective meaning. This might be questionable, and one might ask whether or not the lack of objectivity is a weakness? However, this way of thinking might be a little short sighted. Evaluating uncertainty factors is not only about obtaining uncertainty factor evaluations, but also about the evaluating-process itself. Following the evaluation scheme provides an understanding and an insight regarding the background knowledge at hand and this is in itself very valuable.

Aven and Aven (2011) also talks about enterprise risk. They propose to regard enterprise risk as conceptually being like any other risk, thus conceptually as  $(A, C, U)$ . Then, the risk is simply described as a combination of an impact and a knowledge based probability. Uncertainty factors are identified as in Flage and Aven (2009), however sensitivities are only obtained on impact values and not on probabilities. Like in Aven and Aven (2011), enterprise risk is in this thesis regarded conceptually as  $(A, C, U)$  and described accordingly. However the enterprise risk is described through a risk register containing a description of the event  $A$ , the probability of that event  $A$  and the predicted consequence if that event  $A$  were to happen<sup>9</sup>. Uncertainty factors are evaluated in terms of uncertainty, but sensitivity is evaluated over both the corresponding probability and the corresponding predicted consequence, thus over two dimensions, rather than only over an "Impact". Uncertainty factors are not only seen as additional information in the risk description, but more as a measure on how well the current state of knowledge reflects the actual phenomena at hand. This measure can then be used not only as a source of information, but as an indication of where uncertainty factor reducing measures and risk reducing measures should be made. To get an even better insight of the identified uncertainty factors it is recommended to plot them in a sensitivity uncertainty diagram as in figure 5.2 and figure 6.5. The diagram provides a visual representation of the characteristics inherent in the

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<sup>9</sup>Each risk could easily be plotted in the probability-impact diagram (risk map) like in Aven and Aven (2011)

uncertainty factors, as well as showing the amount of uncertainty factors that is present. It also provides a feel of the uncertainties hidden in the background knowledge.

It should be acknowledge that the risk register entry in its entirety only to a lesser extent, reflects the uncertainty factors hidden in corresponding background knowledge. This is because only average uncertainty factor evaluations is used rather than the entire list of uncertainty factor evaluations (see Section 5.4). This is due to practical concerns regarding the actual size of the register. Even so, through a sufficient database system (as described in Section 4) it should off course be possible to obtain all relevant uncertainty factors both listed and in graphical form (uncertainty sensitivity diagram). Only including average uncertainty factor evaluations in the register only provides a very crude picture of the uncertainty factors hidden in the background knowledge, and if one were to plot these in a sensitivity uncertainty diagram, as in the example case, total risk in an enterprise (see figure 6.5 in Section 6.2) one will only obtain a rather shallow picture of the uncertainty factors hidden in the background knowledge of the entire risk register. Still, it is argued that the average uncertainty factor evaluation for each risk should be included in each risk register entry, since it will if provide the risk register reader a sense of the uncertainty factors involved, and this is valuable.

It is also important to stress what the predicted consequence in the risk register means. It is only a prediction of what will happen if the initiating event  $A$  were to occur. The occurrence of  $A$  does not necessarily imply that  $C^*$  will occur. It is only a prediction, and not an established certainty. Reality is, that  $C$ , given the occurrence of  $A$ , may take on different values. This should also be remembered when reading the register.

Using the risk register as a source of knowledge regarding enterprise risk relies on the analyst being sufficiently familiar with the risk register and one might question whether or not this method is to comprehensive? Getting acquainted with a risk register in a large scale enterprise is not something that could be done in a couple of hours. Depending on the size of the register, it might take weeks or even months. At the same time using uncertainty factors to validate each risk description is indeed extensive work. A risk description might have hundreds of uncertainty factors which needs to be accounted for and a risk register might have thousands of identified risks. Obviously, a quick way to familiarize one self with the enterprise risk and hence the risk register, is needed. The familiarization method

could be top 10 lists, a top-ten-needed-to-be-reduced-type-of-list, or whatever suits the current situation and the level of familiarity needed. However, it is from the author's point of view doubted that enterprise risk as a whole could be summarized down to an interval, a number, a top ten list, or some other simple representation. The enterprise risk in a large scale enterprise might be very complex in its nature, and it should not be expected that there exist a easy way to obtain an enterprise risk picture. Describing enterprise risk through a risk register as proposed in this thesis is a continuous and extensive process which requires involvement and effort. Nevertheless this effort is rewarded with an understanding of the enterprise risk involved, and a solid foundation which one can do decisions on.

The conclusion summarizes how to build and construct a risk register in order to describe enterprise risk.

## 8 Conclusion

This thesis has addressed some problems regarding risk registers in an enterprise risk setting. Two main problems has been addressed. First,

1. Building a risk register which is consistent with the  $(A, C, U)$  risk perspective and describes the enterprise risk.

And second:

2. Building a risk register so that a distinction between the various risk descriptions contained in the risk register can be made based on background knowledge in which the contained risk descriptions are based on.

For the first problem, it is argued that a risk register should, if it is to be constructed in light of the  $(A, C, U)$  risk perspective, constitute a description of the initiating event, a description of the consequence given the initiating event and a description of the uncertainty. It is further specified a register where each entry consists of a description of the initiating event ( $A'$ ), a predicted consequence given the occurrence of that initiating event ( $C^*$ ) and a subjective probability for the occurrence of the initiating event ( $P_s(A)$ ). Thus a risk description in line of  $(A', P_s(A), C^*)$ .

However, all the contained risk descriptions in the risk register are still treated as equal in terms of background knowledge. Therefore, as requested in problem 2, a scheme is introduced which seeks to evaluate uncertainty factors “hidden” in the background knowledge which the risk descriptions are based on. The uncertainty factors are evaluated according to uncertainty, and how sensitive both  $P_s(A)$  and  $C^*$  are with respect to changes in the uncertainty factors. Including each risk description’s uncertainty factor evaluation in the risk register accommodates a distinction between the various risk descriptions based on the background knowledge. The risk register will subsequently describe the enterprise risk according to the area of risk the enterprise is exposed to and provide a distinction between the risk descriptions based on the background knowledge.

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