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Author: Svein Bratseth	
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Master Thesis at the department
Risk Management - Risk Assessment and Management

Thesis Title
A study into how handling of uncertainty within a team is affected by variations in uncertainty understanding and uncertainty description

Author
Svein Bratseth
929792

Program Coordinator and Supervisor
Frederic Emmanuel Bouder

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Foreword

This thesis is the final assignment of a two-year master's program in risk management at the University of Stavanger. The complete research into this topic was performed in the period from January to mid-June 2020. The topic itself came from a major incident offshore fall 2019 where an individual was seriously injured, but the potential in the event was greater with the potential for several deaths. Did this happen due to a difference in the understanding of concepts of uncertainty.

The research into this topic was performed with the guidance of Mr. Frederic Emmanuel Bouder at the Center for Risk Management and Societal Safety at the University of Stavanger. The research method of grounded theory with semi-structured interviews was new to the researcher. Mr. Bouder provided guided as best as possible during what has been an interesting and challenging semester which has been made even more so by the Covid-19 situation which resulted in the closing of the university altogether and the research library.

I would also like to thank all the anonymous interview subjects for allowing me to ask what for most of them were difficult questions. I would like to thank my family and friends for supporting me during this project.

I hope you enjoy reading this thesis. The thesis has been optimised for duplex print, some pages are therefore intentionally left blank.

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Svein Bratseth

Stavanger, 11th of June 2020

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ABSTRACT

The background for this thesis came from a belief that there might be different interpretations of the concepts of uncertainty within a team discussing uncertainty. This might be especially evident in Hazard Identification (HAZID) and Hazard Operability (HAZOP) risk assessments where participants with different backgrounds are gathered on purpose to highlight different points of view. This led to the following research question "*How variations in uncertainty understanding and uncertainty description affect how uncertainty is handled within a team?*". The question was investigated through a literature review of relevant schools of thought along with different uncertainty handling strategies. The understandings within the team were assessed through grounded research with prolonged semi-structured interviews. To not assess all possible backgrounds a cross-section of a team consisting of engineers, economists, risk practitioners, and other individuals not considered in the beforementioned categories were considered. The cross-section of the team assessed consisted of 6 engineers, 2 economists, 3 risk practitioners, and 2 others with a background as manual labour and public administration, 13 persons in total. The different schools of thought were engineering and technical studies, expected utility theory, risk theory, and subjective expected utility theory respectfully.

From the literature review, it is evident that there are many different uncertainty understandings and measures depending on the background i.e. there are many different schools of thought. This is made even more intricate by the fact that a single individual may have changing and at times conflicting understandings of uncertainty. From this finding, it is surprising that the interview subjects provided a fairly coherent understanding and measure of uncertainty. The majority stated that they understand and measure uncertainty through probability. However, the difference lay in the description. All of the interviewees claimed to use subjective probability even though this is not allowed in expected utility theory where only frequentist probability is allowed. The relevant interviewees said that frequentist probability is sometimes used as a basis for the final subjective probability. However, the mindset is still on frequentist probability. All the other schools of thought allow for and use both subjective and frequentist probability. The evaluation and inclusion of rare events are difficult in general and all interviewees agree, there is not enough imagination to visualise these outcomes. Frequentist probability, i.e. expected utility theory, ignore these events, the interviewee confirms this. Subjective probability, i.e. all the other schools of thought, may take it into consideration however, low assigned probability often results in it being ignored. Except for risk theory, through the *managerial review and judgment* step, rare events with low probability and limited knowledge may be included. However, none of the risk practitioners state that this is done.

The literature on attitude and handling of uncertainty falls along the lines of reduce, tolerate, and denial this was confirmed by all of the interviewees with that exact prioritisation. Reduce uncertainty as fare as possible, then create plans to manage residual uncertainty, finally decide to go or nogo. Interviewees said that reduction is done by gather information. The new information may take on different meanings depending on the background. For frequentist probability, new information may confirm existing data, however, new rare events may not be captured. For subjective probability, new information may provide confidence in assigned probability and new rare events. None of the interviewees mentioned having experienced a conflict of action regarding this. An observation was that a few interviewees claimed that at times it might be desirable to increase uncertainty to look for new options. These were not along the lines of the schools of thought, but more client and contractor.

During HAZID and HAZOP type risk assessments, there are most likely different perceptions of uncertainty. To align these a project-specific guideline detailing the different concepts on uncertainty description, how to take into consideration rare events, handling uncertainty may be considered to avoid confusion, miscommunication, and to align expectations, and ultimately may also avoid rare unwanted events. Such a guideline may also be useful for persons looking into the assessment after the fact. Considering establishing such a guideline is the result of this grounded research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

Abbreviation	Description
ALARP	As Low As Reasonably Practicable
BACT	Best Available Control Technology
Client	The company ordering the work
Contractor	The company performing and executing the work
DT	Decision Theory
EUT	Expected Utility Theory
HAZID	Hazard Identification
HAZOP	Hazard Operability
MC	Monte Carlo
QRA	Qualitative Risk Assessment
RAP	Rational Actor Paradigm
RCT	Rational Choice Theory
SCT	Social Choice Theory
SEU	Subjective Expected Utility
SoK	Strength of Knowledge

Chapter 1. INTRODUCTION

To try to protect something that humans value risk assessments are often performed. It should be noted that these assessments may find positive unintended consequences, however, in this thesis only the negative unintended consequences are of interest. For the unintended consequences, there are uncertainties with respect to these consequences. It is this uncertainty and different uncertainty understandings and descriptions which are of interest in this thesis.

The motivation for this topic came from an incident during an offshore marine operation within the oil and gas sector. The incident resulted in a single person being seriously injured, however, the potential for injuries was large. A similar type of operation has been performed before with great success. The previous times the operation was performed it had gone through risk assessments of the Hazard Identification (HAZID) and Hazard Operability (HAZOP) type. During HAZID's and HAZOP's the operation to be performed is examined in detail to reduce the likelihood of an unwanted event. The same risk assessments were performed this time as well i.e. the operation had been extensively risk assessed. What was different this time. Of course, several aspects are different, no operation is identical in every way. However, it made the author wonder how uncertainty is understood and described within a team and the possible uncommunicated differences in understanding may affect the handling of uncertainty. Having also previously read some risk assessment documents, risk assessment guidance documents [1], and critiques of such documents [2], there seems to be an inconsistent and a "loose" use of the word *uncertainty* and where risk assessors use the word without providing an interpretation. It is the author's initial belief that this lack of explicitly describing the interpretation used in the assessment is an indication of a lack of understanding that different interpretations exist. The team members are unaware that their statements can be interpreted differently. The effect of this "lack of knowledge" on the team performing the assessment is unknown. This led to the development of the research question presented below. Through this thesis the author will try to put some light on the subject of uncertainty and try to determine whether or not an undeclared difference in the concepts of *uncertainty* within a team in HAZID and HAZOP type risk assessments have an impact on how uncertainty is handled. Handling of uncertainty may also involve selection of which unwanted events to ignore and which to consider further. A look into the decision-making process is considered beneficial.

The HAZID and HAZOP type risk assessments were of interest because participants from different fields converge during these meetings. Such risk assessments usually consist of about 20 people with a wide range of backgrounds such as engineers, economists, manual-labour, etc. The potential for miscommunication is considerable. During HAZID and HAZOP type assessments the operation to be performed is reviewed in detail and risks are identified and mitigated [3, p. 117].

There are many facets to uncertainty however, this thesis will only cover and discuss the most relevant for the task at hand. Take for instance uncertainty for the standpoint of art, or music, etc. uncertainty would then be appreciated for entertainment. These are not considered.

RESEARCH QUESTION

Based on the introduction above the following research question is proposed.

> How variations in uncertainty understanding and uncertainty description affect how uncertainty is handled within a team?

The research question above has been divided into the following sub-tasks or questions for easier handling.

1. Perform a literature review of the different schools of thought with respect to uncertainty understanding and measure, how to describe uncertainty, and how to deal with uncertainty.
2. Determine how to set up, execute, and evaluate qualitative research.
3. Find relevant interview subjects and perform an in-depth semi-structured interview with a focus in the following areas
    a. Uncertainty understanding and description both on a company level and on a personal level
    b. Modelling and estimation of uncertainty
    c. Inclusion of rare events and the knowledge dimension
    d. Experience with uncertainty miscommunication and worsening of events
    e. How do you and your company act when faced with uncertainty, how do you make a decision
4. Evaluate interview subject responses in relation to their background and school of thought.
5. Evaluate methods of handling approaches when faced with uncertainty in relation background.
6. If misalignment of team members exists provide recommendations on how to align the different concepts of uncertainty.

A complete set of interview questions may be found in Appendix 2.

In order to investigate these areas, a grounded research approach was chosen due to the complete lack of information on this topic. The research was performed by a series of prolonged semi-structured interviews of a cross-section of a risk assessment team. This cross-section consisted of engineers, economists, risk practitioners, and others. The other category was included to included other individuals not included in the before mentioned categories. The answers were compared against relevant schools of thought. These schools were risk theory, expected utility theory, engineering, and technical studies and subjective expected utility theory for the “others”. The report is structured as follows. First, a literature review section on how to understand uncertainty, human rational behaviour, different schools of thought, different uncertainty descriptions, etc.. Second, a section on how the research methodology. Third, a section on the results of the interview. Forth, a discussion of the results. Finally, a conclusion of the research.

Chapter 2. Literature Review

In order to constructively discuss the research question and the sub-questions presented in the previous section, it is considered beneficial to present the relevant theoretical foundation and concepts. The main content of the literature review will be as follows. A background on how uncertainty may be understood, followed by a rationale for the background for the different schools of thought. After this comes a section on different methods for describing uncertainty. The different schools of thought have different techniques for handling rare events and knowledge, a section on this is also included.

2.1 Understanding Uncertainty

Uncertainty is a word widely used in public speech and the affiliation people have with the word varies depending upon where one originates. This is one of the issues with uncertainty, that despite it being a part of many fields it is not central to any except maybe the risk field and a certain degree statistic. There is no coherent argumentation on uncertainty across all areas resulting in different assumptions and beliefs [4].

Several words exist for the lack of knowledge like the German word *nichtwissen* (loosely translated into *not knowing*) to the English version of *ignorance*. In 1999 Knorr introduced the term *negative knowledge* which may be interpreted as *knowledge on the border of knowing*. However, the most popular and the most generic term is *uncertainty* [1, p. 14].

An observation Knorr and Smithson makes is that *anyone referring to uncertainty cannot avoid claiming to know something about who is uncertain about what* [4, p. 15]. Smithson's definition handles this by stating that if *A* views the proposed idea from the position of *B* (denoted *A'*) and *A* does not agree then *A* is uncertain, illustrated in Figure 2-1. The proposed definition allows the participants to define what is meant by uncertainty. The definition allows *A* and *B* to disagree about uncertainty. It is worth noting that *A* and *B* may, in fact, be the same person. It also allows for *A* disagreeing with *B*. This definition incorporates anything *B* thinks *A* could or should know (but doesn't) and anything which *B* thinks *A* must not know (and doesn't). *B* may be a perpetrator as well as an attributor of uncertainty. [4, p. 15], [5, p. 6]. The take-away from this is that there are many different understandings of uncertainty even within oneself and these may not always be consistent.

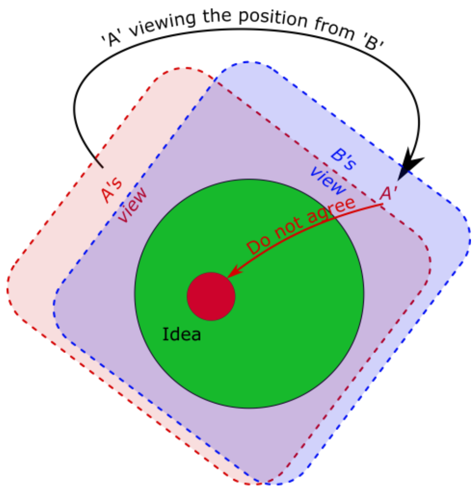


Figure 2-1: Smithson's Definition of Uncertainty

It is important to state that the origin of uncertainty is not solely objective imposing itself on us for the natural world there are also cultural and social elements. Other cultures may have different ways of expressing uncertainty [4, p. 15]. This illustrates that there can indeed be several understandings of *uncertainty* within a team. However, it does not provide a method for providing a common understanding of uncertainty. In order to have a meaningful discussion on uncertainty, it is important that a common understanding and representation of uncertainty is established. A proper discussion is not possible unless the participants in the discussion have a common language. This is more difficult when the participants come from different fields and cultures [4, p. 322]. It should be noted that a common understanding of uncertainty is not paramount in all cases, emergency responders, for instance, can act effectively without knowing the uncertainty of the task at hand [4, p. 322].

Some of the methods for understanding uncertainty is through the use estimation, causal reasoning, and sense-making exercises. Probability theory is just a framework to describe a particular kind of uncertainty. However, others ranging from quantitative and mathematical to qualitative and narrative [4, p. 322]. In sections below are relevant uncertainty and risk understandings presented.

It is worth noting that it is possible to have a good representation of uncertainty, through the use of for example probability, without having a good understanding of uncertainty. During Hájek's investigation into the philosophy of probability, he found that the mathematics of handling probability is more advanced than the philosophical question of what probability actually is and is not [4, p. 323].

2.2 Rational Behaviour

In order to constructively discuss the different positions of team members, it is considered beneficial to describe the foundational thinking of human and organisational behaviour, the concept of rational action. The rational behaviour and Western culture have been exported throughout the world with implementation into a wide variety of institutions. It underpins institutions that structure markets, education, legislative government, industrial management, etc. [6, pp. 22–23].

Social science is as mentioned that backbone for much of specialised theories and schools of thought that follows. A brief description of the social science understanding of risk and uncertainty is provided below. Within social science, there are many definitions of risk used where one of the more commonly used definitions is provided by Eugene A. Rosa. According to Rosa's definition, a risk is then *a situation or event in which something of human value has been put at stake and where the outcome is uncertainty.* This definition of risk contains several key features [6, p. 17].

1. Expresses the duality of uncertainty of the human existence both environmental and man-made;
2. Gives a detailed explanation of states that are properly conceptualised as risk;
3. Embeds the conventional definition of $Risk = (Probability \cdot Consequence)$;
4. Covers both positive and negative risks.

Another key person is Ortwin Renn which combined the different social science definitions of risk resulting in a definition containing three elements [7, p. 2]:

1. Outcomes that have an impact on something that human's value;
2. The possibility or uncertainty of the occurrence of the outcomes. The outcomes can be either positive or negative;
3. A formula to combine the two elements.

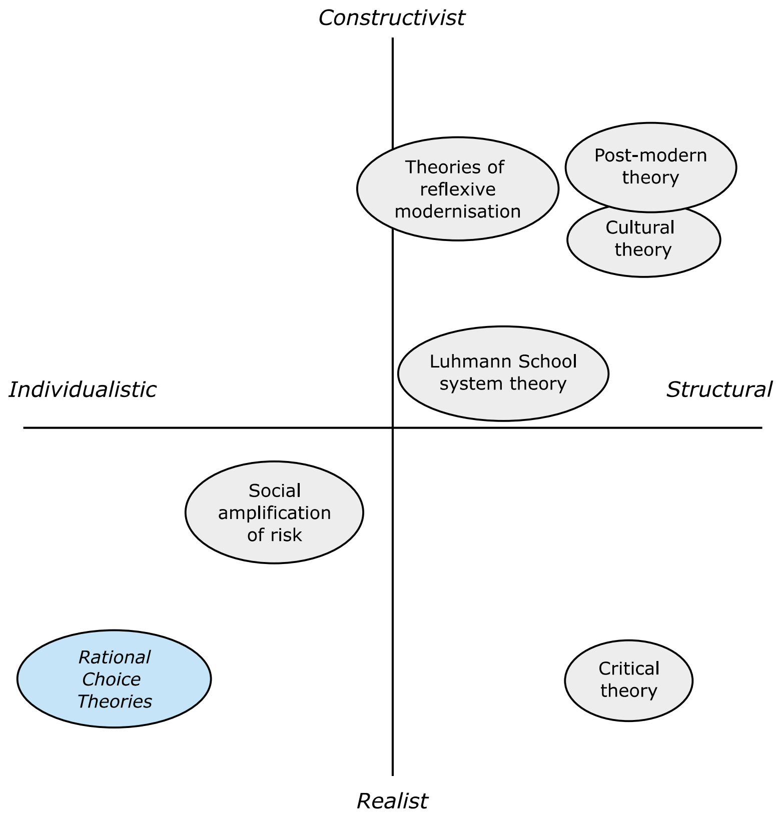
This definition of risk and most other within social science is based on the assumption of human agency which involves choosing between several options [6, p. 18].

From the definition of risk provided by Renn there are within social science seven approaches to risk [7, p. 25]:

1. Rational choice approach;
2. Reflexive modernisation approach;
3. Systems theory approach;

4. Critical theory approach;
5. Post-modern perspective
6. Cultural theory approach;
7. Framework of social amplification of risk.

It is outside the scope of this thesis to describe them all however, Figure 2-2 shows where on the *Constructive – Realist* axis and *Individualistic – Structural axis* each of the different approaches lay. The Y-axis (*Constructive – Realist* axis) shows the foundation of knowledge. Within the field of social sciences risk, and subsequently also uncertainty, there exists two different interpretation of the origin of risk and uncertainty, it can either be a social construct or as a real phenomenon [7, p. 2]. Where *Constructive* means that all knowledge is socially constructed while *Realist* means that all knowledge can be physically experienced through data collection and theoretical reasoning. Where on the X-axis (*Individualistic – Structural* axis) indicates the basic unit of the analysis. It is a normative continuum between *individualistic* and *structural* focus when investigating risk debates. The focus can either be on the individual or a society as a whole. Moving from the left to the right along the X-axis the focus is more and more on complex social phenomena which cannot be explained by individual behaviours only [7, pp. 23–24].



(O. Renn, Risk Governance: Coping with Uncertainty in a Complex world, Earthscan, 2008)

FIGURE 2-2: GENERAL RATIONALITY THEORIES OF SOCIOLOGICAL SCIENCES

The concept of rational behaviour has its origin back in classical Greece and has gone through some modifications by influential philosophers like Hobbes and Kant to modern times. It is, however, mostly centred in and based on Western culture. The concept of rational behaviour uses the Western culture as a view of the world, this flows further down through *general theories* and down to the special theories as illustrated in Figure 2-3. At the *General Theories* level is the idea that rationality is a general theory of human behaviour. This idea is the most influential research tradition in social sciences ever and has led to among other things the functioning of markets, property rights, etc. One of the most popular general theories or paradigms is the *Rational Actor Paradigm (RAP)*. The versatility of RAP allows it to be used for differing fields such as psychologists and economics [6, pp. 22–23]. The idea of rational behaviour persists at all levels which is a concept that states that humans are rational organisms and that the world can be explained by the interaction between by its individual parts. The idea behind rational action is that of *human agency*. Human agency means that the person or organisation has the ability to make their own free choices. All social science assumes that humans have this ability and are able to choose between a variety of behavioural options. It is also assumed that humans and organisation are goal orientated capable of making strategic decisions where outcomes are linked to decisions. This involves weighing the different options [6, pp. 22–23], [7, p. xiii]. This means choosing the option most suitable or beneficial to them.

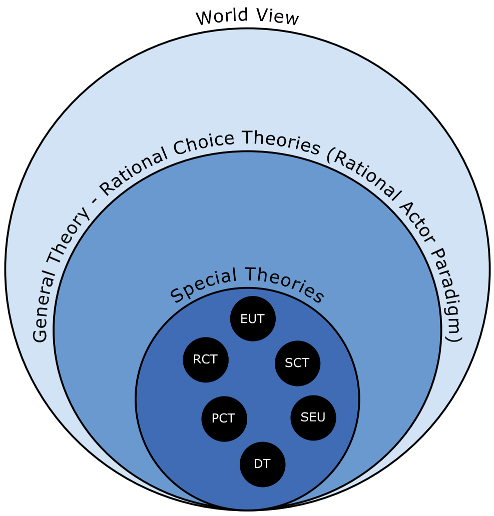


FIGURE 2-3: THREE LEVELS OF RATIONALITY – RATIONAL ACTOR PARADIGM

Mentioned above, one of the most popular theories for human behaviour is the *rational choice theories* and where subversion RAP is one of the most used. Figure 2-3 shows how different special theories fit into the larger world view. At the core of RAP lie the idea of human agency which is the foundation for risk and uncertainty within social sciences and western culture [6, p. 18].

At the *Special Theory* level, rational action is the basis of the specific theories and models such as the *Expected Utility Theory (EUT), Subjective Expected Utility (SEU), Social Choice Theory (SCT), Rational Choice Theory (RCT), Public Choice Theory (PCT), Decision Theory (DT)* and others. These models then produce predictions and conclusions [6, p. 23].

Especially within economics have the idea of rational action been adopted and incorporated at all three levels. The implementation is so complete and so unshakeable that even when faced with irrefutable evidence the idea still remains, any problem lives in the special theories only. Only in the face of a better *world view* will the underlying idea of rationality be questioned and possibly be replaced [6, p. 25].

How an individual or organisation understands uncertainty depends upon its epistemic orientation, which can be divided into two contrasting axes. These contrasting axes are *quantifiable – ineffable axis* and *subjective – objective axis* illustrated Figure 2-4. The quantifiable – ineffable axis describes how quantifiable the uncertainty is ranging from quantifiable expressed solely by numbers to be described with words. While the subjective – objective axis describes whether the uncertainty is objective "out there" in the physical world or subjective "in here". By *epistemic orientation,* it is meant the way one leans when it comes to accessing and using knowledge [4, p. 326]. There are three basic modes of knowledge *rationalism*, *empiricism,* and *metaphorism. Rationalism* relies mainly on clear thinking, logical consistency, and rational analysis of ideas, *empiricism* involves active observation and seeking of sensory experience and *metaphorism* focuses on symbolic cognitions and universal insights or awareness. For further information on see [8]. This epistemic orientation has a direct influence on how uncertainty is understood and represented and many debates at its core is a disagreement upon wherein Figure 2-4 one stands. However, over the last decades, there has been a gradual shift for risk assessments from being almost completely in the objective quantifiable quadrant to moving diagonally more into the subjective ineffable quadrant. The move allows for the inclusion of social constructs, qualitative, and narrative accounts [4, p. 327].

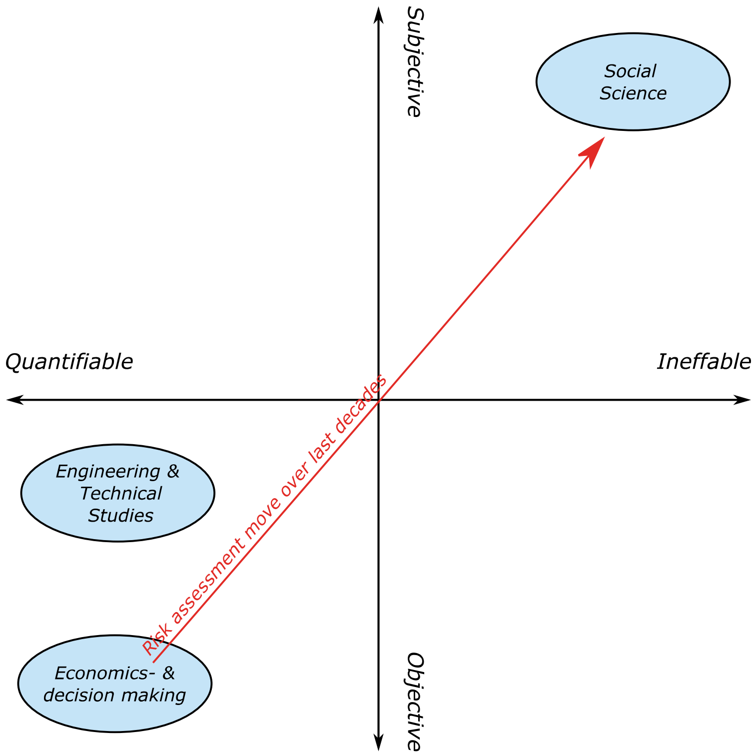


FIGURE 2-4: UNCERTAINTY CONTRASTS

2.3 DIFFERENT SCHOOLS OF THOUGHT

From Smithson's definition of uncertainty in section 2.1 and the abundance of different backgrounds and approaches mentioned above, there is a considerable likelihood that there are conceptual different understandings of uncertainty within a team. Smithson's definition also allows for an individual to have a different understanding of uncertainty for different situations which may be conflicting. It is therefore of interest to identify the background of the most relevant team members participating in a technical HAZID and HAZOP type risk assessments. A selection of understandings and their interpretation of risk and uncertainty are therefore presented below.

2.3.1 EXPECTED UTILITY THEORY

Within a team, there is usually one or more members with an economics background. Risk and uncertainty within the economic field have been heavily influenced by *Frank Hyneman Knight*. In his book [9] he divides uncertainty into two categories which ha names *risk* and *uncertainty*. *Risk* is objective or measurable quantifiable uncertainties where an accurate measure of the "odds" may be established. While *uncertainty,* also referred to as *true uncertainty* or *Knightian uncertainty,* is unquantifiable uncertainties, where it is not possible to measure the "odds" [9, p. 20]. The true uncertainty is therefore often disregarded. One issue with using this separation is that we seldom have *objective measurable uncertainties* and in most cases, there will be *true uncertainty. Objective measurable uncertainty* exists primarily in a controlled environment with pure game of chance like casino etc [10].

There are a few issues with Knight's definition. Firstly, is that assuming that a form of uncertainty is objective and measurable (risk) when in fact it is unmeasurable uncertainty (true uncertainty). This may have unforeseen consequences and lead to an incorrect conclusion and subsequently a wrong decision. Secondly, the *objective measurable uncertainty* is probabilities that are based on statistics and frequentist probabilities, see section 2.4.2 for further description. Using this approach, it is assumed the future will continue similarly to the past. However, this may not always be the case. Take for instance the 2008 financial crash and subsequent financial slowdown. This slowdown, or negative growth, was not in any of the growth predictions of the affected countries. The issue is that the failure of the frequentist model comes as surprises [11]. Thirdly, trying to modify Knight's description of risk and uncertainty to be able to incorporate subjective or Bayesian probability makes the concept hollow [12, p. 75]. Fourthly, within economics there is a conceptual difference in attitudes in dealing with uncertainty. On one side there are the advocates for formal decision-making theories that claim that uncertainty can be reduced by the study of information and preferences. On the other side, there are the advocates for that stand that uncertainty is irreducible [4, p. 201].

One of the most common methods of making a decision within economics and decision-making is to use expected utility theory or some variant of the expected utility theory like rank-dependent theory or weighted utility [6, p. 24]. Equation (2.1) show the expected utility function where the aim is to find the option with the highest expected utilisation [4, p. 197].

$$E[u(x)] = \sum_{s} \pi_s \cdot u(x_s) \qquad (2.1)$$

Where $S = \{1, 2, 3, \dots, s\}$ is the space of possible states $x = \{x_1, x_2, x_3, \dots, x_S\}$ is a list of state-contingent outcomes. π_S is the probability of state s. u is the utility function. It is possible to use subjective probability, however, this leads to the Savage formulation and the subjective expected utility theory. The most common probability description within expected utility theory is frequentist point estimation [4, p. 197], [11]. By using only point estimate the possible wide range of possible outcomes is not taken into account. For further reading on expected utility theory see [9], [13]. There is a degree of "arbitrariness" in the establishment of the utility function [11, p. 21].

One of the benefits of using the expected utility theory is that when there is a sufficient amount of relevant statistical data the decisions it recommends are quite objective. In many cases, the option with the highest utilisation is selected. However, in many cases, the relevance of the statistics may be questionable.

Figure 2-6 presents the decision process for expected utility theory. The decision is based on the output from the decision analysis e.g. expected utility function. The information this probability is based upon or the background knowledge is not presented. The background distribution for the frequentist probability provided may have a wide or narrow distribution there is no way of telling from a single value. Any information on this must be included in additional documentation. This information is based on established statistical principles and can be easily described.

Due to the use of frequentist probability only, any event with large uncertainty or a low probability of occurrence is ignored. Black swan events are ignored due to their extremely low probability. Expected utility theory addresses only historically frequent events.

Figure 2-5 summarises the different uncertainty components of expected utility theory.

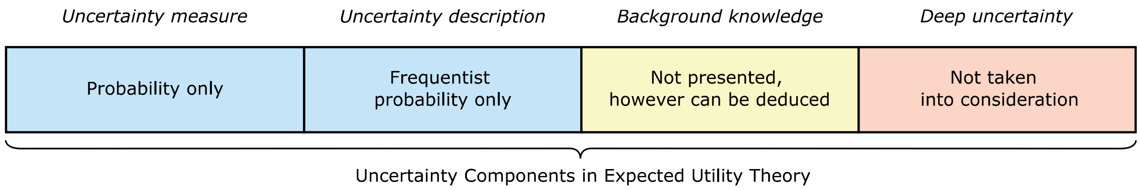
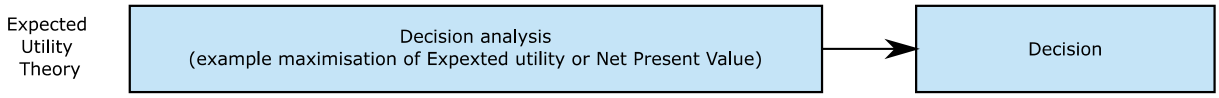


FIGURE 2-5: EXPECTED UTILITY THEORY UNCERTAINTY COMPONENTS

Figure 2-6 shows how a decision is made using expected utility theory.



(T. Aven, "On How to Deal with Deep Uncertainty in a Risk Assessment and Management Context")

FIGURE 2-6: EXPECTED UTILITY THEORY – DECISION MAKING

2.3.2 SUBJECTIVE EXPECTED UTILITY THEORY

Within social science, uncertainty may be described quantitatively as well as qualitatively. However, under the rational choice theory, the simplest form is captured through the *subjective expected utility theory* (SEU). The subjective expected utility theory is quite similar to the expected utility theory used in economics, described in section 2.3.1. The difference being that both factors are subjective [7, p. 26], [14, p. 216] see equation (2.1). The subjective expected utility theory is expressed in equation (2.2).

$$SEU = \sum_{j=1}^{n} P(E_j)\,U(x_j) \tag{2.2}$$

$P(E_j)$ may be either subjective or frequentist probability of event j, probability interpretations may be found in sections 2.4.2, 2.4.4 and 2.4.5. However, it is required that the assessor assigns a single value to the probability. Similar to the expected utility theory an interval probability is not possible. While $U(x_j)$ is the subjective utility function of event j. A person or organisation would chose the option which maximises or optimises the utility [7, p. 26].

There are some issues with the subjective expected utility theory. First, similarly to the expected utility theory, it is assumed that people and organisations always act rationally by linking decisions to outcomes. However, this may not always be the case effectively eroding the foundation of the theory [7, p. 26]. Secondly, RAP is in the lower left-hand corner in Figure 2-2 i.e. all of the assessed school of thought, which makes it more suitable for independent systems not influenced by external societal forces. Subjective expected utility theory has over several years been criticised by the social sciences for being too narrow focusing too much on probability and expected value, and also for claiming to be value-free [7, pp. 42–43], [15, p. 122]. Thirdly, subjective expected utility theory addresses the outcomes as subjective probabilities that the person links with the different consequences of the decision options. The probability of these consequences is captured by the strength of the subjective belief in whether or not the outcome will manifest itself [7, p. 27]. However, a representation of the belief solely by probability may not be sufficient since the knowledge upon which the belief is build may not be sound [16, p. x]. Contrary to frequentist probability a subjective probability may consider rare events with deep uncertainty and limited knowledge. The concepts of deep uncertainty and background knowledge assessment is described in section 2.5.

An issue which is similar to the expected utility theory, there is a strong degree of arbitrariness in the choice and establishment of utility function [11, p. 21]

Figure 2-7 illustrate the uncertainty components within subjective expected utility theory.

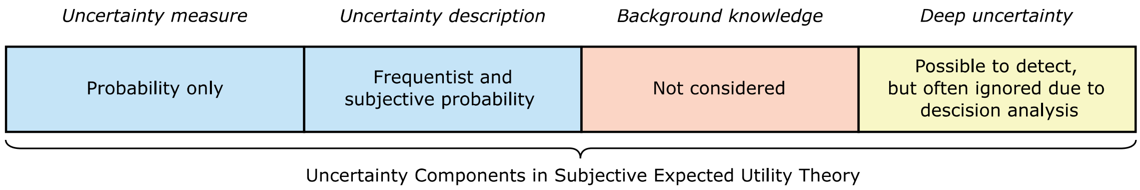


FIGURE 2-7: SOCIAL SCIENCE UNCERTAINTY COMPONENTS

Figure 2-8 shows how decisions are made using subjective expected utility theory. Notice that there is no review of decision analysis before a decision is made. There is in a sense an automated selection of the most desirable choice.

(T. Aven, "On How to Deal with Deep Uncertainty in a Risk Assessment and Management Context")

FIGURE 2-8: SUBJECTIVE EXPECTED UTILITY THEORY – DECISION MAKING

2.3.3 ENGINEERING AND TECHNICAL STUDIES

The risk and uncertainty understanding within the engineering and technical studies is quite similar to the understanding provided by *subjective expected utility theory* described in section 2.3.2. The most commonly used definition used by engineers is $Risk = Probability \cdot Consequence$. Traditionally in engineering uncertainty is something that may be found by for example performing *Qualitative Risk Assessment* [16, p. 6]. During a QRA the probabilities are represented by objective probabilities (classic or frequentist interpretation, see section 2.4.1 or 2.4.2 respectfully). Another form of risk assessment that is commonly performed is HAZID and HAZOP assessments. From the equation $Risk = Probability \cdot Consequence$ each risk requires a single value for probability and consequence. During HAZID and HAZOP assessments the probability can be either be objective as described above but also by subjective measures (urn standard or betting approach, see 2.4.4 or 2.4.5, respectfully). Due to the nature and time constraint of engineering HAZID and HAZOP risk assessments where the aim is to find a practical approach to a series of concrete questions or risks the preferred description is subjective probability.

Similar to the subjective expected utility theory the probability may be either frequentist or subjective. However, the statistical foundation for frequentist probability and background knowledge for subjective probability is not considered or included. Taking into consideration the background knowledge the assessment is built up is in general not done. Engineering and technical studies suffer from the same problem of single number representation that plague expected utility theory and subjective expected utility theory [18, p. 529], [19]. The detection of possible unwanted events with large uncertainty is possible due to the option of using subjective probability. However, the author is unable to find and engineering approach properly taking into consideration rare events with low deep uncertainty. Only risks with a high product of $probability \cdot consequence$ will be addressed. This means that low probability events will be ignored unless the consequence is enormous. Figure 2-10 shows how decisions are made. Similarly to the subjective expected utility theory, the decision analysis provides a direct link to a decision. The highest risk will be addressed.

Figure 2-9 shows the different uncertainty components and which are taken into consideration within engineering.

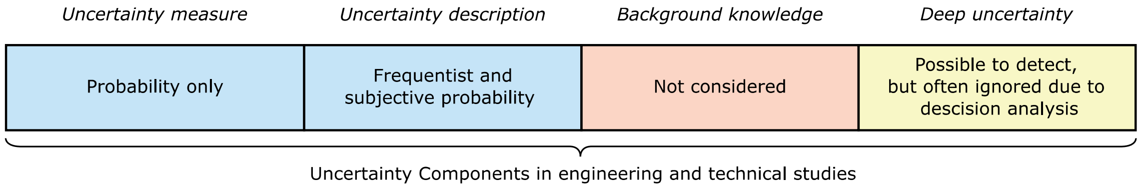


FIGURE 2-9: ENGINEERING UNCERTAINTY COMPONENTS

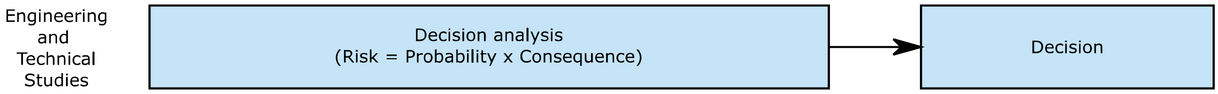


FIGURE 2-10: ENGINEERING AND TECHNICAL STUDIES– DECISION MAKING

2.3.4 RISK THEORY

The concept utilised in risk theory is different from the other fields, a more in-depth description of therefore considered beneficial.

The risk field is one of few fields which has taken upon itself to properly understand uncertainty and describe risk. The practitioners found that, as indicated above, that there are many different understandings of risk and uncertainty and none of them may be used as a general description. However, previous attempts to establish an agreed-upon definition of risk across fields have failed and it is not realistic that such a definition will be agreed upon in the near future [20].

One of the findings made by the practitioners of risk theory was that solely using probability to measure uncertainty may be an imperfect or incomplete tool. If a subjective probability is presented, this reflects the assessors assigned probability of occurrence only, not the knowledge upon which it is based. For example, if an export assigns a probability of 0.2 of event A occurring and a layperson also assigning a probability of 0.2 of event A occurring. This additional information, i.e. uncertainty reducing information should be presented.

It might be useful to mention one of the most general definitions of risk which are provided by Aven and consist of two dimensions *consequence* and *uncertainty* [21, p. 22].

- Something we value at stake where the consequence of our action will impact whatever is at stake to a greater or lesser state;
- Uncertainty about the outcome.

This definition of risk is in line with the Society of Risk Analysis and ISO and provides a clear separation between the *risk concept* and *risk description.* These will be described briefly below.

Risk Concept

For every action or activity, there is a consequence or a set of consequences (C) of which there is *uncertainty* (U). The components (C) and (U) encompasses the risk concept and is usually written as (C, U). The consequences can be into two parts, into events (A) (example, gas leaks, terrorist attacks, etc.) and their associated consequences (C). The concept of risk may then be written as (C, U)or (A, C, U) [16, p. 13].

The consequences are with respect to something that humans value (human life, environment, financial loss, etc.) in relation to a reference value (planned value, objectives, etc.). Focus is usually placed on negative outcomes because these are undesirable consequences. However, there are also positive consequences where some of them are the desired outcomes and some are unforeseen positive outcomes. Take for example a downturn in a marked. It might mean a reduction in profit which is bad, however, it may result in one of the competitors folding which again may result in increased market share for the remaining actors. Every action has a single or multiple outcomes and they are unknown [16, p. 13].

Risk Description

The concept of risk is defined in the previous section, however, this does not provide a tool for describing and managing risk. From the section above it is determined that risk has two dimensions, consequence and uncertainty. The risk description is then obtained by specifying the *consequences* (C) and using a measure for *uncertainty* (Q). The most common measure of uncertainty is probability (P) however, others exist. The most relevant descriptions of uncertainty are presented in section 2.4. The most prevalent description of uncertainty, in addition to the frequentist probability used by Knight, is the subjective probability provided by Di Finneti (betting approach, see section 2.4.4) and Dennis Lindey (uncertainty standard interpretation, see section 2.4.5). By specifying the consequences, it is meant to identify a set of quantities of interest (C') which characterises the consequences (C). The quantities of interest (C') is then the observable quantities of the risk analysis, for example number of fatalities, production loss, etc. These are the quantities we would like to estimate a value for and assess uncertainty during the risk analysis to create an as clear as possible risk picture at the time of making a decision. Different alternatives can then be considered. It is important to note that the risk picture is only a decision support tool for decision-makers, not an automated decision tool [16, p. 14].

Earlier in this section, it as mentioned that there is also uncertainty related to the knowledge upon which the uncertainty description is based. The risk description (C', Q) is then coloured by the background knowledge (K) of the assessor. A general description can then be written as $risk\ description = (C', Q, K)$ or alternatively (A', C', Q, K) where (A') is some specified A event [16, p. 14].

There are a few benefits to using this approach. Due to the separation of each individual risk, there is the possibility to describe them differently e.g. a risk may be addressed using frequentist probability, another subjective probability, and a third with interval probability. This allows for risk by risk assessment of the background knowledge (K) and an assessment of the possibility of black swans i.e. the level of uncertainty. The assessment of the background knowledge does not result in a modification of the probability, but more in the form of ancillary information to be taken into consideration during decision making. This assessment of the background knowledge may be done through a Strength-of-Knowledge assessment as described in section 2.5. The assessment of rare deep uncertainty events is possible due to the option of using subjective probability.

Figure 2-11 illustrates which uncertainty components the risk theory takes into consideration.

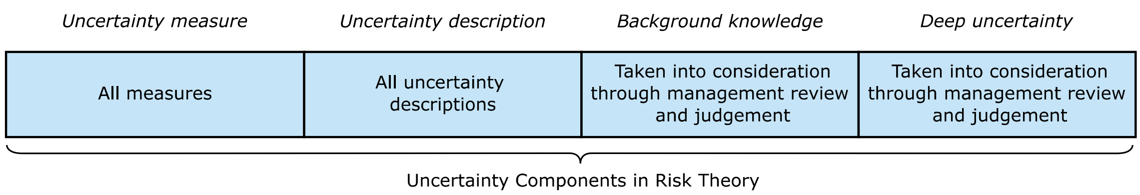
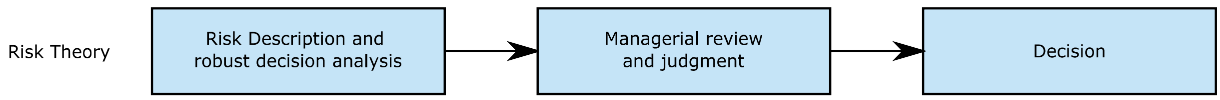


FIGURE 2-11: RISK THEORY UNCERTAINTY COMPONENTS

Utilising the risk field (SRA) and risk theory description of risk and uncertainty each risk will be addressed separately and presented to decision-makers for them to evaluate and conclude as illustrated in Figure 2-12. This is one of the drawbacks which is also a benefit is that all risks must be reviewed through the “managerial review and judgment” stage in order to address the most critical risk. The review may be time-consuming. This is different for the other approaches where the decision is to a degree given as output from the assessment.



(T. Aven, "On How to Deal with Deep Uncertainty in a Risk Assessment and Management Context")

FIGURE 2-12: RISK THEORY – DECISION MAKING

2.4 UNCERTAINTY DESCRIPTION

From the previous sections, it is clear that most understandings of uncertainty on some level use probability. However, this is not as straight forward as it first sounds. There are many different descriptions of uncertainty. Traditionally there have been five recognised interpretations of probability, *classical, logical, subjective, frequentist,* and *propensity* [22]. These are described in sections below.

First, let us look at two different understandings of uncertainty from a probability standpoint. Use throwing a die as an example, before throwing a die there is uncertainty in the outcome. In general, it may be stated that there is uncertainty in relation to the outcome X as the true value of the outcome X is not known. An alternative expression of saying there is uncertainty about X is to say that knowledge about X incomplete [20]. If one possesses complete knowledge there would be no uncertainty about X. Knowledge is described as justified beliefs [20]. Returning to the example of the die. The knowledge assumes that the die is fair. However, this may not be the case, the frequentist probability of any outcome may be $1/6$, $i = 1, 2, \dots, 6$. There is uncertainty about p_i. The knowledge may not be complete and there is uncertainty about the next throw [21, p. 109].

2.4.1 CLASSICAL PROBABILITY

The classic interpretation of probability applies only in situations where the probability for each outcome is similar [23, p. 214]. This can be expressed by equation (2.3) below.

$$P(A) = \frac{Number\ of\ outcomes\ resulting\ in\ A}{Total\ number\ of\ outcomes} \tag{2.3}$$

A typical example of classical probability is throwing a die where the probability of any given number of eyes is $P(1, 2, 3, 4, 5\ or\ 6) = 1/6$. Assuming a fair six-sided die is used. Each possible outcome must have the same probability. In order for the probability to be classical, the probabilities need to adhere to the "principle of indifference" which states that there is no evidence favouring a specific outcome. This interpretation of probability is useful primarily in gambling and not so much in a risk context. This is because in a real-world risk assessment the number of outcomes is not finite and the probability for each outcome is not equal [23, p. 214]. The classical probability will not be discussed further in this thesis.

2.4.2 FREQUENTIST PROBABILITY

One of the more frequently used interpretations, especially within economics, is the interpretation of *frequentist probability.* Frequentist probability is then defined as *the fraction of times the event A occurs if identical experiments where repeated an infinite number of times under similar conditions*. Expressed in Equation (2.4) below [23, p. 214], [24].

$$P_f(A) = \lim_{n \to \infty} \frac{n_A}{n} \tag{2.4}$$

There are different interpretation frameworks, however, the most prevailing framework is to assume the existence of the frequentist probability $P_f(A)$ and then apply the law of large numbers to establish $P_f(A)$ the limiting frequentist interpretation. The most common approach then is to first establish a model, for example, exponential or normal distribution, which closely reflects the real world. Statistical analyses are then performed on the model. For some situations, it is quite easy to establish a large number of experiments under similar conditions, for example, a population of 100 000 men. The probability of a random 20-30 years old man dying can be quite well predicted using $P_f(A)$ [23, p. 215].

There are, however, considerable limitations to using frequentist probability. The notion of an *infinite number of repeatable experiments* can in many cases be questioned. Take the example above once more. It can hardly be argued that all men are equal. Some may drink excessively, while others may exercise regularly. These aspects may certainly impact the mortality rate. The number of identical experiments can be limited. For some situations the concept of frequentist probability becomes useless. Take for example guilt or innocence of an accused person[23, p. 215]. Frequentist probability has considerable drawbacks for rare events.

2.4.3 Logical Probabilities

The concept or idea of logical probabilities was first proposed by Keynes (1921) [25]. This type of probability claims to express an objective logical relationship between different proposals. The concept is also known under the name evidential probabilities where evidence instead of logic applies [22]. The concepts are as follows, there is a number $P(h|e)$ between 0 and 1. This number is a measure of the *objective degree of logical support* of the logic/evidence e gives to support the hypothesis h. *Franklin* in *Resurrecting Logical Probability* [26] states that this idea has some initial appeal as it represents a *level of agreement* between scientists, juries, etc. when evaluating hypothesis in light of the evidence. However, a clear interpretation of the logical relation has not been presented and when using logical probabilities it is not clear how to interpret 0.2 vs 0.3 [22]. It is initially unknown at what level this description is widely used in a risk analysis setting.

2.4.4 Subjective Probability - The Betting Approach

Within social science, engineering, and technical as well as the risk field subjective probability is used considerably.

The theory subjective probability was proposed independently of each other at approximately the same time by *de Finetti* in *Fondamenti Logici del Ragionamento Probabilistico* in Italy (1930) and by *Ramsey* in *The Foundations of Mathematics* in the UK (1931) [27]. This interpretation is sometimes also referred to as knowledge-based probability. Subjective probability then provided is a pure epistemic description of uncertainty as this is based on the assessor's background knowledge [23], [28, pp. 35–36].

The interpretation of the betting approach provided by de Finetti goes as follows. Say that the assessor provides a probability of 0.1. This is then interpreted as the assessor is willing to pay 0.1 unit of money if he or she can receive 1 unit of money in case A occurs and 0 unit of money otherwise. This interpretation is easy to understand and is quite commonly used in subjective probability literature [22].

Consider an example using this interpretation on a nuclear facility. The assessor provides a probability of an event A occurring to be $P(A) = 0.005$. This means that the assessor is indifferent to receiving 0.005 units of money or gambling where the gain is 1 unit of money (euro) if A occurs and 0 units of money (euro) otherwise. The unit of money may be expanded to 1000 euros. The assessor would then be indifferent between receiving a payment of 5 euros or a bet where the yield would be 1000 euros if the nuclear event A were to occur nothing otherwise, illustrated in Figure 2-13. However, if nuclear event A were to occur receiving 1000 euros may be considered trivial. The benefactor of the bet may not be alive to collect. The issue is that there is a link between assigned probability and the willingness of the assessor to gamble with money. The question "How important is 1000 euro to you?" becomes relevant. The assessor's value judgment of money has, in reality, nothing to do with his degree of belief in the event A occurring. When the assessor is asked to provide a subjective probability as an expert to the decision-makers they would appreciate that the advice is separated from the assessor's willingness to gamble with money. So far only the assessor's subjective probability interpretation has been mentioned. However, the subjective probability interpretation of the receiver/decision-maker should also be taken into consideration. The decision-makers may be more or less willing to gamble than the assessor [27].

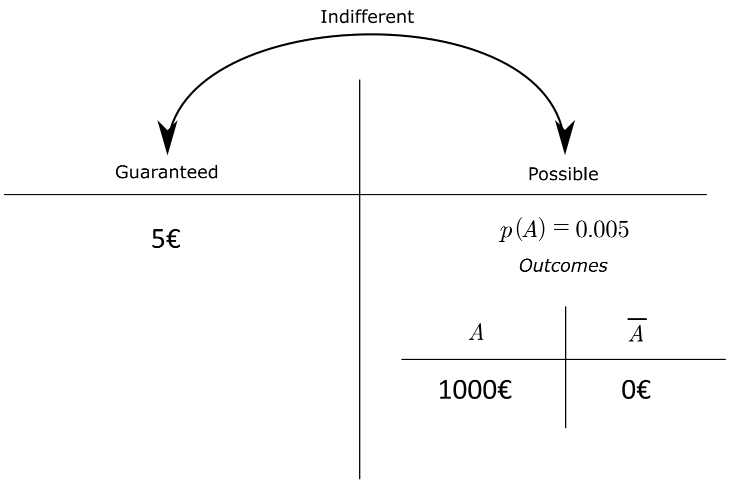


FIGURE 2-13: DE FINETTI BETTING APPROACH OF PROBABILITY

Despite the flaws of using this interpretation of probability, it is quite popular, especially among economists and decision-makers. One reason for this is that the field of subjective probability is highly influenced by pioneers such as *de Finetti*, *Ramsy,* and *Savage*. They do present different frameworks for understanding the concepts however, they do share a common characteristic which is that the probability assigned is an inseparable combination of probability assigned and value judgment about money or other attributes [27].

The argument provided by *Ramsey* for this view is that people's belief may be determined using a combined preference-utility method. This method is based upon providing two scenarios where the assessor is indifferent between which to choose. The first scenario consists of a lottery where the assessor would receive a payment if A occur and no payment otherwise {€x if A and €y otherwise}. The other scenario is a fixed payment of €z . The probability of A, $P(A)$, may than be written as in equation (2.5) [27].

$$P(A) = \frac{U(z) - U(y)}{U(x) - U(y)} \tag{2.5}$$

U denotes a utility function on the money. This interpretation of subjective probability suffers from the same problems as the *de Finetti* interpretation as described above. There exist several other definitions that can be placed in this group [27].

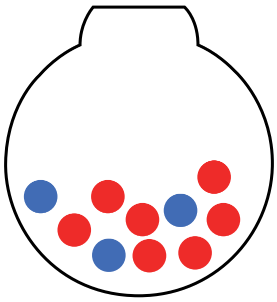
The work done by the three pioneers *de Finetti, Ramsey,* and *Savage* has spawned considerable work on subjective probability, however, only a limited number of works performed challenges the connection between the probability assigned and the personal attitudes to money [27]. However, *Lindley* has proposed an interpretation where the subjective probability is separated from other value judgments. This interpretation is presented in section 2.4.5.

It is initially believed that this understanding to some degree is used in a risk assessment setting.

2.4.5 Subjective Probability - The Urn-standard Approach

Another subjective probability interpretation has been provided by *Lindley* in *Understanding Uncertainty* [29]. When the assigner provides a probability of occurrence of a particular event, it then is his or her personal opinion and it is based on that person's knowledge. If the assessor provides a probability of say $P(A) = 0.3$ of event A occurring, then the assessor compares the outcomes with reference to a standard. One of the more user-friendly standards is the *urn standard*. Given the same probability as above $P(A) = 0.3$ the assessor then has the same degree of belief in the occurrence of the event in question as randomly drawing a blue ball out of an urn with 3 blue and 7 red, 10 balls in total. The urn standard is illustrated in Figure 2-14. This type of probability is always conditional in the assessor's background knowledge K, the complete notation is $P(A|K) = 0.3$. In some cases the given K part is not included, [16, p. 15], [23, p. 23]. It is initially believed that this understanding to some degree is used in a risk assessment setting.

$$P(A) = P(A \mid K) \tag{2.6}$$



$P(A) = 0.3$

(T. Aven Risk Analysis, Wiley, 2015)

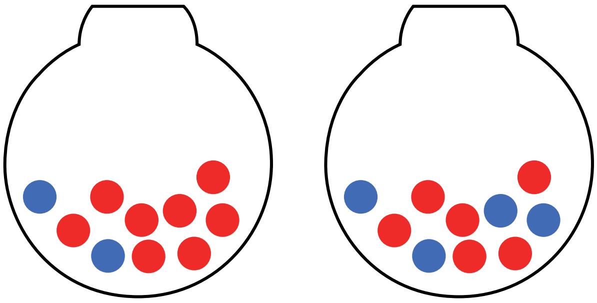
Figure 2-14: Urn Standard

2.4.6 Imprecise Probabilities

The basic concept of imprecise or interval probability is that the assessor is not willing to provide a single value subjective probability, but instead willing to provide and interval.

Using the betting approach by *de Finetti* the lower probability is then interpreted as the maximum price the assessor is willing to pay for a bet that yields 1 unit if A occurs and 0 unit otherwise. The upper probability is then interpreted as the minimum price the assessor is willing to sell the same bet [30].

The assessor may not be able or willing to be as precise as giving a precise number $P(A) = 0.3$ as described in section 2.4.3. The assessor can then provide a lower probability $\underline{P}(A)$ and an upper probability $\bar{P}(A)$. This may be represented by a probability interval, say $[\underline{P}(A), \bar{P}(A)]$ where $0 \leq \underline{P}(A) \leq \bar{P}(A) \leq 1$. Where the difference then is $\Delta P(A) = \bar{P}(A) - \underline{P}(A)$. The assessor may than provide a $\underline{P}(A) = 0.2$ and $\bar{P}(A) = 0.4$. This may than be interpreted using the urn standard. The assessor then determines that the probability is greater than 2 blue balls out of 10 and less than 4 blue balls out of 10 [23, p. 223]. This is illustrated in Figure 2-15.



(T. Aven Risk Analysis, Wiley, 2015)
FIGURE 2-15: IMPRECISE PROBABILITY

Lindly argues that the imprecise probability makes the subjective approach unnecessarily complicated. He argues that he has yet to find a situation where the precise probability is inappropriate and this is fixed by employing an upper and lower probability values [31, p. 229], [23, p. 223]. This uncertainty description is considered to be of limited relevance as the probability in a risk assessment usually provided by a single number only. However, in order to not exclude too many alternatives, it is included and considered.

2.4.7 PROPENSITY INTERPRETATION

Propensity interpretation regards probability as an objective property of the real world. The probability is thought of as a physical propensity or a natural tendency of a certain type of physical situation to result in a certain outcome [22].

When discussing the propensity interpretation, a die example is often used. The dice tendency or habit to land on certain numbers is a measure of its propensity to do so. In order to determine the would-be tendency of the dice an endless series of throws must be performed. There are two different interpretations of this Peirce and Popper. *Peirce* then imagines that the relative frequentist probability of the event in question would oscillate around the habit of the event. A difference between *Peirce* and *Popper* is that *Peirce* regards the habit as a property of the dice while *Popper* regards the habit as a property of the entire chance set-up of throwing of the dice.

It is initially believed that this understanding is not widely used in a risk assessment setting.

2.5 DEEP UNCERTAINTY AND STRENGTH OF KNOWLEDGE

One of the differences between the different schools of thought is the inclusion of deep uncertainty and strength of knowledge. It is therefore beneficial to briefly describe these concepts.

DEEP UNCERTAINTY

Deep uncertainty refers to situations where the knowledge supporting the argument is poor and a reliable prediction cannot be established. Hypotheses may be established; however, their support is weak. Typical examples of deep uncertainty are many types of natural disasters. This means that it is limited if any statistical data on these events. It is then difficult to establish an accurate prediction model that may lead to a precise cause and effect relationship. With an increased level of uncertainty, the potential for black swans also increases as illustrated in Figure 2-16 [23, p. 162].

Typical tools for assessing deep uncertainty is ALARP, BACT, etc.. Further discussion on how to deal with deep uncertainty see [23, p. 165].

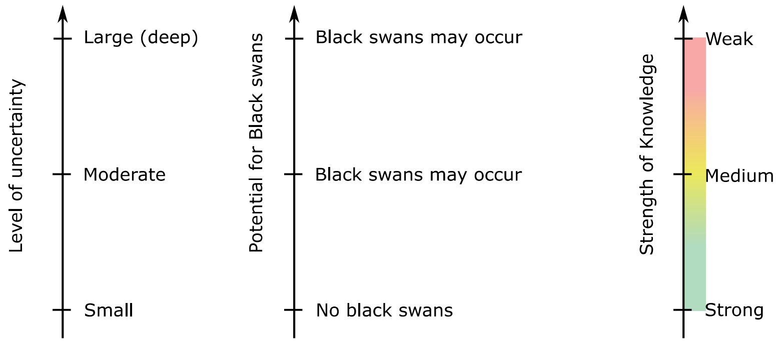


FIGURE 2-16: LEVEL OF UNCERTAINTY

According to Aven in order to take into consideration deep uncertainties, it is required to have a managerial review and judgment step that can see beyond the framework and context of the assessment [32].

STRENGTH OF KNOWLEDGE

When a subjective probability is used the probability assigned is based on the belief of the assessors. In order to evaluate the "goodness" of the subjective probability, a Strength of Knowledge assessment may be performed. The following aspects should be considered [33].

a. The reasonability of the assumptions;
b. The amount of relevant data or information;
c. Degree of agreement among experts;
d. To what degree is the phenomena involved understood and accurate models exist;
e. The degree to which the knowledge has been thoroughly examined (for example with respect to unknown known; i.e. others have the knowledge, but not the analysis group).

Determining the Strength-of-Knowledge level may be done by assessing the background knowledge the probability is based on in relation to a set of criteria. The strength of knowledge may take one of three states, *weak, medium,* or *strong*. With increasing uncertainty, there is a decrease in the strength of knowledge level as illustrated in Figure 2-16.

A set of criteria was put forth by Flage and Aven for the three strength-of-knowledge categories are as follows.

The strength of knowledge is Strong if *all* of the subsequent criteria are meet, Ref. [16]:

a. The assumptions made are seen as very reasonable;
b. Large amount of reliable and relevant data/information is available;
c. There is a broad agreement among experts;
d. The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.

The strength of knowledge is Weak if *one* of the subsequent conditions are true, Ref. [16]:

a. The assumptions made represent strong simplifications;
b. Data/information are non-existent or highly unreliable/irrelevant;
c. There is strong disagreement among experts;
d. The phenomena involved are poorly understood, models are non-existent or known/believed to give poor predictions.

The strength of knowledge is Medium if the classification is somewhere in-between [16].

2.6 Attitudes to and Handling of Uncertainty

Having determined that there is uncertainty in relation to the activity what can be done. Below is a list of attitudes associated with uncertainty [4, p. 322]:

- Deny (said not to exist);
- Banish (set aside as being 'out of bounds' and not dealt with);
- Reduce (usually by gaining more knowledge);
- Accept or tolerate;
- Surrender to;
- Control, harness or exploit.

It may be argued that at least within some fields like economics and decision making there is a drive to reduce uncertainty as much as possible. However, for some areas within engineering reducing uncertainty as much as possible is not desirable and at times beside the point. The position is that of the engineered solution should be tolerant of irreducible uncertainties [4, p. 324]. Due to the different positions and interests, there might be conflict. This conflict may result in a discussion on whether obtainable information should be collected or not [4, p. 326].

The list of attitudes to uncertainty above may be recategorized in a more control-oriented manner [4, p. 327].

- Banishment (anticipation);
- Reduction (anticipation);
- Tolerance (resilience);
- Relinquishment or denial.

The attitude to uncertainty may be divided into three different categories [4, p. 327].

- Actively sought (exploring new options);
- Voluntarily accepted;
- Imposed (uncertainty is not desirable).

Table 2-1 shows a matrix of different uncertainty attitudes and control orientations.

Table 2-1: Uncertainty Handling Mechanisms

		Uncertainty Attitudes		
		Actively sought	**Voluntary accepted**	**Imposed**
Control orientation	Anticipation	Randomized assignment in experiments	Subjective probabilities in decision making	Statistical forecasting
	Resilience	Musical improvisation	Complex adaptive system management	Precautionary principle
	Relinquishment	Aleatory influences in visual art	Some versions of constructivism	Fatalism, relativism

Note: Table taken in its entirety from [4, p. 327].

It is important to note that any coping strategy is not static and may be modified and adapted to suit the circumstances and that there is no single recipe for dealing effectively with uncertainty [4, p. 332].

Within Western culture especially it has been argued that there has been and to some extent is a tradition to overemphasis on only the negative aspects of uncertainty and trying to reduce uncertainty as much as possible. In many cases, there are perfectly good reasons for this. However, it should be noted that without uncertainty there would not be creativity or freedom to choose otherwise. This view that ignorance or uncertainty as binary, either positive or negative, may not be entirely correct as humans and organisations may engage with uncertainty as a mixture of the two. Take for example if an established methodology for an operation is known to work, there might still be value in exploring other methods for the purpose of expanding possible options. There may be a willingness to be exposed to some uncertainty to expand knowledge. Horgon' argues in his book *The End of Science (1996)* that science is running out of areas to discover and that the *ignorance* or *nichtwissen* needs to be replenished from time to time [4, p. 327].

2.7 Cautionary and Pre-cautionary Principle

When faced with large uncertainties one of the management strategies is through the use of the cautionary and pre-cautionary principles [23, p. 165]. A decision-making strategy must take into consideration the effects on risk as they are provided by the risk assessment in addition to the uncertainty dimensions that could not be captured in the assessment. The final outcome will then be founded on both calculated risks in addition to the *cautionary principle* and the *pre-cautionary principle* [16]. These two principles are a matter for decision-makers and not for the risk assessors.

The essence of the *cautionary principle* is that caution should be the overriding principle when there are uncertainties related to the consequences of an activity, i.e. the probability of unwanted events. This could be done by implementing a risk reducing measure or possibly by not performing the activity altogether. The level of caution has to be balanced between several concerns such as cost. This means that the level is somewhat subjective and most industries have a minimum requirement with respect to personal-, public safety, and environmental protection which can be justified by referencing the *cautionary principle* [16]. The ALARP principle gives a lot of weight to the cautionary principle [34].

The *pre-cautionary principle* says that *"in the case of lack of scientific certainty on the possible consequences of an activity, we should implement precautionary measures or not carry out the activity".* The *pre-cautionary principle* may be considered as a special case of the cautionary principle [16].

2.8 Theory Comparison

Table 2-2 shows a comparison between the different schools of thought in question.

Table 2-2: Theory Comparison

	Uncertainty measure	Uncertainty description	Background knowledge	Deep uncertainty
Subjective Expected Utility Theories	Probability only.	Descriptions based on probability presented by a single number. Can be either subjective or frequentist.	Assessor's knowledge of the system at hand may be assessed. However, findings are not properly evaluated due to a lack of *managerial review and judgment*.	Possible to take into consideration through subjective probability. However, often ignored in decision analysis.
Expected Utility Theory	Probability only.	Only frequentist probability used	Not included – probability based solely on statistics i.e. possible to derive.	Not included.

	Uncertainty measure	Uncertainty description	Background knowledge	Deep uncertainty
Engineering and technical study	Probability only.	Descriptions based on probability presented by a single number. Can be either subjective or frequentist probability	Assessor's knowledge of the system at hand may be assessed. However, findings are not properly evaluated due to a lack of *managerial review and judgment*.	Possible to take into consideration through subjective probability. However, often ignored in decision analysis.
Risk Theory	Any uncertainty measures.	All measures, subjective and frequentist probability being the most common.	Evaluated through SoK assessment and implemented through *managerial review and judgment*.	Taken into consideration through the cautionary and pre-cautionary principle, and through the ALARP and BACT tools. Implemented through *managerial review and judgment*.

All of the theories evaluated, except for risk theory, use probability as the only measure for uncertainty. However, despite using the same uncertainty measure there are differences in what is incorporated into the uncertainty. Take for instance expected utility theory where only objective uncertainty based on statistics is taken into consideration. This is a considerable limitation as it limits its practical use when applied to novel areas. Subjective probability allows for the assessor to prescribe a probability that can be different from a frequentist probability if there is one. The frequentist probability will then be used as a starting position. This may be useful in situations with few or no historical equivalent events. The evaluation of events with deep uncertainty may be taken into consideration if a subjective probability is used. However, full integration is only possible with the additional managerial review and judgment step of the risk theory. The inclusion of background knowledge is only really relevant for subjective probability. Since for frequentist probability, the process of deriving the desired probability is based on established statistical principles. Subjective probability, on the other hand, has no established principles for determining background knowledge. The estimation is totally subjective. The strength of background knowledge cannot be addressed through the probability, hence only risk theory with the additional *managerial review and judgment* step takes background knowledge into proper consideration.

Chapter 3. METHODOLOGY

The overarching question proposed in section Chapter 1 will be investigated through qualitative research which involves a literary review of relevant theories, semi-structured interviews. The following sections will describe the methodology used.

According to Kvale the goal of the qualitative research interview is as follows.

> *"An attempt to understand the world from the subjects' points of view, to unfold the meaning of peoples' experiences, to uncover their lived world prior to scientific explanations* [35, p. 1]*".*

In order to perform sound systematic qualitative research seven steps need to be performed. These are listed below [35, pp. 88–92].

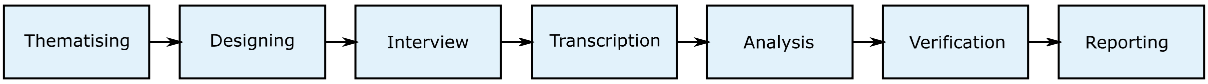


FIGURE 3-1: RESEARCH METHODOLOGY

1. *Thematising*. This refers to the conceptual clarification and theoretical analysis of the topic to be investigated. May also involve establishing hypothesis;
2. *Designing*. This refers to the design of the study and the work to be performed by considering all the seven steps before the interviews start. It also involves how to obtain the intended knowledge;
3. *Interviewing*. Conduct interviews based on guidelines;
4. *Transcribing*. Prepare interview material;
5. *Analysing*. Determine based on the purpose of study which method must be used to analyse material;
6. *Verifying*. Determine the consistency of the results and how well the study investigates what was intended;
7. *Reporting*. Create a report highlighting the methods used and findings.

3.1 RESEARCH METHOD

Qualitative research methodology provides different types of methodical approaches when performing investigations. The method was chosen based on the research question, available resources, and available time.

Within the field of social science, there are several methods of performing qualitative research methodologies such as *narrative research*, *phenomenological research*, *grounded theory,* etc. For each of these methods, there are no standardised practices and approaches to be applied when performing qualitative data analysis. The research seeks to understand the subjects in a particular context, which in this case is the understanding and description of uncertainty in general. The data gathered may come in the form of audio recordings, interview notes, and documents, and may in many cases be unstructured information [36, pp. 6–7].

The chosen method of research into this topic is the *grounded research* approach where the goal is to develop a theory derived from data collected and through process analysis only. This is consistent with the goal of this thesis which is not to test hypotheses yet to try to develop a theory based on information [36], [37].

The chosen research approach is to utilises a combination of a considerable literary review of different schools of thought when it comes to understandings and descriptions of uncertainty in combination with semi-structured interviews to determine the subjects understanding of the different concepts of uncertainty. However, there are considerable weaknesses with both the qualitative and quantitative research methods. Some of these weaknesses may be mitigated by introducing a quantitative element into qualitative research [38, p. 101]. Performing an additional quantitative study is considered impracticable. Section 3.4 describes the methods of increasing the quality or *trustworthiness* of grounded research.

3.2 Semi-Structured Interview

It is the intention to perform interviews of employees at different levels of the company ladder within different companies ranging from engineers to project managers and HSE personnel. The common denominator is that they all may attend HAZID and HAZOP type risk assessments.

For this study, the number of interview subjects should be in the range, 15-20 people. The final number will depend upon time and resources as well as available interview subjects.

The semi-structured interview method was chosen based on the lack of a situation that may be observed and the exact questions to be asked are not known at the initiation of the project. During the semi-structured interview, the interviewer allows the subject to speak freely and only provide guidance to stay on topic. The prepared questions should, therefore, be viewed more as a guideline than actual questions. The questions or guideline may be modified between each interview session allowing for the implementation of additional knowledge gained. This flexibility to modify the questions has an obvious down-side which is that not all interview subjects will be asked the same questions. The self-driving aspect of the interview removes some of the interviewer's personal opinions and biases as the direction should be minimal. However, this also requires the subject to be increasingly motivated to "answer" questions and drive the interview by him- or her-self [38, pp. 92–93].

The interviews have to the greatest possible extent been performed in one sitting. The semi-structured interview consists of three parts [39].

1. Opening part, consisting of establishing a level of trust by asking open-ended questions;
2. The middle part, consisting of more in-depth questions;
3. Conclusion, probing further into sections of interest, possible contradictions, and ending the interview.

The intended questions or guideline are presented in Appendix 2. However, due to the nature of the semi-structured interview, the questions are viewed more as a guideline and the interviewer will only avoid the subject drifting off-topic.

When performing such an interview two jobs need to be performed simultaneously by the interviewer (I) follow the line of inquiry set by the research question and (II) verbalize the actual conversational questions in an unbiased manner.

3.3 Data Analysis

The chosen method of research is the grounded research approach where the theory shall be derived from data collected and through process analysis only. The goal of the author is not to test hypotheses, but to try to develop a theory based on information [36], [37]. A structured way of analysing the data is needed, Figure 3-2 shows these steps.

The process requires ample time to analyse and for reflection. The final number of interview subjects may, therefore, be different from originally intended. The analysis develops as the study progresses, this means that early or first iteration of interview analyses should have a broad approach with an open mind and should be revisited again at the end of the study [39, p. 119].

A structured way of analysing the data is needed, Figure 3-2 shows these steps.

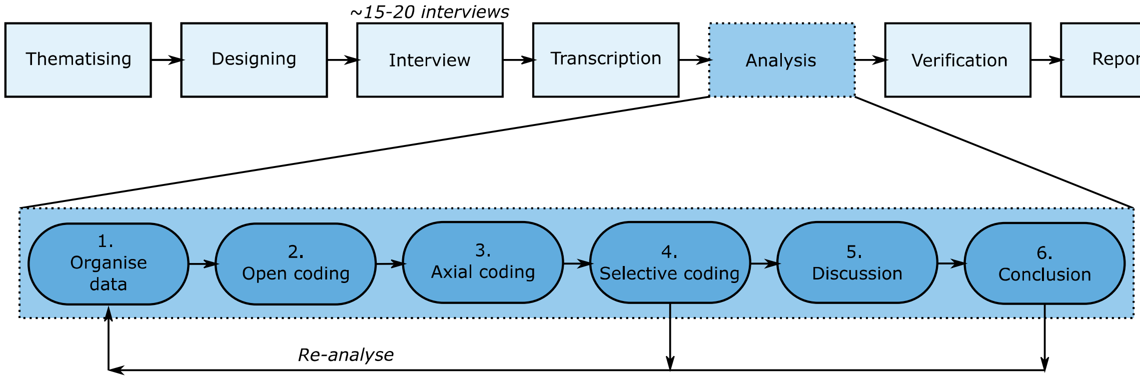


FIGURE 3-2: QUALITATIVE DATA ANALYSIS PROCESS

Below the steps are described in detail. However, for further information see [39]. The coding used for grounded research is usually divided into three stages where each stage refines the relationships between the elements [36], [37], [40].

1. *Organise data*. Labelling and making data accessible. During this stage, the following questions are asked (I) who is telling? (II) where is this happening? (III) when did it happen? (IV) what is happening? (V) why?;
2. *Open coding*. During this stage, important words and groups of words are identified and labelled. Questions like "What is the data a study for? What category does this incident indicate? What is actually happening in the data?".
3. *Axial coding*. The labels created during the previous stage are grouped into categories depending upon their relationship.
4. *Selective coding*. During this step, the researcher finds core categories and relate them to the other major categories eventually becoming the basis for the grounded theory.
5. *Discussion*.
6. *Conclusion*.

During step 2 (open coding) key point coding is used. Key points that are regarded as important are identified in the transcript, given an identifier attribute [41]. The ID system starts with a P for a key point with a letter for each interview then a number indicating a key point in the interview. If analysis at a later stage prompts for a split in ID numerals will be added to the ID. Table 3-1 show an example of an interview transcript ID, key point, and associated code. The ID must be uniquely defined in order to be able to return to the correct section in the transcript for possible later evaluation of content and context.

TABLE 3-1: KEY POINT CODING EXAMPLES

ID	Key Point	Open Code
P_B_003_02	Produces most likely probability based on statistical data.	Probability based on statistics
P_P_010	Company has not produced a guideline on how to understand and describe uncertainty.	No guideline
P_U_023	Company needs to improve with respect to "rare events"	Considerable improvement potential for rare events
P_U_024	Probability background information not presented in a systematic manner.	Background information not included systematically

Figure 3-3 shows examples of how open coding are grouped through axial coding. Dedicated software exists to handle coding at different stages. However, for this thesis, the coding is performed manually.

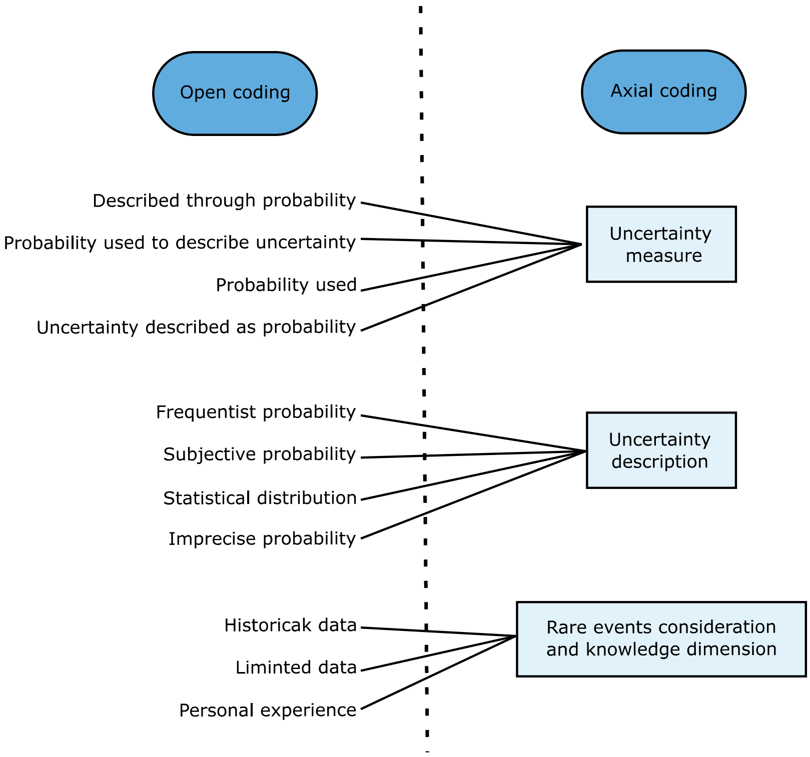


FIGURE 3-3: EXAMPLE OF AXIAL CODING

3.4 QUALITY CONTROL IN GROUNDED THEORY RESEARCH

In order to test or verify the quality of the research design, a set of four tests are commonly used. These are commonly (I) Construct validity, (II) Internal validity, (III) External validity, and (IV) Reliability. Where the validity steps, in short, describes how the study was performed and why it was executed the way it was. While reliability indicates how trustworthy the study is and how to replicate the results [42, pp. 42–46]. However, these steps as they are described in [42, pp. 42–46] are not directly relevant for grounded theory research, some modification is required. These modifications are commonly described as *trustworthiness* and are briefly described below [43]–[45].

1. Credibility (may be seen as construct validity);
2. Transferability (may be seen as internal validity);
3. Dependability (may be seen as external validity);
4. Confirmability (may be seen as reliability).

Credibility may be viewed as sort of similar to internal validity in positivistic research. Credibility, on the other hand, refers to how much of the acquired data accurately describes the event. The credibility of the research may be increased by for example having prolonged interaction with interview subjects, triangulation of information. The questions used to guide the interview may also be updated between interviews [43]–[45]. The credibility of this thesis will be ensured by the triangulation of considerable literature review of different theories and prolonged semi-structured interview as illustrated in Figure 3-4. Additional qualitative study such as field observations may be performed to further increase the credibility, however, in this case, it is not considered to be useful since during a risk assessment the underlying understanding of uncertainty, which this thesis studies, is not discussed. Sending a quantitative questionnaire to triangulate

the methodology is considered impracticable due to resource limitations and the closed nature of questions.

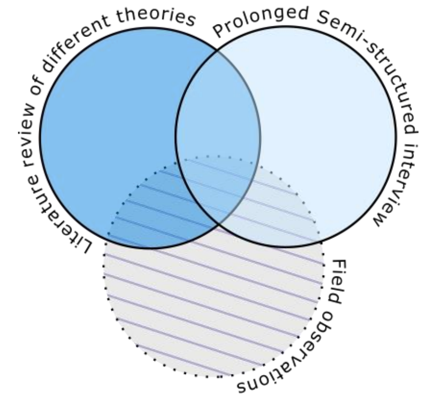


FIGURE 3-4: DATA COLLECTION TRIANGULATION

Transferability may be viewed as sort of similar to external validity in positivistic research. It refers to the applicability of the findings of the study in other settings. Transferability may be increased through a clear description of the research, diversity in participant's perspective and experience, research methodology, interpretation of the results, and contributions from peer debrief [43]–[45].

Dependability may be viewed as sort of similar to reliability in positivistic research. Dependability refers to the stability of results over time. This involves the evaluation of findings, interpretations, and recommendations by the participants so that all are supported by data provided by the participants [43]–[45].

Confirmability refers to the repeatability of the findings if independent researchers are provided with the same data to verify that the findings are real not imagined by the researcher [43]–[45].

3.5 ETHICAL ISSUES

Below are typical ethical issues when performing grounded research and semi-structured interviews.

- *Privacy.* The interview or study may move into areas that were not intended at the beginning of the interview. Where some might be tempered to focus on sensational elements. There is also an issue if the interview moves into private areas and the interview subject wants it to remain private [46].
- *Confidentiality*. Confidentiality is threatened when there is a transfer of information that was previously secret. The confidentiality is most at threat when writing the report and particularly when using quotes [46].
- *Informed consent*. Informed consent implies that the interview subject is familiar with the privacy and confidentiality before agreeing to the interview [46]. This is resolved by having the participants sign a consent form prior to the interview, see Appendix 1.
- *Harm*. Some interviews concern sensitive matters which may make the interview intense potentially harming both interviewer and interview subject. [46]. The interview is not considered to be emotionally intense for the interview subject.
- *Dual role and over-involvement*. The interviewer may take on the role of both scientist and therapist when performing the interview. The interviewer may use techniques to draw out information from the participant while at the same time be highly knowledgeable about the field in question. The interviewer may be increasingly drawn away from researching during the interview. The interviewer may be increasingly involved in the interview subjects' personal lives. It may be argued that some degree of involvement is desirable [46]. This may be an issue with this study as the interview subjects are all colleagues or team members from other companies.

- *Power and politics*. The concept of power has several aspects. The interview subject might feel obliged to participate in the interview due to their relationship, for example, a doctor-patient relationship. The relationship may also influence the direction the interview takes moving into areas the interview subject would keep secret. The power difference is of greatest importance when interviewing vulnerable groups. The interviewer's political stand may be altered by the interview subject for example on the subject of feminism a female interviewer may easily take the position of the female interview subject [46]. This is not considered to be an issue as the interviewer wields limited to no power over interview subjects. The subject in question is considered fairly free of politics.

Chapter 4. Results

This chapter presents the main findings from the interviews. The results are divided into the following seven categories which correspond to the sub-questions of the research question, *Uncertainty understanding, Uncertainty description, Uncertainty guideline, Handle uncertainty, Rare event consideration and Knowledge dimension, Modelling and estimating uncertainty* and *Miscommunication and No worsening of event.* Appendix 4 show the coding spreadsheet.

At the onset of the research 19 relevant persons agreed to be interviewed. These interview subjects were selected to get a cross-section of a typical team making up HAZID and HAZOP type risk assessments. However, upon the final request and scheduling of time, many declined. The final number of interview subjects numbered 13. This is slightly less than what was optimal between 15 and 20. The final distribution of interview subjects ranges from engineers, risk practitioners, economists, and social science, illustrated in Figure 4-1. However, as the number in Figure 4-1 shown there is a majority of engineers among the interview subjects. In Appendix 3 a very brief background description of the different interview subjects is presented. The results within each category will be provided by the numbers of interview subjects having replied one way of the other. It is also of interest to include a statement or a claim made by one of the interviewees. No direct quotes are presented in this report. To ensure anonymity all interviewees will be addressed as "he" regardless of gender.

One of the interview subjects, (P_U), has a special status as he has a background in engineering and economics but is passionate about risk and is therefore considered as a risk practitioner.

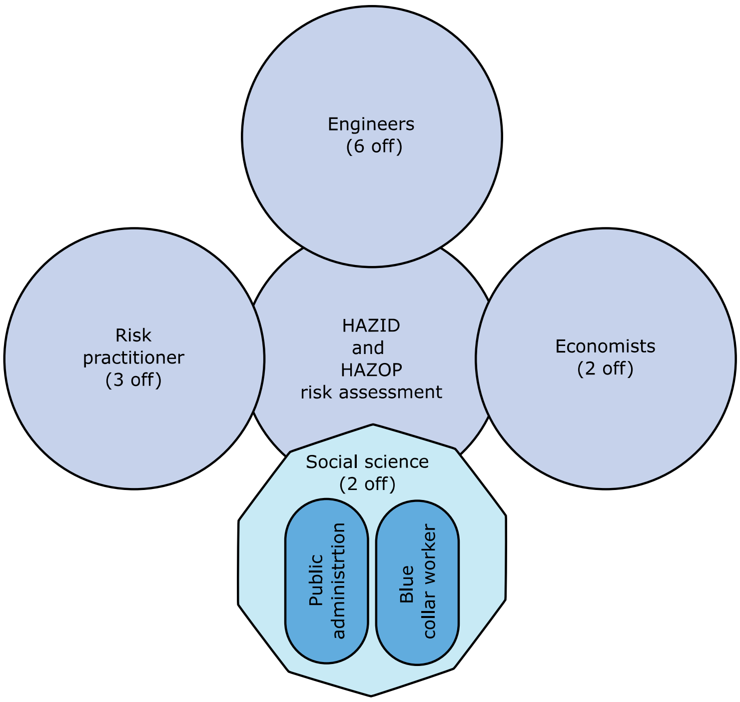


Figure 4-1: Example of Backgrounds in HAZID and HAZOP

The area of interest is during HAZID and HAZOP type risk assessments. However, when interview subjects were asked the questions they were asked how "they" would explain it in general, not as it might be explained in a HAZID or HAZOP setting. This was to try to make the answers as correct and neutral as possible.

4.1 Uncertainty Understanding

The research question posted that there might be different understandings and measures of uncertainty within a team. From the literature review, it is evident that there at least could be multiple understandings within a team. Based on the interview responses there is a difference in the understanding and measure of uncertainty within the team interviewed. However, this is only a single team and may not be representative of all teams. The answers provided are heavily skewed towards measuring uncertainty through probability, 12 out of the 13 stated this. The one interviewee, (P_M), that stated that he is not always willing to measure uncertainty through probability, claimed that the selection of uncertainty measure is dependent upon the context. Based on the background of the interview subjects, (P_M), it may be difficult to place in the correct category. He was placed in the "others" category assuming to use subjective expected utility theory. This individual may at times use a more "constructive" view of uncertainty where the uncertainty is a social construct, see Figure 2-2. However, the individual used probability most of the time, this anomaly is therefore disregarded. The utilisation of an uncertainty measure other than probability is not possible under the subjective expected utility. Through the interview, he, (P_M), does not explicitly state how the selection of uncertainty understanding and measure is performed.

The potential for misalignment in understanding and measure between the team members was actually mentioned or hinted at by a couple of the interview subjects, (P_G and P_L). (P_L) said that there is definitely a difference is risk picture presented, however, there is often an agreement on the consequence this means that there is a difference in probability assigned. While (P_G) stated that during risk assessments of the HAZID and HAZOP type there is no discussion on uncertainty understanding and measure. When there is a disagreement, the starting positions of the individuals are not stated explicitly. The fact that he mentioned this indicates that he at least has considered the possibility at the time of the interview if not before.

Viewing the responses in connection with the literature review it is logical that most of the replies focused on probability as the uncertainty measure as this is the most widely used measure. This is in line with the different schools of thought, except for the interview subject (P_M).

It was to a certain extent anticipated that the two interviewees, (P_E and P_P), that have risk education would at least mentioned the possibility of using other measures then probability as is this an option in risk theory. However, this was not the case as these presented probability as the only measure. A reason for this might be that none of these are "pure" risk practitioners as they both have a degree in industrial economics with a focus on risk. This combination may lead them more in the direction of financial risk. However, throughout this report, they will be considered as risk practitioners.

One of the interview subjects, (P_O), claimed that a probability is coloured by the knowledge and attitude of that individual. The individual may be averse to uncertainty or venturous.

4.2 Uncertainty Description

When answering the question on which uncertainty description they use, the interview subjects present a picture which at first is difficult to understand. Out of the uncertainty descriptions described in section 2.4 only three were mentioned by the interview subjects namely *frequentist probability, subjective probability,* and *interval probability*. These three descriptions will be discussed in light of different backgrounds.

13 out of the 13 interview subjects replied that when providing a probability, it is to some degree a subjective probability. However, upon further questioning the answers where less clear cut and to some degree more in line with the literature review.

4.2.1 Engineering and Technical Studies

6 out of the 6 engineers interviewed said that when they assign a probability it is a subjective probability. According to two of the interview subjects, (P_B and P_D), the subjective probability provided is in many cases too high as the probability of an event is usually conditional while the

probability given in a usually unconditional. Both continue to say that with increased experience comes more correct subjective probability. However, the risk assessments where engineers typically attend are often HAZID's and HAZOP's and these are often considered quite technical of nature where the uncertainty is primarily focused on the probability of technical failures and whole systems failure. The failure probabilities of these components may be found by experiments. A frequentist probability could potentially be available. However, in many cases, the relevant historical data is not available at the time of risk assessment. One of the interview subjects, (P_D), claimed that it would be beneficial to have more historically based probabilities since it is more objective. He also claimed that much of the historical data required to provide a frequentist probability may be available. Currently, it is not utilised to its maximum. However, an observation made is that there is an increased tendency to use frequentist probability with increasing seniority. This might be due to actual gained knowledge about the availability of data and confidence in using the data for similar events.

One of the interview subjects, (P_D), said that the subjective probability provided during HAZID and HAZOP type risk assessments is primarily established by 2-4 members disagreeing. The remaining team members remain silent. The subjective probability is therefore not set by necessarily an agreement among all team members.

It is quite common to express the probability as a single number for both frequentist and subjective probability. However, some of the interview subjects, (P_D, P_B, P_Q, and P_O), said that it is not uncommon to present the probability through imprecise probability either as a numerical interval or as a qualitative description (e.g. "low", "medium" and "high"). For example, during a risk assessment, the probability for an event is set to "medium" probability that has a range of 10% - 30%. The exact implementation of these types of intervals into the $risk = consequence \cdot probability$ description is unclear. (P_B), claim that often "worst-case probability" is used.

4.2.2 Expected Utility Theory

2 out of the 2 interview subjects with an economics background (P_R and P_S) both replied that they primarily use frequentist probabilities to describe uncertainty. One of the interviewees, (P_R), said that these frequentist probabilities are taken from evaluations provided by external companies such as Erst and Young or PriceWaterHouseCoopers. These frequentist probabilities are subsequently assessed and modified to better suit the assessor's beliefs. He continues to state that the probability provided is a subjective probability based on historical data. This is corroborated by the interview subject (P_S).

Often when using frequentist probability there is a distribution of probabilities. This leads to the question of which probability to use, should the most likely probability be used, worst-case, or a percentile. There is a subjective dimension to the use of frequentist probabilities as well. However, the description of the choice of probability can be done precisely and calculation of that probability is fairly simple.

These statements and arguments are somewhat in line with the literature review which states that only objective measurable uncertainties (known as risks) are taken into consideration. While the unmeasurable uncertainty called true uncertainty is disregarded.

4.2.3 Risk Theory

2 out of the 2 interview subjects with a background in risk management (P_P and P_E) claim that there is a mixture of the use of frequentist probability and subjective probability. However, there is consistency in the different uses and the uncertainty description is dependent upon the area it is used. During a detailed *Qualitative Risk Assessment* (QRA) of for example explosion forces on an oil rig, the probability of exceedance for the different areas is almost solely based on frequentist probabilities and calculations thereof. However, during HAZID and HAZOP type risk assessments, the probability provided is mainly of the subjective probability type. During such risk assessments the subjective

probabilities may be built on historical data or memory of the participants. One of the interview subjects, (P_P), confirmed what was said by (P_D) that the subjective probabilities are often discussed by a limited number of persons attending often about 3-4 persons. The majority of the persons attending HAZID and HAZOP type risk assessments do not contribute to the probability setting.

The interview subject (P_U) has as mentioned a special status and he said that the subjective probability provided is highly dependent upon the setting it is provided. It is therefore important to as best as possible to ensure that all participants have the same context understanding when providing a subjective probability.

When these views and statements are viewed in connection with risk theory, we can see that they are quite well aligned. The theory allows for the use of all uncertainty descriptions which also includes frequentist and subjective probability.

4.2.4 Subjective Expected Utility

2 out of the 2 interview subjects, (P_M and P_L), claimed that they assign a probability it is solely a subjective probability, represented by a single number. Both also said that they were not comfortable expressing a subjective probability in a HAZID or HAZOP risk assessment settings. There might be a feeling that unless you have substantial historical data on the question, your belief does not matter. These two interview subjects did not provide any further rationale for the subjective probability position.

In the light of the literature review on subjective expected utility the use of a single value subjective probability is permissible with the subjective expected utility theory. It was difficult to extract further information provided by the interview subjects on this topic.

4.3 Miscommunication and Worsening of event

There was a general consensus among almost all interview subjects (12 out of 13), irrespective of background, that there is at times miscommunication when discussing uncertainty. One of the interview subjects, (P_M), claimed that there is no miscommunication without providing any further explanation for this view. Another interview subjects, (P_R), state that whether this is due to a difference in uncertainty understanding and description or bad semantics is difficult to determine. While another interviewee, (P_S), claimed that there is miscommunication, engineers primarily use subjective probability while economists typically use frequentist probability and interpret any statement accordingly. The interviews did not yield any further information on this topic.

All of the interview subjects (13 out of 13) have difficulty saying that an event has been made worse by the fact that there might be different uncertainty understandings and descriptions within the team during the performed HAZID and HAZOP risk assessments. This difficulty stems from the fact that if an unwanted event occurs several aspects have failed and tracing this back to differences in understanding and description is difficult. The interviews do not guild any further information on this topic.

4.4 Modeling and Estimating Uncertainty

Below are two sections on how to model and estimate the probability for frequentist and subjective probability. Interval probability will not be discussed as it is in principle the same as or subjective probability.

4.4.1 Frequentist Probability

In order to establish a frequentist probability, it is required to have some historical data. This data may come from actually performed experiments as mentioned in section 2.4.2. It may come from as one of the interview subjects, (P_E), said through calculation from established standards provided by for example DNV. The data may be provided as a distribution and in some cases, the desired probability may be calculated directly from the single distribution. However, this may not always be possible. According to three other interview subjects, (P_P, P_U, and P_B), sometimes it is desirable to combine a series of distributions. In these cases, Monte Carlo (MC) simulations are used to model and estimate a combined distribution and the extracting of relevant probability.

In some cases, all the information required to perform a Monte Carlo is not available. According to one of the risk practitioners, (P_P), in these cases, it may be required to assume a distribution (for example a uniform distribution, triangular, normal, etc.) in order to be able to perform a Monte Carlo simulation. This introduces to an extent a subjective probability.

4.4.2 Subjective Probability

In some cases, it is not desirable or even possible to find a reliable frequentist probability. However, it is usually possible to assign a subjective probability. The selection or estimation of a subjective probability can to some degree appear to be arbitrary and lacking in foundation. In result section 4.2 it was stated that all of the interview subjects use to some extent subjective probability. However, when asked if they compare the estimated subjective probability to an external model like the urn standard or betting approach, see section 2.4.4 and 2.4.5, they say that this is never performed. This is consistent among all the different backgrounds and companies.

One of the interview subjects, (P_P), which has a risk background, claimed that it is not important to establish the correct probability. Unwanted events occur due to unforeseen events, not due to incorrect setting of the probability of the event. The important thing is the discussion about the event, not the probability setting.

4.5 Uncertainty Guideline

The interview subjects consisted of employees from four different companies. All of the interviewees (13 out of 13) claim that the company they work for does not have or they are not aware of having a general company guideline on how to understand and describe uncertainty. However, one of the interview subjects which is a company manager, (P_R), said that in his work with other company managers there is a guideline. His work partly consists of creating scenarios and estimating a probability for each scenario. This is an exercise that is performed by many of the decision-makers and all the decision-makers have the same instruction on how to perform the exercise and how to interpret the uncertainty. It is, however, understood that this guideline is intended for use by higher-level management irrespective of the manager's background.

It is surprising that none of the interview subjects with risk background or experience, (P_E, P_P, and P_U), say that their company has a guideline on how to understand and describe uncertainty. These three reflect two of the four companies which may suggest that at least these two companies, maybe all four companies, lack a general guideline, not only that the interview subjects were unaware of the existence of a guideline.

Some of the interview subjects have at the time of interviewing considered that a guideline could be beneficial. One of the interview subjects, (P_I), claimed that during a risk assessment it would be beneficial with greater guidance on how to interpret the uncertainties. While another, (P_Q), said that it would be beneficial to have a proper guideline to ensure that there is alignment in understanding.

4.6 Rare Event Consideration and Knowledge dimension

One of the major differences between the different uncertainty descriptions is the ability to take into consideration rare events with large uncertainty. Another area that is of interest is the incorporation of background knowledge for the probability.

4.6.1 Frequentist Probability

RARE EVENTS

From the literature review, a frequentist probability is not capable of taking into consideration rare events. This is also in line with statements made by the interview subjects. One of the interview subjects, (P_P), that has a risk background said that the inclusion of rare events is an issue when using frequentist probability since only frequent events are considered. A frequentist probability is therefore incapable of looking into the future and any predictions made may, therefore, be incorrect. He also mentions that events with a low initial event probability, but have large know-on effects are difficult to consider. This is backed up by, (P_R), which has a background in economics. He claimed that rare events are not only difficult to take into consideration due to low event frequency but also because the models themselves are created for a “normal” situation. Running the models outside of this “normal” state may make the predictions made by the models invalid. As examples, he mentioned that the 2020 drop in oil price was modelled and to some extent evaluated. However, the current Covid-19 situation has not been taken into consideration.

The interview subject, (P_U), says that it is difficult to include or take into consideration rare events using only frequentist probabilities as rare events have such a low probability and some rare events have never occurred. This is corroborated by another interviewee, (P_S), which claimed that rare events are difficult to consider due to limited historical data. These events are therefore often based on subjective probability. Covid-19 was not taken into consideration despite there being historical data.

One of the interview subjects, (P_O), said that the only method for trying to take into consideration rare events is through gathering more information. However, this does not allow for the inclusion of events that have never occurred.

KNOWLEDGE

Taking into consideration the knowledge dimension in a frequentist probability may be difficult. In a frequentist probability setting the knowledge is captured in the accuracy of the distribution. In order to increase accuracy additional information must be gathered. This additional knowledge will provide a more accurate prediction or better fitting distribution under “normal” situations and may not provide information on rare events. Say that there is no difference in the estimated probability with the increased knowledge there is no method of seeing this increased knowledge in the probability provided. The above statement is supported by two of the interview subjects, (P_R and P_P), which said that it is difficult to include the knowledge dimension and that the knowledge dimension is often neglected. The knowledge dimension, however, may be included through supporting documentation.

One of the interview subjects, (P_E), summed it up quite nicely when he said that with a decreasing amount of information the assigned probability is increasingly subjective.

4.6.2 Subjective Probability

RARE EVENTS

Coming from a position using subjective probability the options for taking into consideration rare events are substantially increased compared to using frequentist probability. The probability may be assigned directly by the risk assessment team themselves. This allows for the inclusion of rare events where there is no or limited data. The issue with rare events is that few if any of the team members have information on them.

Based on the answers provided during the interviews it may be argued that there is no structured method for finding possible rare events and determining the probability. All interview subjects agree that finding, consideration, and implementation of rare events is extremely difficult. One of the interview subjects, (P_P), said that during HAZID and HAZOP type risk assessments questions like "has this happened before in the industry" are asked to determine if the event in question is possible and has it occurred. While another, (P_D), said that they use structured "what-if analysis" to find rare events. One of the interview subjects, (P_U), which works with risk mentioned that in order to determine important rare events, events, where large forces are at play, are examined in great detail. This is to increase the possibility of detecting a black swan event with large consequences and subsequent reduction of probability of such an event. However, this method only detects rare events with a large consequence. He also mentions that there is a considerable improvement potential with respect to finding "rare events". The interview subject continues saying that it is important that the organisation is learning in order to a greater extent take into account rare events. By this, it is meant that any insight gained is shared both inside and outside the organisation. The insight should not be located at any one individual and solely depending upon the participation of this one individual in future risk assessments. Two of the interviewees, (P_P and P_L), said that in some cases semi-relevant historical data is modified to make an attempt at taking into consideration rare events. However, this approach only tries to estimate the probability of an identified rare event. The approach is only considered relevant where the subsequent subjective probability is lower than the historical data and through this process ignoring the possible unwanted event. Consider the opposite situation where the subsequent subjective probability is higher than historical probability. This would either indicate that there was virtually no historical data to start with effectively making this a pure subjective probability or the historical probability were too high to be considered a rare event.

One of the interview subjects, (P_E), claimed that a limited amount is time is spent when the potential consequences are low. Meaning that only events with large initial consequences are assessed. This excludes the rare events which have a low probability and a low initial consequence, however, it has a large knock-on consequence. Another of the interview subjects, (P_L), which has an extensive career, claimed that time pressure reduces the ability to imagine and evaluate rare events. He refers to the increased focus this has received over the years and that more time is allocated to rare events assessment. However, even though more time is spent on the HAZID and HAZOP risk assessments, this may not be the best environment for the creativity required to find black swans.

Three of the interview subjects, (P_D, P_L, and P_U), said that the biggest issue with assessing rare events is the lack of imagination among the risk assessment team. The team is simply not able to think that a rare event becoming an issue.

KNOWLEDGE

For frequentist probability, the background knowledge may be established because it is based on known statistical principles. However, since a subjective probability is based on the person's belief the background knowledge cannot be deduced after the risk assessment has ended. It is therefore considered quite important to somehow capture the background knowledge level. To get in writing the assessors' knowledge about the question at hand.

All the interview subjects claimed that the background knowledge for a subjective probability is not captured and show presented during HAZID and HAZOP type risk assessments. One of the interview subjects, (P_U), said that background knowledge underpinning the subjective probability is not captured, represented, and presented in a systematic manner. While another, (P_E), claimed that it is assumed that the subjective probability provided by the risk assessment team is correct i.e. that their knowledge is complete. If the assessment team disregards an event it is because it is irrelevant.

Some of the interview subjects, (P_L, P_D, P_I and P_O), said that in order to take into consideration events of which there is limited knowledge, and possibly also low probability, a "buffer" may be added to the subjective probability. The "inflated" probability ensures that it is not ignored due to low probability. This is done by first estimating a subjective probability and then adding this buffer to the probability. Neither the size of the “original” subjective probability nor the “buffer” probability is captured which means that the final probability is solely subjective. There is no separation between the probability assigned and knowledge about phenomena. One of the interview subjects, (P_E), which has a risk education and is aware of the Strength of Knowledge concept (SoK) as described in section 2.5, said that the strength of knowledge of the subjective probability is not assessed nor captured.

4.7 Handle Uncertainty

There is a general trend among all the interview subjects that the overall thing to do when faced with uncertainty is to reduce uncertainty as far as possible until there is a point where a go or no-go decision must be made. One of the interview subjects, (P_E), claimed that uncertainty cannot be eliminated only reduced except for not performing the activity. Meaning that eventually a go/no-go will be reached. One of the interview subjects, (P_U), said that a typical standard risk management plan consists of five stages where stage #4 refers to risk identification (probability and consequence) while stage #5 refers to a reduction of risk and uncertainty. Another four of the interview subjects, (P_P, P_B, P_I and P_O), said that the uncertainty is reduced through the ALARP principle. None of these four interview subjects provided further details on how the uncertainty is reduced through ALARP. Despite there being a consensus on the desire to reduce uncertainty the approach taken to reduce the uncertainty is varied. None of the interview subjects stated that they invoke the cautionary principles this is despite it giving considerable weight to the ALARP principle.

According to two of the interview subjects, (P_U and P_L), it is essential that everyone has the same physical understanding of the event in question to be able to have a somewhat comparable probability within the team. (P_U) said that, it is therefore currently an increased focus on visualisations and augmented reality simulations. A common understanding within the team of possible event reduces the probability of unwanted events occurring. He also stated that the probability of an unwanted event is reduced by increasing the level of knowledge in cooperation with suppliers or experts. While another interviewee, (P_M), stated that when handling uncertainty, one tries to unify the understanding then determine the validity of uncertainty and then seeking to reduce it. These approached falls into a strategy that increased competency and knowledge and thereby reducing the probability of unwanted events.

It is also of interest to mention that two of the interview subjects, (P_P and P_O), claimed that one of the methods of handling uncertainty is through manageability and the creation of action plans to reduce any imposed uncertainty. Manageability may be applied to any uncertainty level. This also includes handling rare events. This view is substantiated by another interview subject, (P_S), with an economics background, which claimed that reduction of uncertainty of rare events may not be value-adding. He said further that it is better to create plans to be able to handle them if it occurs. It may be expensive to have Covid-19 reduction measures implemented for all future events. According to one of the interviewees, (P_S), it may be in some cases better to create a more resilient system able to handle rare events than trying to reduce the uncertainty. This view is backed up by (P_O) which claimed that it is wise to add resilience towards forces outside of your control.

There is as mentioned a general trend that the uncertainty must be reduced. However, there is a slight time-dependent difference in attitudes towards uncertainty not so much along the lines of background but more along the line company and client. In general, there is no interest among the interview subjects (11 out of 13) to increase uncertainty and thereby seeking new options. However, two of the interview subjects, (P_U and P_D), that works for the client said that during the initial stages of a project it is to some extent desirable to have some uncertainty and explore new options. This is illustrated in Figure 4-2. The attitude towards uncertainty changes over time.

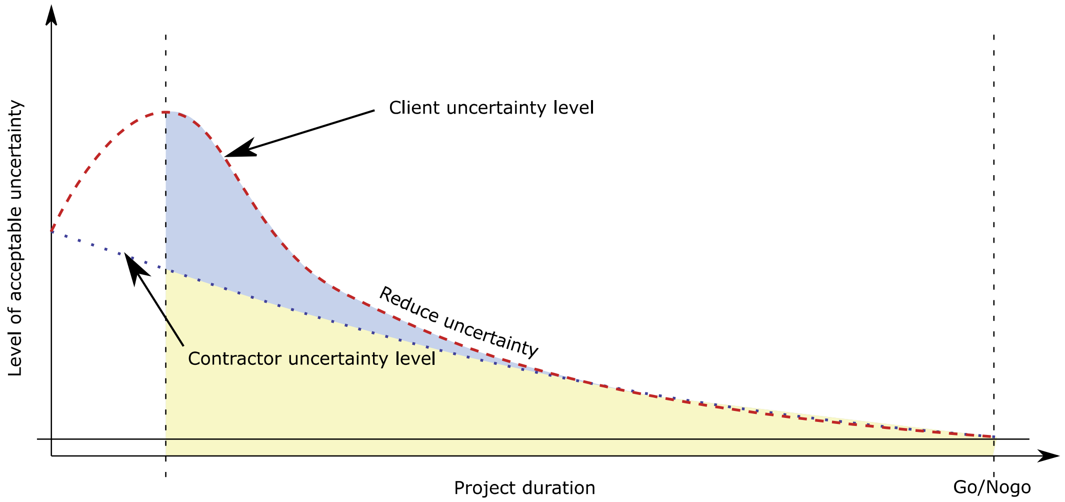


FIGURE 4-2: HANDLING UNCERTAINTY ATTITUDE

Chapter 5. DISCUSSION

The discussion that follows will discuss the results in further detail with respect to the different schools of thought. However, first, a section briefly discussing the data gathering and analysis process.

5.1 DATA GATHERING AND ANALYSIS PROCESS

LITERATURE REVIEW

At the onset of research into this thesis, it was assumed that the different schools of thought were along the lines of the profession. Meaning that engineering would be different from economists, risk practitioners, and social science. This, however, has not been the case. Through the study, the engineering and technical studies schools of thought were quite similar to the subjective expected utility theory, and joining these two together initially may have been wise.

SEMI-STRUCTURED INTERVIEW

In order to investigate the research question the method of grounded theory with the use of semi-structured interviews as a data-gathering method. This was done because of time and resource constraints. In order to ensure that as many aspects as possible are covered the number of interview subjects should be between 15-20. The final number of interviewees was 13. This is on the low side and should ideally be higher. However, due to the current Covid-19 situation, the number of relevant interview subjects did not exist. The interview subjects do at least provide a relevant cross-section of the persons typically attending a HAZID or HAZOP type risk assessment. Of the 13 interview subjects, 6 were engineers, 2 were economists, 3 were risk educated and 2 had other backgrounds which are considered to be more in line with subjective expected utility (manual labour and public administration). From the numbers presented above, it may be argued that except for the group engineers the number is too low to be able to draw any conclusion and it is to a certain degree hard to disagree with this.

The interviews were performed through the semi-structured interview process. The interview subjects are then freer to answers as they see best and the question which as provided in Appendix 2 is more a guideline than actual questions. Due to this freedom for the interview subjects to answer as he or she sees most appropriate, it was difficult to ensure that each interview had the same format without leading the subject too much. This was especially true for some of the interview subjects where the concepts of among other things frequentist and subjective probability were new. This made the information provided to the interview subjects slightly different every time. The issue was exacerbated further by the lack of experience on the behalf of the interviewer. With increasing experience, this became less of an issue however, the interviewer was never really comfortable with the interview process. The initial idea was to record all interviews however, surprisingly few of the interview subjects agreed to this. This resulted in having to take detailed notes while trying to keep the interview subject on topic. The dual-task has without a question resulted in a loss of some of the comments made. The skill of interviewing has become evident to the author. The fact that all the interview subjects are Norwegians has made the interviewing easier.

DATA ANALYSIS

To ensure that as few biases as possible were transferred from one interview session to another all the interviews were performed before the content analysis began. This is not to say that interview biases can be neglected. Issues like re-phrasing of the questions because initial bad phrasing and interview subjects requesting additional information before answering did occur. The analysis was performed with an open code as exemplified in Table 3-1 with axial coding closely in line with the questions asked. The seven axial coding categories were *uncertainty understanding*, *uncertainty description, uncertainty guideline*, *handling uncertainty*, *rare event consideration and knowledge dimension*, *modelling and estimating uncertainty,* and *miscommunication and worsening of event*. Based on the results provided along the axial codes above and the discussion below it hopefully will be possible to draw a conclusion on the overarching research question.

QUALITY CONTROL

The quality control of grounded research is divided into four pieces *Credibility*, *Transferability*, *Dependability,* and *Confirmability*.

The *credibility* of the research is ensured by prolonged interviews with the intent of having interviews lasting 45-60 min. However, the duration lasted from the shortest being about 30 minutes from start to finish and 90 minutes for the longest. The interview lasting 90 minutes was ended due to the interview subject having to attend another meeting. By that time all the questions had been answered and that the interviewee was knowledgeable about the subject and could have continued. While for the shortest 30-minute interview the interview subject had no further comments or thoughts on the matter. It is therefore believed that the essence of the interview subject's understanding has been captured. Once all the interviews were performed is was assessed against the concepts provided by the different schools of thought. Initially, it was not considered beneficial to perform field studies such as participating in HAZID and HAZOP risk assessments. However, having analysed the interviews and reflected on it, it may have been interesting to perform some field observations and question the interview subjects directly during the assessment if allowed or directly after assessment ended. This, however, would be subject to further study.

The *transferability* in this research is hard to comment on without having discussed this with persons in other fields. However, it may be imagined that it could be relevant for all teams consisting of multidisciplinary and multi background personnel.

The *dependability* over time may to some extent be considered quite good in this research. A team will most likely have some variations in the build-up and the schools of thought might be different, but the basic conclusion and recommendation would be the same.

The *confirmability* is difficult for a single researcher to evaluate by himself. The results are quite in-line with the different schools of thought which increases the confirmability.

ETHICAL ISSUES

From an ethical perspective, there were not that many issues. The major areas of concern were *privacy, confidentiality,* and *informed consent*. To ensure *privacy* the interview subjects are anonymous throughout the coding system described in section 3.3. The link between the names and information provided is only kept in a single spreadsheet that will be deleted upon submission of the thesis. Since all interviews were performed in Norwegian and the notes translated during the transcription the *confidentiality* is ensured by not providing any quotes. There is, however, at times through the thesis it felt necessary to describe the background of the person making a claim, and based on this information it could be possible to determine how this is. In order to ensure *informed consent,* the interview subject was made aware of their rights through a consent form that was issued prior to the interview. It is not known to what degree this was actually read as very few of them were send back to the author with a signature. However, the interview subjects were informed of their rights and the purpose of the interview during the initial stages of the interview.

5.2 Interview Response

The interview results presented in Chapter 4 will be discussed below.

5.2.1 Uncertainty Understanding

From the results of the interviews presented in section 4.1, it may be concluded that there is a difference in uncertainty understanding and measure in the team interviewed and that this could also be the case for other teams. It is however not surprising that there are differences in understanding and measure of uncertainty within a team because as mentioned in section 2.1 on Smithson's definition of uncertainty an individual may not be consistent with oneself over time. The difference in understanding and measure is made even more substantial considering that a group of people with different backgrounds are made to discuss hazardous events during typical HAZID and HAZOP risk assessments.

The alignment within the interviewed team when it came to uncertainty understanding was quite good, almost as good as can be expected. This uniformity could be due to the fact that all interview subjects were Norwegians with the common basic education and societal and cultural understanding this entails. Such a good alignment may not have been the case had the team more multi-cultural.

It may be argued that when team members gather with the different background they come as complete persons which also includes an understanding and measure of uncertainty that may not be compatible with other team members. This aspect should at least be considered by the risk assessment facilitator and aligned as much as possible. During the early stages of HAZID and HAZOP risk assessments there is often a very brief introduction of the persons attending stating typically name, age, education, and area of responsibility. This brief introduction is more intended to get to know the other participants on a more personal level, not necessarily to better understand the background for the individual's uncertainty understanding. However, it may be used to at least get a feeling with other participant's views.

An aspect that should be mentioned is that an individual's understanding of uncertainty is coloured by his knowledge and attitude to uncertainty. An individual may be averse while another might be venturous. it is difficult to imagine that these two personalities would provide similar probabilities for an unwanted event. This difference in attitude might be difficult to align, but an attempt should at least be made to understand the background for their statement.

5.2.2 Uncertainty Description

As mentioned above there is considerable potential that within a team there will be differences in understanding and measure of uncertainty. This difference may be aggravated further by different team members describe probability differently. From the results presented in section 4.2, it may be evident that with the diverse setup of team members attending HAZID and HAZOP type risk assessments that there will be differences in the underlying description of probability. The differences range from economists using almost solely frequentist provided (expected utility theory), engineers, and social science using almost solely subjective probability. With risk practitioners spanning the entire range as illustrated in Figure 5-1. Some of the interview subjects replied that interval probabilities were used. However, all of these were engineers and how the interval probability is applied in the $risk = consequence \cdot probability$ description is unclear. The implementation may be through a predetermined calculation in the background producing a single value. This calculation would be highly subjective, and it can be argued that it might be better to predict a subjective probability directly. However, the relevant interview subjects did not provide sufficient information to understand the inner workings and will hence not be discussed any further. The clash in the description may be illustrated by an example. If during a risk assessment a probability for an event is set to let say 0.15 by a random team member. Without any further discussion, the engineer and non-technical members may understand this as a purely subjective probability provided by the assessor while an economist may assume that it is based on historical data. Thinking that the provided probability is based on historical data may put greater confidence in the number then what it should have. From a risk theory perspective, this becomes more confusing at the theory allows for both subjective and frequentist probability. This misalignment in uncertainty description may be to a certain extent be mitigated by providing information on one's origin.

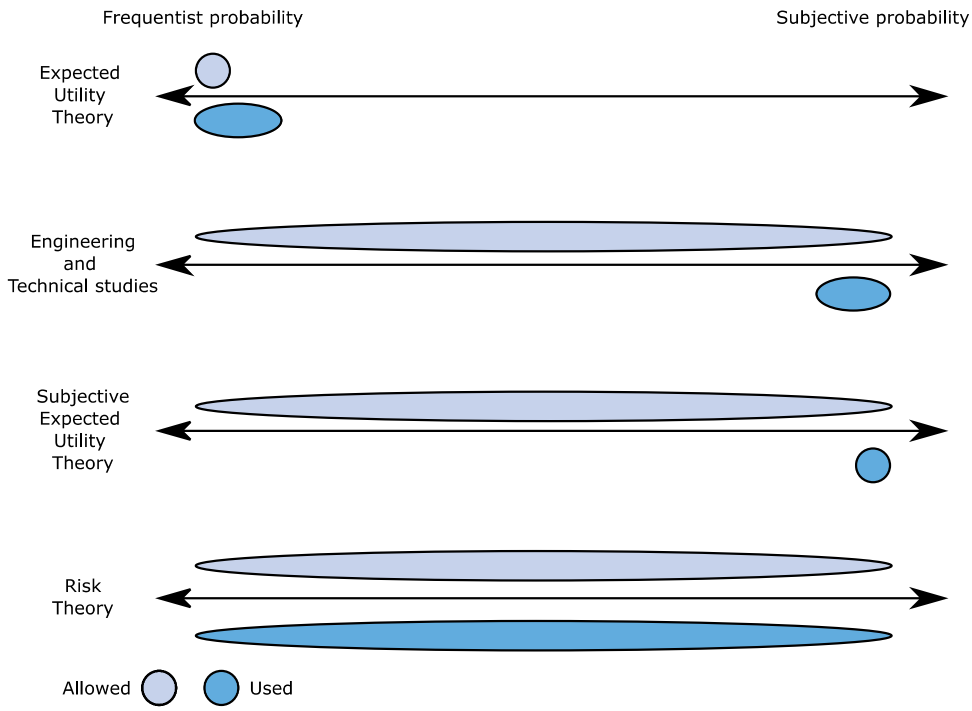


FIGURE 5-1: UNCERTAINTY DESCRIPTIONS USED

At the onset of the interview, all participants answered that they use subjective probability. However, during further questioning, economists almost exclusively use frequentist probability, with only minor modifications when required. The same argument was made by some of the senior engineers, they modified frequentist probability to better suite relevant situation. This may indicate a difference in understanding of what constitutes a subjective probability is also subjective. A slight modification to a frequentist probability may to some still be a frequentist probability while to others this would make it subjective.

Some of the interview subjects said that it is usually only a few of the team members in HAZID and HAZOP risk assessments contribute to the actual probability setting. The "heavy" involvement of these few team members may be interpreted by the rest of the team as these persons have the greatest knowledge of the event at hand and should, therefore, be allowed to discuss in peace. However, this may not be the case. It may be that these are the most comfortable expressing their opinion in public. This was mentioned by one of the interview subjects with 40 years of relevant experience i.e. considerable knowledge, however, he was not comfortable expressing his opinion in public.

5.2.3 MODELLING AND ESTIMATING UNCERTAINTY

When trying to model and estimate a probability from historical data the data may be provided in the form of among others a frequentist probability or a probability distribution. If a distribution is used the desired value can be estimated from this distribution the estimation is fairly simple. However, this may not always be the case. Sometime the final probability may be a combination of several distributions. A Monte Carlo simulation would then be required to calculate or estimate the probability. The issue comes when there is limited or no historical data available to create a distribution. According to (P_P) it is then common to assume a distribution. If there is absolutely no data available and there is no "feeling" about the distribution a uniform distribution may be used. In such a distribution all outcomes have the same probability, throwing of a single die is an example. However, according to (P_P) it is more common to use a triangular distribution because there are some data or feeling on the distribution even though the data is incomplete. The process of assuming a distribution will at least to a certain extent make the final probability subjective. Assuming an incorrect distribution may have an impact on the final probability distribution. Sensitivity checks may be performed to determine how sensitive the final probability distribution is to changes in the assumed distribution. This may be used to determine the subjectivity of the probability estimation. Another point which is more subjective is the extraction of the probability to be used or presented, should the “best-estimate”, “most likely” or a percentile be used. The selection of probability may be stated in standard however if not the selection is highly subjective. A benefit of the Monte Carlo simulation is that is can be quite easily be recreated however, it may be time demanding. The overall method and processes for modelling and estimating probability are established for frequentist probabilities. Monte Carlo simulations it is not used during HAZID and HAZOP risk assessments unless already executed. This also applies to the estimation of frequentist probability, unless already calculated it is difficult to use during HAZID and HAZOP type risk assessments.

In contrast to the frequentist probability the subjective probability, does not have an agreed-upon model to estimate probability. The subjective probability may be compared against an external model such as the urn standard. However, as noted in section 4.4.2 none of the interview subjects said that they compared their subjective probability. The only comparison made is through some guidewords and questions like “Has this occurred in the industry before? If yes how often?”. This is first a screening for the potential of event followed by a probability estimation. The inclusion and evaluation of rare black swan events may be difficult using this method. The lack of comparing the estimated subjective probability to an external model makes it more difficult for the other risk assessment team members to personally understand and assess the probability provided. Also, the lack of an external probability standard makes it more difficult to reproduce the risk assessment if required. Due to the fairly quick estimation process of subjective probability and the “all things considered” ability it is widely used during HAZID and HAZOP risk assessments. It should be noted that the goal is not to estimate an as accurate probability as possible at all costs. According to one of the interview subjects, (P_P), that claimed that events are not made worse by assigning incorrect probability. It is the events not though of that is dangerous. He stated further that the goal in HAZID and HAZOP type risk assessments is to establish a ballpark figure of the subjective probability and then reduce it. Trying to establish a subjective probability at all costs may be counterproductive. Further assessment should then be performed. This is corroborated by another interviewee, (P_E), which claimed that it is not the probability in itself that is important, but the discussion it creates.

5.2.4 Rare Event Consideration and Knowledge dimension

According to the interview subjects, the incorporation of rare events and the incorporation of the knowledge dimension into HAZID and HAZOP type risk assessments is very difficult. This is consistent among all the different schools of thought. It may be argued that only the risk theory is capable of taking this into consideration.

ENGINEERING AND TECHNICAL STUDIES

Coming from an engineering and technical side the use of either frequentist or subjective probability is quite liberal. However, frequentist probability does not easily allow for rare events. Subjective probability allows for the consideration of future rare events as long as the risk assessment team has the imagination to consider these events. The probability of a rare event is very low (close to zero) resulting in that it may in many cases be disregarded automatically. In order to not “automatically” disregard rare events a “buffer” is sometimes added to the probability. This will make the rare event appear more probable then it actually is. The real issue is that the school of thought does not allow for any additional assessment outside $Risk = Probability \cdot Consequence$. This difficulty is expressed by the interview subjects.

The inclusion of knowledge is generally not performed as the knowledge cannot be easily be taken into consideration in probability. Either the knowledge being in connection with frequentist probability and its distributions or strength-of-knowledge assessment for subjective probability this information must be addressed in supporting documentation. This may be done, however, the only criterion for decision making is a high risk with respect to $Risk = Probability \cdot Consequence$. Low risk with a weak strength-of-knowledge may be disregarded when it if fact could be high risk. The evaluation cannot be done due to the missing managerial review and judgment stage in Figure 2-9. This difficulty is confirmed by the interview subjects.

SUBJECTIVE EXPECTED UTILITY THEORY

The inclusion of rare events and knowledge for subjective expected utility theory is similar to the above arguments for engineering and technical studies. The low subjective probability may lead to an automatic decision to neglect the event. A relevant interview subject, (P_M), made a comment which may apply to all fields, it is important to continuously seek rare events and do not disregard previous rare events due to infrequent occurrence.

The inclusion of the knowledge dimension has the same issues as the engineering and technical studies school of thought. Unless it is assessed and taken into consideration separately, which the subjective expected utility theory does not allow for, there is no good method for the inclusion of knowledge.

EXPECTED UTILITY THEORY

The incorporation of rare events in the expected utility theory is different from the two abovementioned schools of thought due to the probability being almost solely derived from statistical frequentist data. Rare events are in general therefore not really considered. This is confirmed by one of the interview subjects which states that the current Covid-19 situation is not taken into consideration. Despite the fact that a global pandemic is not a rare event. It is only 10 years since the last potential pandemic (Swine flu) and 100 years since the last pandemic (Spanish flu). Due to the rarity, the frequentist probability of such events is close to zero. Rare events may also invalidate the models used to estimate probability as some models are constructed to reflect the "normal" world. With a changing world the model may no longer be valid, and probabilities provide by models are not trustworthy. According to one of the interview subjects, (P_R), a final subjective probability assessment is performed to be able to "modify" the frequentist probability and if desirable take into account rare events. This final modification of probability moves the expected utility theory more in the direction of subjective expected utility theory. The modification of frequentist probability is along with a fully subjective probability the only method for considering rare events. Another option is knowingly ignoring all rare events.

When it comes to the inclusion of knowledge in the probability provided both relevant interview subjects (P_R and P_S) said that it is not included. (P_R) claimed that it is difficult to put a number on the knowledge and how to incorporate it. There is no difference in the single probability value provided for a scenario where there is limited information and a case where there is considerable information. Only through additional documentation can the knowledge dimension be presented. The decision-making process in expected utility theory illustrated in Figure 2-6 shows no evaluation of knowledge. The decision analysis leads directly to a decision.

RISK THEORY

In contrast to the abovementioned schools of thought, it is one of the benefits of risk theory that it does not provide an "automatic" recommendation from the decision analysis to the decision-makers. This is ensured by the introduction of an additional stage of "managerial review and judgment" as shown in Figure 2-12. During this stage, it is possible to include rare events in the risk assessment that may be beyond the scope of the assessment or a rare event not originally considered due to low probability. Even though this allows for the inclusion of rare events the issue of having the imagination to find them persists. However, none of the risk practitioners, (P_E, P_S, and P_U), said that they use the risk theory to its full potential.

Through the step of "managerial review and judgment" the knowledge upon which the subjective probability is based may be assessed through a strength-of-knowledge assessment as described in section 2.5. An assessment of the strength-of-knowledge may be presented to the decisionmakers for a complete review before making a decision as shown in Figure 2-12. This allows the decisionmakers to know which event and probability to place the most trust and to have the ability to trace the subjective probability. The interview subject, (P_E), mentioned strength-of-knowledge in his interview, however, he said that it is not assessed or presented during typical HAZID and HAZOP risk assessments.

5.2.5 Dealing with Uncertainty

Having established that there are different methods for understanding and describing uncertainty, how can uncertainty be dealt with. This will be discussed in the section below.

HANDLING

The attitude among the interview subjects goes along the lines of *reduce*, *tolerate,* and *relinquish or denial*. The general trend is to reduce uncertainty as much as possible, followed by tolerate by creating plans and manage uncertainty. The final stage is to determine to continue with the measures in place or to stop.

For the reduction stage, there are several suggestions, however, the general trend is that gathering and increasing the amount of information is the most common approach. The gathering of more information may take on different meanings depending on which school of thought one uses. For an individual using only frequentist probability i.e. expected utility theory, additional information may only validate or reduce uncertainty of the already existing belief and further information may not detect rare events. While for an individual using subjective probability, additional information may put more confidence in the probability provided and also possibly detect rare events. This difference in the method of handling uncertainty may cause some conflict during HAZID and HAZOP risk assessments. However, none of the interview subjects stated that there were disagreements during HAZID and HAZOP risk assessments on the purpose of uncertainty reduction.

By having a common physical understanding of the context during HAZID and HAZOP risk assessments the probability expressed may be more easily understood.

Gathering information also involves sharing information creating a cycle of information gathering and sharing. One of the interview subjects said that it is more and more common to use visualisations and simulations to ensure that all participants have the same understanding. Some of the interview subjects state that uncertainty is reduced through the ALARP principle. The ALARP principle states that a safety measure shall be implemented unless the cost of implementation grossly outweighs the gains. The principle constantly compares the cost of implementing the risk reducing measure with not implementing it. It allows for a sliding perspective with the two extremes an extreme safety perspective or an extreme economic perspective and something in between [34]. The selection of perspective was not discussed by any of the interview subjects. Some of the interview subjects mentioned manageability as a handling technique. However, limited information was provided on the exact setup and execution of such a plan. Further discussion on this topic is difficult.

When it comes to attitude to uncertainty there is as mentioned a difference along the line of client and contractor. There might be interest among the clients to spend time and money on exploring new options and therefore at times increase uncertainty. This may be due to acknowledgment that in order to be competitive in the future one needs to constantly develop and improve. In order to improve new options needs to be explored. This attitude should also be shared with the contractor, however, with tight finances, it is understandable that performing potential non-adding value activities for free is not attractive. The expectation from the client towards the acceptance of "crazy" ideas should be provided. The concept of exploring new ideas and learning sort of falls into the same category. One of the interview subjects, (P_U), stated that among the highly educated team members there is a tendency for something called "fixed mindset" where there is a reluctance to learn. These individuals are less interested in looking for new options, increasing their skill-level, and thereby, in the long run, reducing uncertainty. According to this individual, this is a considerable issue when it comes to the reduction of unwanted events. He continues by claiming that only by learning from one's mistakes and trying new approaches can the company survive.

MISCOMMUNICATION AND WORSENING OF EVENT

According to most of the interview subjects, there are in many cases miscommunication when discussing uncertainty in general. It is logical to also assume that this miscommunication may also occur when discussing uncertainty during HAZID and HAZOP type risk assessments. The reason for this may be varied as discussed above. Having a guideline on how to discuss uncertainty may be useful. Such a general company or project guideline may allow for better inter-team understanding, and also improve uncertainty communication and improves on bad semantics. It may, however, be difficult to determine the effectiveness of aligning the uncertainty understanding and description with respect to reducing the likelihood of unwanted events. According to the interview subjects, it is difficult to say that unwanted events were made worse due to different uncertainty understandings. When a serious unwanted event occurs, failure has occurred on many levels. It is therefore not known whether or not an alignment of the different concepts among team members would help. However, it is difficult to argue that it is negative.

UNCERTAINTY GUIDELINE

The interviewees' reply to the existence of an uncertainty guideline is difficult to interpret. All of the interview subjects stated that none of the four relevant companies have established general guidelines on how to understand and describe uncertainty. This is also stated by the three risk practitioners who should be aware of the existence of such guidelines. The upper management of one of the companies states that they use a guideline to ensure alignment between assessors. A similar guideline could be considered for a company or a project to ensure alignment in risk assessment. The desire for guidance was mentioned explicitly by one of the interview subjects.

In typical HAZID and HAZOP risk assessments, the team members are typically from several companies. Trying to align the understanding across all the different companies may be difficult. However, on a project level, this may be possible. The implementation of a project-specific guideline on the concepts of uncertainty, how to understand and measure uncertainty, describe uncertainty, how to take into consideration rare events, how to deal with uncertainty at different times, etc. would be considered beneficial to align team members, avoid confusion and align expectation.

Chapter 6. CONCLUSION

In this thesis, it has been attempted to put some light on and try to answer the following research question "*How variations in uncertainty understanding and uncertainty description affect how uncertainty is handled within a team?*". The research question has been addressed by performing grounded research. Grounded research was selected due to the lack of available previous work on the subject. The work consisted of looking into relevant schools of thought followed by multiple prolonged semi-structured interviews. Relevant schools of thought have been selected based on an assessment of typical members present in technical HAZID and HAZOP risk assessments. Typical technical HAZID and HAZOP attendants are engineers, economists, risk practitioners, and others. The selected relevant school of thought are engineering and technical studies, risk theory, expected utility theory, and subjective expected utility theory for the "others" category. The in-depth semi-structured interviews were used to triangulate the results ensuring quality. The interviews were performed on a cross-section of a team having performed HAZID and HAZOP risk assessments. The cross-section of the team consisted of 6 engineers, 2 economists, 3 risk practitioners, and 2 other falling into the subjective expected utility category, 13 persons in total. The number of interview subjects in each category is a result of available interview subjects and not a proportional fraction of attending within each category during a risk assessment.

From the literature review, it is evident that there might be various understanding of uncertainty within a team due to the different backgrounds of the individuals. It is also possible for an individual to have a changing and at times conflicting understandings of uncertainty. It may, therefore, in a sense, to be expected that none of the interview subjects have the same understanding. It was therefore surprising that the interview subjects were quite consistent and uniform in their response. The reason for this alignment may be due to the fairly uniform upbringing, basic education, and cultural understanding since they were all Norwegians. All but one of the interview subjects replied that they understand and measure uncertainty through probability. Despite there being others, probability is the most frequently used measure. The one individual not always willing to use probability said that his use of uncertainty measure depends upon the context it is used. The use of other than probability as an uncertainty measure is allowed in a more general social science understanding. Based on the background of this individual he is considered to be a part of the subjective expected utility theory group were other measures than probability is not permissible. The "other than probability" description is considered an anomaly and disregarded. All the other interview subjects replied probability which is allowed for all the different schools of thought. Within HAZID and HAZOP type risk assessments, it is definitely a benefit that the different team members have the same uncertainty understanding.

Despite there being relative consistency on the understanding and measure of uncertainty this is not the case for the description of uncertainty. Depending on the school of thought some descriptions of uncertainty mentioned in section 2.4 may not be used. The greatest limitation is put on the expected utility theory which only allows for the use of frequentist probability. While all the other schools of thought i.e. subjective expected utility theory, engineering and technical studies, and risk theory, allows for the use of frequentist as well as subjective probability. The interview subjects replied that all of them use subjective probability, even the interview subjects using the expected utility theory. This means that there is some violation of basic principles. However, upon further questioning, the answers fell more in-line with the respective schools of thought. Both practitioners of expected utility theory say that they use primarily frequentist probability however occasionally use frequentist probability as a basis which is modified to better suit the assessor's belief effectively making it a subjective probability. This modification undermines the *expected utility theory* which in principle moves it in the direction of *subjective expected utility theory* were subjective as well as frequentist probability is allowed. The other schools of thought allow for the use of subjective as well as frequentist probability. Some of the interview subjects claimed to use interval probability, however, the actual implementation of this is hard to determine. The probability is taken into consideration as a single number for all schools of thought except for *risk theory*. The conversion from a probability interval of say 10%-30% to a single number probability is difficult and none of the interview subjects provided a solid rationale on this topic. None of the interview subjects claimed to use the more exotic uncertainty descriptions such as logical-, imprecise-, and propensity probabilities. This was to a certain degree expected.

One of the benefits of using frequentist probability based on statistics is that the methods used for deriving and estimating the final frequentist probability are well established. The process may be complicated and time-consuming like performing a Monte Carlo simulation where a series of distributions are combined into one, but it is known. An issue with the Monte Carlo simulations is that sometimes it might be required to assume a distribution. This assumed distribution makes the final estimated frequentist probability to a certain extent subjective. Several relevant interview subjects confirm that this approach is widely used when estimating frequentist probability. However, performing a Monte Carlo simulation during HAZID and HAZOP type risk assessment is impractical due to time constraints. Monte Carlo simulations will therefore not be used during these assessments only the presentation of results from already executed simulations. The same can be said for frequentist probability calculations based on statistics. During HAZID and HAZOP type risk assessments, subjective probability is the preferred uncertainty description. When assigning a subjective probability there are methods for making the subjective probability more "objective" such as comparing it to an external model such as the betting approach or urn standard. None of the interview subjects claimed that external validation is performed. Comparing the subjective probability to an external standard might make the assigned probability easier to understand.

The inclusion and consideration of rare events are one of the areas where there is a considerable difference between the different schools of thought. Schools of thought using frequentist probability only (i.e. expected utility theory) cannot include rare events because either there is no data or the frequentist probability is too low for it to be considered. This is confirmed by the main users of frequentist probability. Practitioners of *expected utility theory* have a hard time including events with low probability even with historical data. Covid-19 was mentioned as an example, this was not taken into consideration despite there being historical relevant data such as the 2009 Swine flu and the 1918 Spanish flu. Subjective probability, on the other hand, is based on the assessor's belief and therefore allows for the inclusion of rare events with limited or even no data. Most of the interview subjects say that rare event consideration is difficult and improvements on detection and implementation are desirable. The general consensus is that there is not enough imagination for rare events and of what can go wrong. A rare event can only be implemented if it is identified. The detection of rare events during HAZID and HAZOP type risk assessments is therefore important. The detection and proper implementation are difficult for most schools of thought, i.e *expected utility theory*, *subjective expected utility theory,* and *engineering and technical studies*, as the decision analysis leads directly to a decision. For these schools of thought, the frequentist probability estimated, or subjective probability assigned is one of the major drivers on what is considered important. This means that rare low probability large consequence events are neglected due to their "rareness". This, on the other hand, is not an issue with *risk theory* which may implement measures against rare events through the *managerial review and judgment* stage regardless of assigned probability level. However, none of the risk theory practitioners claimed to use this additional step. During HAZID and HAZOP type risk assessments unless there is a conscious choice to further evaluate the rare events many of them may be ignored.

The inclusion of knowledge upon which the probability is based may be important. For frequentist probability, the knowledge may be easily found because it is based on established principles in statistic i.e. the frequentist probability may be reproduced if desired. However, for subjective probability, there is no method for deducing the probability assigned since the probability is based on the assessor's knowledge. An evaluation of the assessor's background knowledge known as strength-of-knowledge assessment may be performed to determine the level of knowledge the assessor's have on the question at hand. This assessment also enables to a degree the possibility to deduce the subjective probability if desired. However, only the *risk theory* schools of thought take the knowledge dimension into consideration through the *managerial review and judgment* step. The other schools of thought ignore this dimension. When the interview subjects were asked how they take into consideration the knowledge dimension all of them said that it was not taken into consideration. They said that it is difficult to include it in a single number for probability. Some of the interview subjects said that for events with limited knowledge a "buffer" on the subjective probability may be used. The "inflated" probability does not provide a realistic perspective on the likelihood of an event or of the knowledge of the situation at hand. Neither of the risk practitioners mentioned taking the knowledge into consideration. During HAZID and HAZOP type risk assessments the knowledge dimension is not considered by any of the schools of thought.

According to most of the interview subjects, there are definitely miscommunications when discussing uncertainty. The reason may be due to the different concepts used by the different schools of thought where some are mentioned above. However, it may also be bad semantics on the part of the speaker. Whether or not this miscommunication results in more severe events is difficult to categorically answer since when an unwanted event occurs a series of failures have occurred and tracing it back to a difference in understanding of uncertainty concepts is difficult. This was confirmed by all the interview subjects. Avoiding miscommunication during HAZID and HAZOP type risk assessments must be dealt with from several angles. However, a dictionary with definitions may be useful.

The attitude and handling of uncertainty do imply some sort of future action. From the literature review, the most common methods for handling uncertainty go along the lines of *reduce, tolerate,* and *denial or accept*. These methods were to an extend reflected by all the interview subjects regardless of background. The majority of interview subjects ranked it as follows; reduce as much as possible, when further reduction is not possible then create plans for managing the remaining uncertainty followed by denial or go/nogo. This stepwise process of handling uncertainty may not be the complete picture. Some had the attitude that at times it would be beneficial to have some uncertainty to explore new options. When the new option was explored and considered then the stepwise procedure was applied. This attitude was not so much along the lines of background, but more along client and contractor. The client may be willing to accept a greater amount of uncertainty at times to explore new options. To avoid confusion during HAZID and HAZOP risk assessments it should therefore explicitly express what the desired action is.

Several suggestions were presented on how to reduce uncertainty, however, most said gather more information. The acquisition of additional information may take on different meanings depending on which school of thought one uses. The gathering of information may be pointless for individuals using frequentist probability i.e. expected utility theory. Further information for them may be gathered through further experiments; however, these will most likely only validate already existing information. The information may only slightly move the estimated frequentist probability. Information on rare events may not be gathered as they would most likely not occur during the additional experiments. The gathering of further information when utilising subjective probability may, on the other hand, be very useful as it strengthens the background knowledge putting more confidence in the subjective probability assigned. There is also the possibility that additional information uncovers rare events. Despite the potential conflict in the value of additional information none of the interview subjects state that new information is not sought. This also reflects the author's belief that more information and knowledge is better. Knowing and then ignoring is better than ignoring it without knowing. The sharing of information may also be viewed as a method for gathering information. It is therefore considered important that participants share their knowledge during HAZID and HAZOP risk assessments. There is currently a drive to reduce uncertainty by ensuring that the team members have the same physical understanding by increased use of visualisation techniques such as augmented reality simulations.

Despite there being a fairly consistent understanding and the description of uncertainty is within the school of thought this is not due to the company having a guideline on how to understand these concepts. None of the interview subjects claimed that their company has a guideline on this topic. Even the risk practitioners which should have known if one existed did not know. This may indicate that none of the four companies represented have a general company guideline on how uncertainty concepts. The fact that it seems like no company has a company-specific guideline on how to understand uncertainty may be utilised. A project-specific guideline may then be created to align the concepts of uncertainty, how to understand and measure uncertainty, describe uncertainty, how to take into consideration rare events, how to deal with uncertainty at different times, etc. A guideline may be beneficial to avoid confusion, miscommunication, and to align expectations, and ultimately may also avoid rare unwanted events. A guideline may also aid individuals looking at the risk assessment after the fact. The establishment of such a guideline is the result of the grounded theory of this research.

Chapter 7. FURTHER WORK

Through the work in this thesis, some areas which are of interest. However, is outside of the scope of this thesis, but should be mentioned for further work. These fall into three categories, field observation, multi-cultural teams, and bad semantics.

The work performed in this thesis focus on a literature review with a series of semi-structured interviews. No field observations were made during actual HAZID and HAZOP risk assessments. It would be interesting to observe how such a risk assessment was performed and if possible question the risk assessment team members directly during an assessment.

The cross-section of the team interviewed through this assessment were all Norwegians. The literature review pointed out that different cultures have different understandings of uncertainty. It would be interesting to perform the same study, but with a more multi-cultural team selected deliberately.

Another area that was not investigated was the area of bad semantics. During HAZID and HAZOP type risk assessments, the background of individuals attending is varied with different ways of expressing themselves. They may not be completely comfortable using certain words etc. this effect would be exacerbated if the discussion were performed in a non-native language. It would be interesting to look further into the effects of bad language both with native and non-native teams.

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APPENDIX 1. INTERVIEWEE PARTICIPATION FORM

I hereby invite you to participate in an interview session in relation to my master thesis within the field of risk management on the topic of different understandings and interpretation on uncertainty. The purpose of the investigation is to look into undeclared and inconsistent differences in understanding and interpretation of uncertainty within a team. The research question of this study is *how do variations in uncertainty understanding and uncertainty description affect risk perception within a team*.

The topic is investigated through a qualitative research method by performing a literature review of the most relevant theories with semi-structured interviews of key team members. The interview subjects will consist of 15-20 team members within different companies, backgrounds and age.

The interviews will be conducted face to face whenever possible and based on prepared questions will take about 45-60 minutes and preferably in one sitting. The interview will be recorded, and notes taken to ensure all relevant data are captured. The capture of data is essential to analysis processing. Interview and data collected will be strictly confidential for all except researcher. Upon completion of project all data that can be traced back to interview subject will be deleted.

It is important to emphasis that participation is strictly voluntary, and no monetary or other services will be exchanged. The interviewee may at any time without withdraw from the enquiry with repercussion. If there are any questions or further information is needed please contact Svein Bratseth at +47 41215958 or at sveinbratseth@gmail.com, or supervisor at University of Stavanger Professor Frederic Emmanuel Bouder at Frederic.bouder@uis.no.

If you are willing to participate in the study please revert document with a signature. Upon request question may be provided head of interview.

Name	
Date:	Signature:

APPENDIX 2. INTERVIEW QUESTIONS

English version

Opening part (open ended questions)

1. State education and professional background, position within team and company, main tasks and how long you have been with the company?
2. Describe through the use of an example who you understand and describe uncertainty?
3. Describe how your company understand and describe uncertainty?
4. Have you experienced misunderstandings or loss of communication when discussing uncertainty?
5. Can you mention a serious situation that may be contributed to different uncertainty understandings and descriptions? If so what where the consequences.
6. How do you and your company act when faced with uncertainty?

Middle part (in-depth questions on main topics)

7. Describe to me the model used to estimate uncertainty?
8. How would you quantify the uncertainty used?
9. Describe to me how you take into account rare events?
10. Describe to me how you would quantify the uncertainty of an event you have considerable knowledge about and one with limited knowledge?
11. How do you use uncertainty when making a decision?

Concluding part (final comments and ending the interview)

12. Do you have any thoughts on understanding and description of uncertainty not mentioned during thus interview?

APPENDIX 3. INTERVIEW SUBJECT BACKGROUND AND EXPERIENCE

P_A – Void

P_B – Engineer with a master's in Naval architecture from NTNU. Considerable experience.

P_C – Void

P_D – Engineer with a master's degree in Mechanical engineering at NTH. Extensive experience.

P_E – Risk practitioner with a master's degree in Industrial Economic with focus on risk from UiS.

P_F – Void

P_G – Engineer with a master's in Naval architecture from NTNU.

P_H – Void

P_I – Engineer with a master's in Naval architecture from NTNU.

P_J – Void

P_K – Void

P_L – Manual labour, social science, with extensive experience.

P_M – Social science with a degree in Public administration.

P_N – Void

P_O – Engineer with a master's degree in Offshore engineering from UiS. Considerable experience.

P_P – Risk practitioner with a master's degree in Industrial Economic with focus on risk from UiS. extensive experience

P_Q – Engineer with a master's in Naval architecture from NTNU. Considerable experience.

P_R – Economists with a master's degree in finance. Extensive experience.

P_S – Economists with a master's degree in finance. Considerable experience.

P_T – Void

P_U – Risk practitioner with a background in chemistry and finance. Risk enthusiast. Considerable experience.

Appendix 4. Coding

Coding used presented on the following pages. Interviewee background have been removed to ensure confidentiality.

ID	Key Point	Open Code	Similar to ID	Axial code
P_B_002	Uncertainty is what we are unable to put a specific number on it.	-Uncertainty not able to put number on it		??
P_B_003_01	Use probability to describe uncertainty.	-Described through probability		1p
P_B_003_02	Produces most likely probability based on statistical data.	-Probability based on statistics		2f
P_B_004	There are no concrete guidelines on description and understanding of uncertainty.	-No guideline		3
P_B_005	Definitely misunderstandings between team members due to different backgrounds.	-Misunderstandings -Difference in background		2s
P_B_006	Team members with considerable experience may see the probability more easily.	-Experience gives more correct probability		2s
P_B_007	Difficult to say that an unwanted event has become worse due to different understandings of uncertainty.	-No worsening of event		7
P_B_008_01	Rare events occur as a result of team not thinking it or considering it. Not due to setting incorrect probability.	-Rare event due to lack of imagination		5.1
P_B_008_02	Rare events occur as a result of team not thinking it or considering it. Not due to setting incorrect probability.	-Correct event probability less important		1p/5.1/6
P_B_009	Relatively easy to discuss and agree upon consequences, however, discussing probability is much more difficult.	-Difficult to discuss probability -Subjective probability		2/2s
P_B_010	Often worst-case probability is used in combination with worst-case consequence even though they can not coincide.	-Worst case probability used		2i
P_B_011	Probability is actually conditional probability P(A|B) however, P(A) is commonly used. Probability provided is too high.	-Conditional probability -Subjective probability given is too high		2s
P_B_012	Sometimes worst-case probability is used while sometimes most likely probability is used. Which to use is a subjective call.	-Frequentist probability -Worst-case or most likely case, is subjective matter		2f/2i
P_B_013	Determining the probabilities is often done by the use of agreed upon standards such as DNV, ISO etc.	-Frequentist probability -Based on recognisted standards (DNV, ISO etc.)		2f/6
P_B_014	The probability is reduced in accordance with the ALARP principle.	-Handle uncertainty by reduction in accordance with ALARP		4
P_B_015	"If one does not have control over the uncertainty one does not have control over the risk".	QUOTATION		xx
P_B_016	The aim is to acquire information and reduce uncertainty.	-Increase knowledge -Reduce uncertainty		4
P_B_017	Technical risk assessments based on probabilities provided by other people's experience; this makes it semi subjective.	-Technical risk assessments semi-subjective -Based on personal experiences		2s/2f
P_B_018	Probability of human behaviour is purely subjective.	-Human behaviour purely subjective		2s
P_B_019	Gather people with diverse backgrounds to collectively reduce uncertainty or uncertainty range.	-Meeting to discuss -Diverse background reduce uncertainty		2p/5.2
P_B_020	Probability provided by meeting personnel is highly subjective.	-Team probability subjective		2s
P_B_021	No urn standard is used to evaluate the subjective probability.	-Subjective probability not measured against urn standard		2s/6
P_B_022	During a risk assessment of the HAZID/HAZOP type unwanted events often a result of technical issues. Probability provided is then often reduced by looking at historical data.	-HAZID/HAZOP -Often technical issues -Frequentist probability		2f
P_B_023	Sometimes a probability interval is considered. However, the "worst-case" is then usually presented.	-Imprecise probability -Worst-case often presented		2i
P_B_024	In order to quantify uncertainty Monte Carlo simulations are used. Done through summing a series of statistical distributions based on frequentist data.	-Monte Carlo simulations used -Series of statistical distributions		2f
P_B_025	Analysis based on established standard such as DNV to achieve ALARP.	-Statistical distributions based on estblished standards -ALARP		2f/4/6
P_B_026_01	Rare events are difficult to consider due to no historical data and hence given a low probability.	-Rare events are difficult		5.1
P_B_026_02	Rare events are difficult to consider due to no historical data and hence given a low probability.	-No historical data		5.1
P_B_026_03	Rare events are difficult to consider due to no historical data and hence given a low probability.	-Hence low probability given		2
P_B_027	Technical risk assessments are often focused around components and the component failure rate may be found. It is possible to find frequentist data.	-Technical risk assessment based on component failure -Possible to find frequentist probability		2f
P_B_028	Probability for personnel behaviour is purely subjective.	-Personnel behaviour highly subjective		2s
P_B_029	Historical data may not be representative for the future, Covid-19 is a good example.	-Frequentist probability -Does not look into the future		2f
P_B_030	VOID	VOID	VOID	VOID
P_B_031	It is difficult to include the knowledge dimension in subjective probability.	-Knowledge not included in uncertainty (probability)		5.2
P_B_032	Sometimes an "interval probability" is most appropriate, however, only the "worst-case" probability is presented.	-Imprecise probability -Worst-case probability usually presented		2i
P_B_033	Generally reduce uncertainty or the probability of unwanted events.	-Reduce uncertainty		4
P_B_034	Reduce through the use of ALARP to an acceptable level typically 10^{-4} probability.	-Reduce until acceptable level typically 10^-4 -ALARP		2f/4
P_B_035	Early in a project it might be desirable to evaluate new options and thereby increase uncertainty.	-Seeking uncertinaty early in project -Later reduce		4
P_B_036	A persons background colours what is important. One originating in finance/economics have in general a great deal of historical data to use, making statistics more familiar then what it is to an engineer.	-Background colours what is important		1/2
P_B_037	Reduce probability of an unwanted event by "safe job analysis" (SJA) and "tool box talks" (TBT). These probabilities are very subjective.	-Reduce probability by SJA and TBT		4
P_D_002_01	Uncertainty described through probability. Often subjective probability is used.	-Probability used to describe uncertainty		1p
P_D_002_02	Uncertainty described through probability. Often subjective probability is used.	-Mostly Subjective probability		2s
P_D_003	Frequentist probability is an advantage if available.	-Frequentist probability when available		2f
P_D_004	Subjective probability is quite often put too high.	-Subjective probability too high		2s
P_D_005	There is no company policy on how to understand and describe uncertainty.	-No guideline on uncertainty		3
P_D_006_01	Definitely a difference in peoples understanding of uncertainty. People with considerable experience will have an different probability-perception compared to a freshman.	-Different uncertainty understanding		1p
P_D_006_02	Definitely a difference in peoples understanding of uncertainty. People with considerable experience will have an different probability-perception compared to a freshman.	-Experience = more correct probability		2s
P_D_007	Different backgrounds are important in HAZID/HAZOPs to view different aspects.	-HAZID/HAZOP -Different views important		2s
P_D_008	Difficult to say that an event has been made worse due to differences in probability description.	-Events not made worse		7

1	Uncertainty understanding (1p: probability, 1n: non-prob)
2	Uncertainty description (2f: frequentist, 2s: subjective, 2i: interval)
3	Uncertainty guideline
4	Handle uncertainty
5.1	Rare event consideration
5.2	Knowledge dimension
6	Modeling and estimating uncertainty
7	No worsening of event

P_D_009	Unwanted events are usually a result of lack of imagination of the risk assessment team.	-Unwanted events result of lack of imagination -Black swans		5.1
P_D_010	Unwanted events are then "black swans" to the team.	See item	P_D_009	5.1
P_D_011	When faced with uncertainty reduce the uncertainty as much as possible before a go/no-go decision must be made.	-In general reduce uncertainty as much as possible -Go/no-go point		4
P_D_012	Early in project it may be desirable to search for new opportunities and hence temporarily increase uncertainty.	-Early in project actively seek uncertainty		4
P_D_013	Subjective probability is almost solely used during a HAZID/HAZOP.	-HAZID/HAZOP -Subjective probability		2s
P_D_014	Subjective probability not evaluated against an external model as the urn standard.	-Subjective probability not evaluted against urn standard		2s/6
P_D_015	If frequentist probability is available this is advantageous as it is more objective.	-Frequentist probability beneficial		2f
P_D_016	When trying to quantify the probability the probability is almost always based on personal experience.	-Quantification of probability -Subjective probability -Personal experience		2s
P_D_017	Disagreement among risk assessment team members on the exact probability presented.	-Disagreement on exact subjective probability		2s
P_D_018	"Interval probabilities" is sometimes used as it is easier to agree upon an interval.	-Interval probability		2i
P_D_019	In order to detect rare events guidewords are used. Typically "have anyone experience or heard of this having occurred in the industry before"?	-Rare events -Guidewords used to detect -"Happend before?"		4
P_D_020	A "what-if analysis" is also used to find rare events.	-Rare events -"What-if" analysis		5.1
P_D_021	It is difficult to take into account the range and knowledge of the event in the probability given.	-Difficult to include knowledge in probability		5.2
P_D_022	Subjective probability based on limited knowledge may be some cases be increased to account for this.	-Subjective probability -Limited knowledge -"Buffer" added to probability		5.2
P_D_023	Generally reduce uncertainty, however, at the start of a project some increased uncertainty may be beneficial to increase options.	-Reduce uncertainty -Start of project some uncertainty is good		4
P_D_024	Uncertainty at the right time is beneficial.	-Uncertainty at the correct time beneficial		4
P_E_002	Uncertainty usually described through probability	-Described through probability		1p
P_E_003	Uncertainty may be reduced, however, not eliminated except by not performing the operation.	-Reduce uncertainty if possible.		4
P_E_004	Strength-of-knowledge impacts uncertainty (probability)	-Sok impacts probability		5.2
P_E_005	No official guideline on how to understand and describe uncertainty. However, probability is used.	-No uncertainty guidelines		3
P_E_006	Uncertainty understanding and description not presented.	-No complete uncertainty defintion presented during assessment		2/3
P_E_007	Risk and probability based on experience	-Subjective probability		2s
P_E_008	Different views on risk, however, agreed upon understanding of consequence which means that the probability provided is different and also the understanding.	-Different view on uncertainty/probability		2
P_E_009	Reduce the probability of event as much as possible.	-Reduce probability until acceptance		4
P_E_010	When there are sufficient historical data approved DNV-GL methodologies may be used to estimate a probability of event occurring (frequentist probability).	-Frequentist -Data -Established models		2f/6
P_E_011	When there is limited or no historical data the probability provided is often a judgement call (subjective probability).	-Subjective -No/limited data -Judgement call		2s
P_E_012	Subjective probability not assessed against a model like betting interpretation or urn standard.	-Subjective probability -No model comparison		2s
P_E_013	Time spent on assessing probability is heavily dependent on the consequence, low consequence limited time spent.	-Only potential critical events are analysed		4
P_E_014	Rare events are only really considered if the consequences are sufficiently high.	-Rare events for high consequence events		4
P_E_015	Strength-of-knowledge is not captured in probability number presented.	-SOK no captured		5.2
P_E_016	Probability presented is a group / collective representation where discussion leads to a correct representation of probability.	-Probability provided by team considered correct		2s
P_E_017	Reduce probability of event as much as possible	-Reduce probability until acceptance		4
P_E_018	No interest in exploring new areas only reduce uncertainty / probability	-No interest in new options		4
P_G_002	Uncertainty is based on statistics	-Frequentist probability		2f
P_G_003	In general uncertainty is based on frequentist probability	-Frequentist probability		2f
P_G_004	Company have no guidelines on how to understand and describe uncertainty.	-No guidelines		3
P_G_005	Uncertainty is described through probability	-Uncertainty described through probability		1p
P_G_006	Difference in uncertainty between two persons is not discussed.	-Uncertainty understanding and description not discussed		1p/2
P_G_007	(Mooring 2019) Difference in uncertainty understanding between two parties. Risk of event not equally understood. Consequence equally understood, difference being in probability description and understanding.	-Difference in probability assigned		2s
P_G_008	(Njord wire installation) Same understanding of uncertainty. Event that occurred was not considered	-Accident considered a black swan		5.1
P_G_009	Reduce uncertainty (probability (P)) until an acceptable level. If this is not possible consider an alternative approach.	-Reduce probability until acceptance		4
P_G_010	Generally limited interest in exploring new opportunities. Only goal is to reduce uncertainty (probability)	-Reduce probability until acceptance		4
P_G_011	Uncertainty (probability (P)) based on experience, subjective probability.	-Subjective		2s
P_G_012	Uncertainty (probability (P)) based on historical data is available, frequentist probability.	-Frequentist		2f
P_G_013	The inclusion of rare events will be a judgment call on a case by case basis.	-Subjective		2s
P_G_014	Background knowledge of is not taken into consideration. For frequentist probability only best-estimate is presented. For subjective only "point value" is presented, assessor's knowledge of potential event not included.	-No SOK		5.2
P_I_002	Uncertainty described as the possibility of an event.	-Uncertainty described through probability		1p
P_I_003	Probability not grounded in theory	-Subjective probability		2s
P_I_004	Probability is commonly used to describe uncertainty	-Same as P_I_002		2s

P_I_005	Company does not have a guideline in how to understand and describe uncertainty. Use probability as this is used in the risk matrix.	-No company guideline -Probability used in risk matrix		3
P_I_006	Acceptable uncertainty level change during a project.	-Changing acceptance level		4
P_I_007	Desirable to reduce probability of unwanted event as much as possible. Reduce through ALARP.	-Reduce -ALARP		4
P_I_008	VOID	VOID	VOID	VOID
P_I_009	Personal perception of what the risk (read probability) is.	-Subjective probability		2s
P_I_010	Probability based on personal experience.	-Personal experience		2s
P_I_011	Difference in risk perception due to difference in probability setting	-Different probability setting		2s
P_I_012	Probability often subjective	-Subjective probability		2s
P_I_013	Difficult to say that event has been made worse due to different uncertainty understanding	-Inconclusive on probability has not made an event worse		2/7
P_I_014	Critical unwanted events are usually a result of “rare events”	-Critical events often “rare events”		5.1
P_I_015	When faced with uncertainty the ALARP principle is used	-Reduce through ALARP		4
P_I_016	Try to reduce probability and consequence	-Reduce probability		4
P_I_017	Reach a go/no-go level on probability and consequence	-Go/no-go limit		4
P_I_018	Probability (subjective) is based on the subjective experience of the team members present.	-Subjective probability -Team member knowledge		2s
P_I_019	Probability is discussed until there is consensus on the subjective probability	-Probability agreed within team		2s
P_I_020	Subjective probability not compared against urn standard or betting interpretation	-No external subjective standard (urn standard)		6
P_I_021	“Rare events” have limited or no historical data	-No/limited data on rare events		5.1
P_I_022	“Rare events” are difficult to take into account	-Rare events difficult to include		5.1
P_I_023	For events based on limited knowledge a “buffer” may be added to the probability.	-“Buffer” added to probability of event with limited knowledge		5.2
P_I_024	For events with considerable knowledge the probability given is more objective.	-Greater knowledge gives a more objective probability -Subjective probability		5.2
P_I_025	Limited data requires a more subjective probability	-Limited data results in subjective probability		2s
P_I_026	Reduce uncertainty until a go/no-go level.	-Same as P_I_017		4
P_I_027	Reduce uncertainty of unwanted events is a continuous event.	-Probability reduction continuous -Consequence reduction continuous		4
P_I_028	There is limited interest in seeking uncertainty to explore new opportunities.	-No interest seeking opportunities		4
P_I_029	No acceptance on taking increased risks, increased probability of event, when considering human life and well being	-Not acceptable taking on increased risk (probability)		4
P_I_030	During a risk assessment it would be beneficial with greater guidance on how to interpret the definitions. The assessment is a little too subjective.	-Greater guidance desirable		2/3
P_L_002	Probability used to describe uncertainty	-Uncertainty described through probability		1p
P_L_003	Reduce probability as much as possible	-Reduce probability until acceptable		4
P_L_004	Company have no guidelines on how to understand and describe uncertainty	-No guidelines		3
P_L_005	Uncertainty (subjective probability) is reduced by putting people with considerable knowledge together.	-Experts meet to reduce subjective uncertainty		2s
P_L_006	Focus is on reducing probability of unwanted event.	-Reduce probability of unwanted event.		4
P_L_007	Different understandings of risk picture (risk = consequence x probability) with agreement on consequence meaning that uncertainty (probability) understanding and description is different.	-Difference in probability assigned may cause accidents		1
P_L_008	It is difficult to categorically say that difference in probability has made an unwanted situation worse.	-No worsening of event		7
P_L_009	An unsafe job (with high probability of an unwanted event) should be altered to reduce probability of event. Reduce probability of event.	-Reduce probability of unwanted event		4
P_L_010	Interviewee contibutes to a limited extent during risk assessment probability assigning.	-Not confirtable with probability assigning		2s
P_L_011	Previously it used to be a more “nonchalant” attitude to risk. Whether this is due to lack of understanding of consequences or probability is unknown.	-Different risk picture (probability or consequence) unknown reason		
P_L_012	Limited experience quantifying probability	-Not confirtable with probability assigning		2s
P_L_013	Probability based on subjective experience	-Subjective probability		2s
P_L_014	Crane collapse due to irregular disassembly of crane. New unusual operation.	-Rare event caused crane collapse		4
P_L_015	All team members did not have the complete risk picture as it was claimed that the operation was safe. Uncertain whether or not the team members present during meeting had sufficient consequence understanding.	-Disagree on risk picture but agree on consequence i.e. different probability understanding		1
P_L_016	Pressure on time may make a situation worse	-Time pressure		5.1/5.2
P_L_017	Today operations are gone through step-by-step in detail minimising the likelihood of critical stages in operation is not assessed. More time is used.	-Critical steps examined to avoid unwanted events. -More time spent		5.1/5.2
P_L_018	Today critical steps are unusual examined in greater detail.	-See similar	P_L_17	5.1/5.2
P_L_019	If there is limited information about a potential event an additional “contingency” probability is added to the assigned probability.	-Contingency probability added to probability of events with limited information -Buffer on probability		5.2
P_L_020	Reduce probability of an unwanted event as much as possible. If residual probability is not acceptable reconsider operation/step.	-Reduce probability of unwanted event until accepted.		4
P_L_021	Repetitive operations/steps should also be considered as having a higher probability of unwanted event due to slight changes in execution or shortcuts increasing probability of event.	-Repetative operations also "rare events"		5.1
P_L_022	It is important that everyone has the same operational/step understanding without this common understanding both the consequences and probabilities will be incorrect.	-Same consequnce understanding essential for subjective probability assigning		2p/5.2
P_M_002	Describe uncertainty as something where you don’t know what is going to happen.	-Uncertainty about outcome		1n
P_M_003	Would not describe uncertainty using probability depends upon the context.	-May not use probability		1n/2p
P_M_004	No company guidance on how to understand and describe uncertainty. Have seen a guideline for risk.	-No guideline		3
P_M_005	Never experienced miscommunication due to uncertainty discrepancies.	-No miscommunication		7
P_M_006	Never experienced worsening of event due to uncertainty discrepancies.	-No worsening		7
P_M_007	When faced with uncertainty reduce uncertainty by unifying understanding between different parts.	-Reduce uncertainty -Unify understanding		4
P_M_008	Never use models to estimate uncertainty	-Dont use models		6
P_M_009	Never quantifies uncertainty	-Never quantify		6

P_M_010	Some rare events have not yet happened while some have been disregarded.	-Rare events -Black swans -Event disregarded		5.1
P_M_011	Must at all times try to seek rare events.	-Continuous seek rare events		5.1
P_M_012	Keep focus on very infrequent events as well.	-Do not disregard infrequent events		5.1
P_M_013	To handle uncertainty one discusses with others to determine the validity of the uncertainty and how to reduce it.	-Validity of uncertainty -Determine how to reduce it		4
P_O_002_01	In a risk assessment HAZID/HAZOP it is not uncommon to not use quantitative probability directly. Use qualitative "low", "medium", "high" probability intervals with corresponding % intervals.	-Qualitative probability -Imprecise probability (low, medium, high)		1p/2i
P_O_002_02	In a risk assessment HAZID/HAZOP it is not uncommon to not use quantitative probability directly. Use qualitative "low", "medium", "high" probability intervals with corresponding % intervals.	-Qualitative probability -Imprecise probability (low, medium, high)		2i/2p
P_O_003	Where the aim is to reduce uncertainty as much as possible.	-Reduce probability as much as possible		4
P_O_004	Company describes uncertainty through qualitative probability intervals using guidewords.	-Describe uncertianty as qualitative probability		2i
P_O_005	Qualitative probability intervals given as "low", "medium", "high".	-Imprecise probability (low, medium, high)	P_O_002_01	2i
P_O_006	Risk = probability x consequence, some conversion to numbers must be made in the background. Unknown what.	-Uncertainty as qualitative probability		2i
P_O_007	Usually a discussion on establishing the qualitative probability interval.	-Probability disagreement among team		2s
P_O_008	It is not uncommon to have miscommunication when discussing uncertainty due to risk assessment team members having different backgrounds.	-Disagreement among team		2s
P_O_009	Difficult to say that an incident has been made worse because due to difference in uncertainty description.	-No worsening		7
P_O_010	In a risk assessment HAZID/HAZOP one tries to increase understanding and reduce probability of event.	-Increase understanding -Reduce probability of event		4
P_O_011	Reduce probability of event until a point go/no-go point.	-Reduce uncertainty -Og/no-go point		4
P_O_012	There is also cost dimension. How much are you willing to pay for the reduction of probability of event.	-ALARP		4
P_O_013	Probability estimation not based on statistical probability calculations. Probability based on subjective understanding. No use of external subjective models to evaluate subjective probability.	-Subjective probability -No external model (urn standard)		2s
P_O_014	Subjective probability based on group knowledge.	-Subjective probability -Group knowledge		2s
P_O_015	Subjective probability given as an interval "low", "medium"," high"	-Subjective probability -Interval probability		2p/2i
P_O_016	Never experienced that the probability provided was based on mathematical modelling.	-Probability not based on modelling		2p
P_O_017	Quantifying subjective probability based on similar project.	-Subjective probability based on previous projects		2p
P_O_018	Final subjective probability provided by risk assessment team.	-Team knowledge		2p
P_O_019	It is difficult to quantify probability of rare events.	-Rare events difficult to include		5.1
P_O_020	For rare events plans are often created in order to handle it if it occurs, more than reduce probability.	-Make more reciliant towards rare events -No reduction in probability		4/5.1
P_O_021	Rare events are not discussed in great detail.	-Identfication of rare events ignored		5.1
P_O_022	The more knowledge one has about a potential event the more confidence there is the probability provided.	-Event with considerable knowledge no add "buffer" on probability		5.1
P_O_023	Events with limited knowledge a "buffer" is sometimes added to account for the lack of knowledge.	-Event with limited knowledge add "buffer" on probability		5.1
P_O_024	The use and size of "buffer" is not explicitly provided in probability. May be documented in supporting documentation.	-"Buffer" size not described in probability -Support documentation		5.2
P_O_025	When faced with probability of an event the aim is to reduce probability of event by gathering more information.	-Reduce probability of event -Increase knowledge		4
P_O_026	May be affected by external forces over with you have no control, aim to create resilience.	-Add reciliance towards outside forces		4
P_O_027	It is important to also consider that people have different attitudes towards risk. Some may be risk averse while some may be risk tolerant.	-Different attitudes to risk, risk averse or risk tolerant		5.2
P_O_028	Background knowledge and attitudes of team may affect the subjective probability to a considerable degree.	-Subjective probability coloured by knowledge and attitude.		??
P_P_002	Uncertainty mainly described by probability based on historical data. The uncertainty will then be the range or spread in statistics.	-Uncertainty described through probability -Spread in probability -Mainly frequentist probability		1p/2f
P_P_003	Break down statistical data to reduce uncertainty.	-Break down statistical data -Reduce uncertainty		2f/4
P_P_004	The uncertainty is reduced through more and more detailed analysis.	-Uncertainty reduction through increasingly detailed analysis		4
P_P_005	In a HAZID/HAZOP risk assessment the probability is usually subjective where usually 3-4 people hammer out the probability.	-HAZID/HAZOP -Subjective probability -Probability set by 3-4 persons		2s/4
P_P_006	The most important aspect of a risk assessment of HAZID/HAZOP type is not to establish probability, but more in the discussion it creates.	-HAZID/HAZOP -Not important to estblish probability -Important to discuss events		2s
P_P_007	During a purely technical risk assessment the only real task is to reduce uncertainty. Historical data widely used.	-Technical risk assessments only aim is to reduce uncertainty -Statistical data used		4/2f
P_P_008	During a HAZID/HAZOP time should be used on identifying potential events not establishing a probability. There is limited added value in this.	-Risk assessment HAZID/HAZOP -The discussion is important -Establishing exact probabilities is not important		4/5.1/2p
P_P_009	By gathering a sufficient amount of people with different backgrounds it is possible to create a distribution of subjective probability.	-Broad team may give a distribution of subjective probability		2s
P_P_010	Company has not produced a guideline on how to understand and describe uncertainty.	-No guideline		3
P_P_011	Hard to say that there has been miscommunication due to differences in uncertainty descriptions.	-No miscommunication		7
P_P_012	Hard to say that a situation has been made worse due to differences in uncertainty understanding and description. It is not that important to determine an exact probability, the important thing is the discussion.	-No worsening of unwanted event -Focus on discussing event -Not important to exactly state probability		2/7

P_P_013	Events does not become worse due to relatively minor difference in probability assigned. Events become dangerous when they are assessed incorrectly.	-Events not dangerous due to slight differences in probability -Unforseen events are dangerous		2s/4
P_P_014	Hard to consider events with low probability that has a knock-on effect causing large critical events (Piper Alpha).	-Difficult with low probability events with large knock-on effects		5.1
P_P_015	When faced with uncertainty the approach is reduce uncertainty until either accept or stop.	-Reduce uncertainty -Until Go/no-GO		4
P_P_016	Another approach is to establish plans which can be initiated, building resilience.	-Create plans -Be more resiliant		4
P_P_017	Get a ballpark figure of probability by using "guidewords" like "has this happened in the industry previously".	-Establish an approximate subjective probability -"Has this happened in the industry before?"		2s/4
P_P_018	Frequentist models are used estimate probability.	-Frequentist probability used -Estimate probability		2f/6
P_P_019	Sometimes assuming a probability distribution is required.	-Assume probability distribution		2f/6
P_P_020	Monte Carlo simulations are used to combine different distributions.	-Monte Carlo simulation -Estimate probability		2f/6
P_P_021	When quantify a probability it is not evaluated against an external model like the urn standard.	-Probability not evaluated against urn standard etc.		6
P_P_022	There is often not enough information or experience to predict "rare events". These are often neglected.	-Not enough knowledge of rare events to predict -Rare events often neglected		5.1
P_P_023	In some cases one tries to take into account rare events by adjusting historical data to provide a more realistic probability.	-Rare events -Adjust historical data to better represent -Subjective probability		5.1/2s
P_P_024	Unwanted events happened due to lack of imagination, not incorrect probability setting.	-Rare events -Lack of imagination -No probability setting		5.1
P_P_025	Backgroundinformation for probability setting is not included.	-Knowledge not presented		5.2
P_P_026	When faced with uncertainty one tries to reduce probability of event until a point where a point where a choice must be made to continue or do something different or stop.	-Reduce uncertainty -GO/NO-go		4
P_P_027	Level of acceptable uncertainty level changes through a project. Early in a project a higher probability of unwanted event is acceptable. Must decrees through the prosject.	-Uncertainty level change -Generally decreasing through project -Go/No-go		4
P_P_028	To handle uncertainty one must first establish or assume a distribution (triangle, normal etc.) for each event area of interest (oil price etc.)	-Frequentist probability -Assume distribution		2f/6
P_P_029	Monte Carlos simulations are then used find total distribution. Then select a 90 or 99-percentil or other probability.	-Monte Carlo -Select probability level		2f/6
P_P_030	Historical probability picture may not be representative if underlaying conditions have changed significantly.	-Frequentist probability not always representative		2f/2s
P_P_031	Identification of possible events one should focus on, do not get stuck determining a probability.	-Focus on identification of possible events -Not get stuck on probability setting		2
P_P_032	"Manageability" refers to is there something we can do with the probability of event or do we have to manage/plan for it.	-Event managability -Resiliance		4
P_P_033	One has to establish somewhat of a feeling where the probability of event is. If one considers having not sufficient information more knowledge should be gained reducing uncertainty.	-Determine ballpark probability -Reduce further if required		2/4
P_P_034	Establishing and presenting probability in a HAZID/HAZOP is not helpful. Should focus on identifying unwanted events and reducing these.	-HAZID/HAZOP don't focus on probaility -Identify unwanted events -reduce probability for these		2/4
P_P_035	Later in project one finds probability of unwanted event by find probability at a component level. At the component level the statistics are good because they are based on laboratory tests.	-Probability at component level		2f/4
P_Q_002	Uncertainty described as probability.	-Uncertainty described as probability.		1p
P_Q_003	No guideline on how to understand and describe uncertainty.	-No uncertainty guideline.		3
P_Q_004	Misunderstandings do occur when discussing uncertainty, however difficult to state that this is due to a difference in description and understanding of uncertainty.	-Difficult to accredit misunderstandings to uncertainty understanding and description.		1
P_Q_005	Misunderstandings may be due to different risk understanding.	-Misunderstanding due to different risk understanding -Different view -Different background		7
P_Q_006	Misunderstandings may be due to differences in risk aversion/tolerance.	-Risk aversion or risk tolerant.		4
P_Q_007	Hard to accredit an increase in severity of an incident due to differences in description and understanding of uncertainty.	-No increase in incident severity.		7
P_Q_008	Regular routine activities are great sources of incidents as there is limited focus on these.	-Routine (non-rare) events are dangerous.		5.1
P_Q_009	When faced with uncertainty seek information and reduce uncertainty.	-Increase knowledge		4
P_Q_010	Reduce uncertainty as far as possible, a decision must made go/no-go.	-Reduce uncertainty		4
P_Q_011	When assigning a possibility there is no reference made to either the urn standard or betting interpretation.	-Ultimately accept or abort.		4
P_Q_012	Sometimes "imprecise probability" is used.	-Imprecise probability -Subjective probability		2i/2s
P_Q_013	Which "imprecise probability" to present is a subjective matter.	-No comparison		2s
P_Q_014	When quantifying uncertainty, the probability is most often based on subjective experience as there is limited frequentist data available.	-"Imprecise probability" used -Which "Imprecise probability" to present is subjective		2i/2s
P_Q_015	VOID	VOID	VOID	VOID
P_Q_016	Those rare events that have been identified will usually get a low probability as limited knowledge is available.	-Rare events gets low probability		4
P_Q_017	There is no systematic approach to identifying rare events	-Subjective probability		2s
P_Q_018	Unwanted events are usually a result of people not having considered this event as a possible outcome.	-No/limited frequentist data		2f
P_Q_019	Knowledge dimension not taken into consideration when presenting a subjective probability.	-Knowledge dimension not included in subjective probability		5.2/2s
P_Q_020	Subjective probability based on peoples perception of the potential event.	-Subjective probability based on knowledge		2s

P_R_002_01	Uncertainty connected to the variables going into the models in order to predict the future.	-Uncertainty with respect to variables going into models -Statistical data -Frequestist probability		1p
P_R_002_02	Uncertainty connected to the variables going into the models in order to predict the future.	-Uncertainty with respect to variables going into models -Statistical data -Frequestist probability		2f
P_R_003	Covid-19 situation is a good example where a change in uncertainty change model prediction with respect to cashflow, results, manning etc..	-Rare events -Undermine predictions -No longer valid -Frequestist probability		2f/4
P_R_004	Models are based on assumptions say oil price etc. Several of these assumptions are no longer valid.	-See similar ID	P_R_003	2f
P_R_005	Uncertainty lay in the lack of belief in the input used in our models.	-Uncertainty lay in the lack of belief in the input used in our models.		2f/6
P_R_006_01	Considerable work done to establish different scenarios and probabilities for these. Typical scenarios would be less than $30 a barrel, $30-$60 a barrel and above $60 a barrel.	-Create scenarios -Accompanying probability		4
P_R_006_02	Considerable work done to establish different scenarios and probabilities for these. Typical scenarios would be less than $30 a barrel, $30-$60 a barrel and above $60 a barrel.	-Create scenarios -Accompanying probability		1p/2i
P_R_006_03	Considerable work done to establish different scenarios and probabilities for these. Typical scenarios would be less than $30 a barrel, $30-$60 a barrel and above $60 a barrel.	-Create scenarios -Accompanying probability		2i
P_R_007	Covid-19 and oil price drop have skewed the probability for each scenario.	-Rare event (Covid-19) -Skewed probabilities for each scenario		4
P_R_008	Probability for an oil price event at the lower end for the next 12-18 months has increased.	-Rare event -Scenario with low oil price increaesd probability		5.1/2p
P_R_009	Uncertainty described through probability.	-Probability used		1p
P_R_010	Probability founded initially on forecasts based on statistical data. Subsequently an individual subjective assessment of the probabilities is performed.	-Frequentist probability then subective probability -Probability based on statistical data -Modifiy probability based on personal belief		2f/2s
P_R_011	Statistically the oil price should be $55 a barrel. However, we believe $25 is more likely.	-See similar ID	P_R_008	2p
P_R_012	Subjective probabilities based on historical data.	-See similar ID	P_R_010	2f/2s
P_R_013	Everyone performing a forecast knows what goes into the model and has the same guideline to ensure alignment among scenarios.	-All have same model and guideline on input -Alignment between scenarios		3/6
P_R_014	Due to guideline provided there is no loss of communication when discussing uncertainty.	-No miscommunication over uncertaint		3/7
P_R_015	When faced with uncertainty we determine what this mean to us. We create plan and measures to handle different scenarios. Try to create a resilient system. Limited influence on probability (ref. oil price).	-Handle uncertainty by creating plans and reciliant systems -Limited influence on probability		4
P_R_016	Create scenarios and then run models on these scenarios to determine among other things cashflow, finance, net present value assessments.	-Create scenarios -Find options -Determine NPV		4
P_R_017	When estimating uncertainty we try to acquire additional information.	-Estimating uncertainty -Acquire additional (qualitative) information		5.2
P_R_018	Rare events are difficult to take into consideration and there are no models. Take as an example the Covid-19 impact in the financial system, there are no model for this. Likewise the drop in oil price we do have models on.	-Rare events (Covid) we have no model -No available probability -Infrequent events (oil price drop) we have model -Low probability		5.1
P_R_019	From a financial perspective there is limited visibility beyond the next 3 weeks. There is limited knowledge about the probability provided, difficult to put a number on it.	-Limited knowledge about probability beyond 3 weeks -Knowledge not included in probability		5.2
P_R_020	When faced with uncertainty there it is not an option to stop whatever we are doing. The selection of approach is based on "net present value" assessments. Always chose the available option with the highest NPV.	-No option to stop -Choose the available option with highest NPV		4
P_S_002	Risk buffer added to probability	-"buffer" on probability		4
P_S_003	Probability used to describe uncertainty	-Use probability		1p
P_S_004	No company guideline	-No guideline		3
P_S_005	Uncertaitny a subjective assessment	-Subjective probability		2s
P_S_006	Definetly miscommunication. There are two different languages. Engineers focus on subjective safety aspects while economists focus on historical data	-Miscommunication -Different languages used -Subjective probability -Frequentist probabilit		7/2s/2f
P_S_007	Hard to mention an evnet made worse by different uncertinaty understanding.	-No worsening of events		7
P_S_008	Use historical data as fare as it goes.	-Frequentist probability		2f
P_S_009	Reduce uncertaity as much as possible until a go/no-go point is reached	-Reduce uncertainty -until og/nogo		4
P_S_010	Reduce uncertainty by collecting further information	-Reduce by collecting more information		4
P_S_011	Four steps to handle uncertainty 1) identify uncertainty 2) gather information 3) evaluate added information base 4) make decision. Decision often based on NPV assessment	-Reduce uncertainty -gather information -evaluate information		4/5.2
P_S_012	Estimate uncertainty based on historical data. No models used to estimate uncertainty. Often a subjective assessment based on historical data.	-Frequentist probability -No models used		2f/6
P_S_013	Probability interval is not used. Worst-case or a percentil used.	-Subjective probability -No interval probability		2s/2i
P_S_014	Historical data provides a good overview of possible outcomes. However, Covid-19 was not considered. This was a black swan.	-Subjective probability -rare events -black swans		2s/5.1
P_S_015	Rare events hard to consider because they fall outside normal event spectrum.	-rare events difficult to consider		5.1
P_S_016	Rare event consideration is highly subjective	-rare events subjective		2s/5.1
P_S_017	Rare events not so much mittigated against, but more through making the system more recilliant	-rare events -recilliance plans		5.1/4

P_S_018	Should every decision made from now on also include a pandemic assessment. These events are so rare that an inclusion will make the future assessments more difficult. There will be excess "baggage".	-rare events not always "relevant" -managerial decision to include		5.1/4
P_S_019	Knowledge dimension provided as part of the discussion and complete assessment. However, presentation of discussion is not presented.	- Knowledge dimension may be provided in support documentation		5.2
P_S_020	Reduce uncertainty as much as possible util og/nogo. Always allow for uncertain even for well known events.	-Reduce uncertainty until og/nogo -Always allow for rare events even for well known events		4
P_U_002	Risk = cause x consequence x probability.	-Uncertainty described as probability		1p
P_U_003	A risk assessment must have a context.	-Risk assessment must have context -Similar context -Similar risk attitude		4
P_U_004	Clear definition of risk.	-No clear guideline on uncertainty		3
P_U_005	Clear procedures on how to handle uncertainty during different project stages.	-Procedures on handling uncertainty		4
P_U_006	Guidewords to determine correct context.			2s
P_U_007	Standard for risk management, 5 stages #4 identify risk #5 reduce.	-Identify uncertainty -Reduce uncertainty		4
P_U_008	Learning organisation thereby taking rare events into consideration.	-Learning organisation -Including rare events		4/5.1/5.2
P_U_009	People have different understandings of uncertainty (probability) due to different backgrounds.	-Different backgrounds -Different uncertainty understanding (probability)		2s
P_U_010	Empower people to have a similar understanding, increased focus on visualising.	-Ensure similar physical understanding -Increased visualisering		4
P_U_011	Different risk understandings within a team.	-Different risk understanding		2p
P_U_012	Potential unwanted events are colour coded to keep focus.	NA		??
P_U_013	Different backgrounds with a common understanding reduce risk.	-Different background -Common understanding -Reduce uncertainty -Reduce probability of event		4
P_U_014	Hard to mention a specific incident made worse by different uncertainty understandings.	-Event not made worse		7
P_U_015	Try to increase competency and thereby reducing risk.	-Increase competancy -Reduce uncertainty		4
P_U_016	Company use Monte Carlo simulations to estimate uncertainty.	-Monte Carlo simulations		6
P_U_017	Use both subjective- and frequentist probability to describe uncertainty.	-Subjective probability -Frequentist probability		2s/2f
P_U_018	Probability not compared against external standards as the urn standard.	-Probability not compared to urn standard etc.		6
P_U_019	Company does not provide or establish probabilities themselves. Ensure suppliers keep correct focus.	-Company rarely estimate probabilities themeselvs -Ensure supplier focus		6
P_U_020	Difficult to incorporate rare event due to the repetitively of these events, no one on the team have experience with these events.	-Difficult to include rare events -Low frequency of rare events -No experience with rare events		5.1/5.2
P_U_021	Company have difficulties imagining these events, these are “black swans” to the team.	-Not enough imagination for rare events -Black swan events are a problem		5.1/5.2
P_U_022	Events with large forces involved (large consequences) should be examined in detail even though no one in team have experienced failure during this event before.	-Potential large consequence a screening for black swans -No experience		4/5.1
P_U_023	Company needs to improve with respect to “rare events”	-Considerable improvement potential for rare events		5.1
P_U_024	Probability background information not presented in a systematic manner.	-Background information not included systematically		5.2
P_U_025	Company actively seeks uncertainty to improve, continuous learning.	-Company seeking uncertainty to increase learning		5.2
P_U_026	Reduce the probability of unwanted event by increasing knowledge and discussing with suppliers.	-Reduce probability of event by increasing knowledge -Discussion with suppliers		4/5.2
P_U_027	Highly educated persons dislike change, they will therefore not try new things, “fixed mindset”.	-Fixed mindset -Educated personnel hard to change behaviour		4