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Author: Leandro José Gutierrez Useche	
Program coordinator: Roger Flage Supervisor(s): Roger Flage	
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ABSTRACT

Risk assessments form the core of the modern risk management process. Based on the execution of risk analysis and subsequent risk evaluations, the risk assessments provide the stakeholders or decision-makers with the 'risk picture' of a given activity.

The degree to which a decision made by the stakeholders will have the desired effect or any effect at all, will depend to a high extent on the quality level of the presented risk picture. At the same time, the risk picture relies on the quality of the risk analysis performed. And finally, the results of the risk analysis will ultimately depend on the concept of **risk** that is used.

It is clear that risk is the keyword of the whole process, and therefore it is of high importance to utilize the definition whose associated description includes all the involved elements. There are several conceptualizations of risk and each one contain different elements, under these definitions there are unique ways to assess, measure and describe risk. As not all the definitions of risk contain the same elements, it is important that the risk definition in use is consistent with the way it is measured or described.

The main objective in this work is to evaluate the consistency between the way risk is defined and the way risk is described in today's risk assessment practices with the purpose of increasing the scientific knowledge within this subject and contribute to a better execution of risk assessment techniques.

The strategy followed in the present research is outlined in a general way by the following sequence. First, relevant risk assessment of different types and from different sectors were collected. Then an evaluation of the collected data was performed with focus on the way risk is defined. The risk definitions were then compared against the associated risk descriptions and then the results were discussed with reference to the main objective of the thesis. Finally, the conclusions and possible recommendations were presented.

The results showed that as a rule, the risk descriptions of the majority of the risk assessments evaluated, present more than just the elements contained in their respective definitions. It is argued that this could be due to the necessity of the risk analysts to express more than just what is entailed by the risk definitions in use.

It was concluded that, in general and as per the evaluated sample, the risk definitions can be deemed consistent with the risk descriptions up to a certain degree. Consistent in the sense that a good number of assessments manage to describe the elements that conform their respective risk definitions, though not completely consistent as the risk descriptions usually included more than such elements. The one exception was when the definition of risk used was the two-dimensional combination of consequences of an activity and associated uncertainty, which successfully managed to cover all the elements presented in the evaluated risk descriptions.

Finally, it is also argued that a risk definition that manages to cover all the risk elements under its related risk description will help the risk assessment team to both accurately communicate the results of the analysis while at the same time keeping the consistency between the risk definition and the risk description.

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Leandro José Gutierrez Useche

1 INTRODUCTION

1.1 Background

More than 2400 years ago the ancient Greeks used their ability to assess risk before making a decision. So far back in human history can we trace risk and risk assessments (Bernstein 1996). Since then, these concepts, and what they convey, have been largely developed. Following this trend, it was primarily during the 1970s and 1980s that the fundamental elements of risk assessment and management were conceived, and many of these elements are still widely used nowadays. (Aven 2016).

Many concepts of risk have been developed, yet no clear definition of the concept of risk itself is agreed upon. Sometimes risk is defined as a probability or as expected values. In some other instances, it is defined as consequences, losses or uncertainties. However, during the last 15-20 years, there has been a shift from more limited perspectives based on probabilities, to ways of thinking which focus on events, consequences and uncertainties (Aven 2012).

Parallel to the evolution of the definition of risk, the methodologies for assessing and managing risk have also matured. As per recent standards (NORSOK 2010, ISO 2018), risk assessments form the core of the modern risk management process. Based on the execution of risk analysis and subsequent risk evaluations, the risk assessments provide the stakeholders or decision-makers with the 'risk picture' of a given activity. Such a picture serves as the main support (together with other additional information) during decision-making situations, in scenarios that convey risk. (Aven 2015)

If we re-visit the previous paragraphs, from end to start, in order to evaluate the relation between the ideas presented, the following statements become evident. The degree to which a decision made by the stakeholders will have the desired effect or any effect at all will depend to a high extent on the quality level of the presented risk picture. At the same time, the risk picture relies on the quality of the risk analysis performed. And finally, the results of the risk analysis will ultimately depend on the concept of **risk** that is used. We see risk is the keyword of the whole process, and therefore it is of high importance to utilize the definition whose description involves all the involved elements: the consequences (and their severity), the measure of uncertainty related to such consequences and the background knowledge on which the assessments are based.

There is limited research work regarding this topic, more broadly how current risk assessment practices adhere to advances within the theoretical foundations of risk. Therefore, the main motivation of this thesis and its empirical work is to cover this gap, by evaluating how risk is defined and described in a set of real risk assessments. This thesis also aims to serve as a contribution to society by influencing in a positive way future practices within risk management and risk assessments.

1.2 Objective

The main objective of this work is to evaluate the consistency between the way risk is defined and the way risk is described in today's risk assessment practices. The purpose will be to increase the scientific knowledge within this subject and contribute to better execution of risk assessment techniques.

Pursuant of this objective, the following goals are defined:

- Research the literature and settle the theoretical foundation for the empirical work
- Set the parameters and conditions for collecting and evaluating the data
- Collect and categorize relevant risk assessment of different types and from different sectors
- Evaluate the collected data with focus on the way risk is defined
- Compare the risk definitions against the associated risk descriptions
- Discuss the results with reference to the objective and theory
- Present the conclusions and possible recommendations

As a byproduct of this work, the final results will be plotted on the six risk definition development paths presented by Aven (2012), to further evaluate to what extent risk definitions used in current practical applications follow the latest theoretical developments.

1.3 Limitations

The scope of this work is limited by the accessibility to actual risk assessments. Only publicly available risk assessments were collected to be part of the evaluated datasets. The reason for this is that many of the risk assessments are private or are kept as confidential documentation by the originators for a variable period of time.

1.4 Structure

This thesis is organized as follows. The **first** chapter presents an introduction into the main topic including background, previous research and the main objective. Chapter **two** makes the reader familiar with the terminology and necessary theory required to comprehend and follow the coming empirical work.

Further on, in the **third** chapter, the method to be utilized for collecting, categorizing and evaluating the risk assessments (data) is established. Chapter **four** dives into the actual collection and evaluation of the data and concludes with the presentation of the results.

Finally, chapter **five** discusses the results against established literature before the **sixth** and the last chapter provides the concluding remarks of the academic work.

1.5 Abbreviations

ALARP – As Low as Reasonably Practicable

ISO – International Standards Organization

ERSO – European Road Safety Observatory

DSB - Direktoratet for samfunnssikkerhet og beredskap (Directorate for Civil Protection and Emergency)

FMEA – Failure modes and Effects Analysis

HAZOP – Hazard and Operability study

NORSOK - Norsk Sokkels Konkuranseposisjon

QRA – Quantitative Risk Assessment

SWIFT – Structured What-IF Technique

1.6 Definitions

Risk concept - In the thesis, this term is used to refer to the way risk defined. What is understood by risk and, depending on the case, what elements are considered a part of it.

Risk description – In the thesis, this term is used to refer to the way risk is expressed

Risk metric - Defined as an index/measure used to express risk

1st person – Defined as employees of a facility, those directly involved in daily operations

2nd person – Defined as persons that benefit from being in the surroundings of the facility but is not directly engaged in work at the plant (for instance persons transporting items in and out of the facility)

3rd person – Defined as people outside the facility that may be affected by the facility's activities (for instance population of a community)

Statens Vegvesen - Norwegian Public Roads Administration

2 THEORY

2.1 Some foundational definitions within the risk science

In this section, some terms and definitions that are often used when discussing risk and risk management will be presented. With this in mind, the reader is invited to consider a day to day situation that involves risks such as, for instance, driving. According to the European Road Safety Observatory (ERSO 2018), there were more than one million people injured due to driving accidents in 2016. Whether it is a small motorcycle, a car or a big truck, different levels of risk are present at all times for the duration of the activity.

Let us imagine that on a nice winter day, we are driving a car towards a cabin in the mountain. This situation can have, among others, one the following outcomes: safely arrive at the cabin, have a car accident and arrive injured, or have a car accident which ends in a fatality. In this example, the specific situation of driving a car to the cabin is what is referred to as an event and the possible outcomes, such as arriving safely at the cabin, are the consequences. According to ISO (2018), an **'event'** is defined as the occurrence of a particular set of circumstances and a **'consequence'** is the outcome of an event.

Back into the driving example, imagine that you are about to drive through a tunnel which is dark and has poor visibility. It could be the case that the road is icy inside. You are then uncertain of the condition in the tunnel. Following (Lindley 2006) there are events that you know to be true, others that you know to be false, but with the majority of events, you do not know whether they are true or false. It is then said that, for you, these statements are uncertain. Said with other words there is **'uncertainty'**.

Due to this uncertainty and based on the weather conditions experienced before entering the tunnel, you then assign a 70% probability of the way being icy inside. Therefore, deciding to reduce the speed in order to lower the risk. In this case, 'probability' is defined by Lindley (2006) as a reasonable measure of a person's uncertainty that a given event will be true or not. More accurately this is the definition of a **'subjective probability'**, subjective because it expresses a person's degree of uncertainty.

An important concept when estimating subjective probabilities is the **'strength of knowledge'**. The 'goodness' of any measure of uncertainty is dependent on the strength of knowledge on which the measure is founded. There could be two opposite assessments of the same risk, however, the first assessment may have been made by an expert with a lot of knowledge on the situation at hand while the second one was made by an inexperienced assessor.

It is important to note that there is another type of probability which is called **'frequentist probability'**. This probability, according to Aven (2014), is the fraction of times a given event occurs if the situation under consideration was repeated infinitely many times. To illustrate thorugh our driving example, if the situation of driving into the tunnel could be simulated infinitely, with exactly the same conditions, then a frequentist probability can be established by the fraction of times ice was found inside the tunnel within the simulation.

2.2 The risk concept

As previously mentioned, what humans understand as risk has developed from original and more narrow definitions based purely on probabilities to a wider view which includes events, probabilities, consequences and uncertainties. This could be due to the fact that, throughout time, people have needed to give risk a definition that best suits their respective situations. Following this, Aven (2012) identified six historical paths from which the current concepts of risk have developed, all originating from de Moivre's 1711 definition. The risk definitions of the mentioned paths are presented below. For this, risk will be defined as 'R' from this point and forward.

2.2.1 Risk as expected value R = (E)

As per de Moivre (1711), the risk of losing any sum is the product of the sum adventured multiplied by the probability of loss. Therefore, risk is defined as 'expected loss' or 'expected (dis)utility' where the letter 'E' stands for the use of expected values to express uncertainty. The expected loss is based on the law of the large number which states that the average of a number of similar independent, identically distributed random variables converges to the expected value of one specific random variable.

This definition is illustrated by the following example. Let us say that an insurance company is covering a big amount of assets, each worth 20000 and with a probability of loss of 1/2000. Then the expected loss for the company equals 20000 x 1/2000 = 10.

Aven (2014) argues about the validity of this risk perspective by exposing the fact that expected values can misguide the decision-makers. The reason is that this perspective does not consider the extreme outcomes as, for instance, two situations with the same calculated value of expected loss do not necessarily represent the same level of risk. Due to this, he then concludes that other than using this perspective as an informative risk index or metric it cannot be adopted as a general definition of risk

2.2.2 Risk as probability and scenarios/consequences/severity of consequences R = (P&C)

Upon the previous definition where risk is defined as expected values (loss), a new perspective was developed. From this new point of view, risk is defined by Aven (2014) as the two-dimensional combination of probabilities 'P' and consequences 'C'. He further states that this definition builds on the shortcomings of the previous definition of risk as expected value, as it considers the severity of the consequences into the overall risk picture. A typical example of a risk index based on this definition are the risk matrices, where risk is categorized as high, medium and low based on evaluations of probability and consequence (severity) of unwanted events.

However, in Aven (2012), Aven (2014) and Aven and Zio (2011), it is debated that this definition is also far from perfect given the fact that uncertainty is considered solely via probabilistic values. Such probabilistic values, whether assigned by experts (subjective) or derived from models (frequentist) are founded on assumptions that depend on the strength of knowledge underlying them. The strength of knowledge behind the numbers can be weak or strong, and this may highly affect the final risk picture presented. Also, many scenarios in real-life situations are unique which makes the case of the frequentist approach a bit harder to defend as it depends on the repeatability of the situations under the exact same conditions every time.

2.2.3 *Risk as consequences/damage/severity of these plus uncertainty R = (C&U)*

Building the arguments regarding probabilities, assumptions and strength of knowledge; comes the R=(C&U) perspective. Aven (2007), Aven (2010), Aven (2014) and Aven and Renn (2009), define risk as the two-dimensional combination of consequences of an activity, 'C', and associated uncertainty (not knowing what the consequences will be), 'U'. Where the focus is normally on negative consequences which are often seen in relation to reference values.

Aven (2014) further explains that under this perspective, risk is described by (C', Q, K), where C' accounts for the consequences identified by the assessor. Often, the consequences are split into events A' (some specified events of A) and consequences C'. The components Q and K are used to describe uncertainty, where Q is a measure of such uncertainty and K is the background knowledge on which C' and Q are based. In this way, the decision-maker is presented not only with the possible consequences of an event but also with a measure of uncertainty (that can be presented by probabilistic values) and the associated knowledge and strength of knowledge behind each number.

2.2.4 *Risk as uncertainty R = (U)*

The perspective of risk as uncertainty evolved directly from the original definition of risk as expected loss and is mostly connected to the economic field. According to Aven (2012), Aven (2014), this definition seems to be based on using the expected value of a given investment as a reference point and then evaluating the uncertainty by comparing it to historical average values for similar investments.

Aven (2012), Aven (2014) argues that, without such a reference level, this definition does not make much sense. Because uncertainty, without considering the possible consequences nor their severity, cannot be used as a general definition of risk. From a personal safety perspective, a person cannot blindly choose an option just because it has the lowest uncertainty as it could also imply selecting the option that has the most severe of the consequences (such as fatality).

2.2.5 *Risk as objective uncertainty R = (OU)*

This perspective defines risk as objective uncertainty 'OU'. It originated from Frank Knight's idea (Knight 1921), where he says that there is risk in the case that an objective probability distribution can be obtained (and uncertainty otherwise). In other words, risk exists only when uncertainty can be expressed employing objective probabilities such as statistics, experiments and mathematical measurements.

This definition of risk gives no space for subjective probabilities, therefore losing value as a general definition of risk. When assessing risk, there are many situations in which objective probabilities cannot be established. Therefore as Aven (2010) states, this perspective becomes empty upon adopting a Bayesian (subjective) perspective on probability.

2.2.6 *Risk as event or consequence of an event R = (C)*

Risk, from this point of view, is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain (Rosa 1998, Rosa 2003). To simplify, that risk is the same as an Event (e.g.: leakage).

It is argued by Aven and Renn (2009) that even though this definition provides a sound foundation for risk research and risk management, it also leads to conceptual difficulties that are incompatible with everyday use of risk in most applications. It is also stated that by using this definition it is not possible to categorize the risk as high or low nor compare different options with respect to risk.

2.2.7 Risk as potential/possibility of a loss R = (PO)

According to Aven (2014), this definition states that a loss may or may not happen (or a loss of different magnitude may occur), he further compares it with the uncertainty about the loss (U) and the (C&U) because the potential/possibility relates to different outcomes.

2.2.8 Risk is the effect of uncertainty on objectives R = (ISO)

As per ISO (2018), risk is the effect of uncertainty on objectives. An 'effect' of uncertainty on an objective can be a deviation from the expected, it can positive, negative or both and can address, create or result in opportunities and threats. Within this definition, risk can be expressed in terms of risk sources, potential events, their consequences and their likelihoods.

2.3 Risk management

Risk management is a continuous management process with the objective of identifying, analyzing and assessing potential hazards in a system or related activity, and to identify and introduce risk control measures to eliminate or reduce potential harm to people, the environment or other assets (Rausand 2011). The risk management process also comprises other activities such as establishing a set of corporative strategies, processes, roles, responsibilities and culture for risk management.

To the above definition, Aven (2015), adds that risk management relates to all activities, conditions and events that can affect the organization and its ability to reach the organization's goals and vision. To achieve proper risk management, the top management of the organization must be deeply involved.

2.4 Risk analysis process

The central part of risk management is the **risk analysis process**. The methodology presents slight variations from author to author, however, the premises are the same. This thesis focuses on the risk analysis process as proposed by Aven (2015) as it presents a structure that is independent of the area of application. Figure 1 presents an overview of the three key steps of the process: planning, risk assessment and risk treatment. Further, the risk assessment step is divided into two parts, risk analysis and risk evaluation.

In the following chapters, the three main steps will be discussed in a more detailed way.

2.4.1 Planning

Before executing any type of risk assessment the problem must be defined. The reason why the analysis is to be performed must be clear and the objectives must be established. Possible scope limitations shall be presented along with the objectives.

Then, the workgroup(s) needs to be assembled, they should include expertise within the relevant fields such as risk experts, system (operational) experts, and mathematician/statistician among others. Further on, a plan which highlights the activities, roles, responsibilities and deadlines for the workgroups must be established.

If several attributes, such as the impact on personal safety, environment and company assets are to be evaluated in the analysis, then it needs to be determined if they will be analyzed separately or combined.

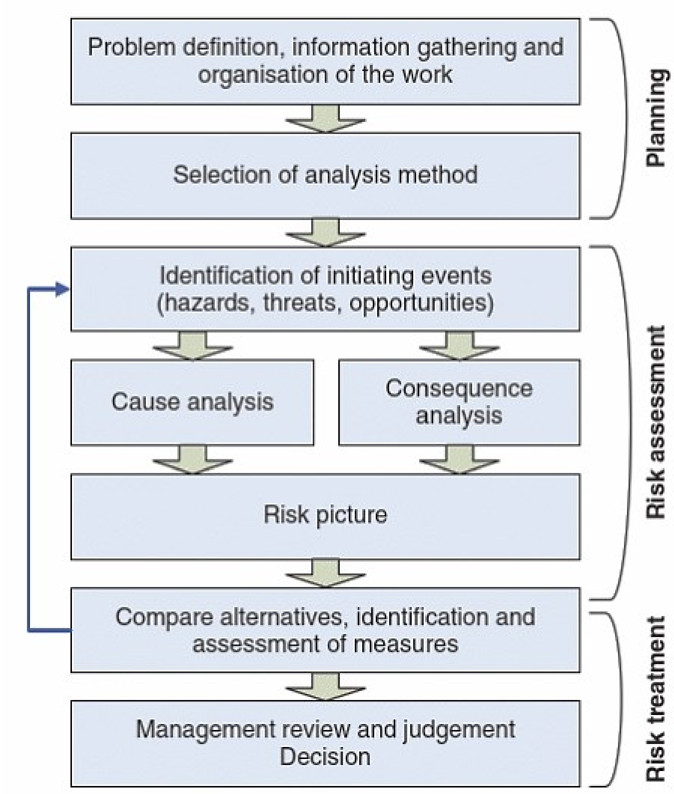

Figure 1 Risk analysis process (Aven 2015)

The next step in the process is the selection of the risk analysis method. Aven (2015), differentiates three main categories of risk analysis methods: simplified risk analysis, standard risk analysis and model-based risk analysis.

A **Simplified risk analysis**, is an informal procedure that established the risk picture using brainstorming sessions and group discussions. The risk picture presented when using this category could be that there that a reduction in fatalities is expected for the coming year.

A **Standard risk analysis**, is a more formal procedure that applies recognized risk analysis methods.

A **Model-Based risk analysis**, makes use of techniques such as event tree analysis and fault tree analysis to calculate risk. By using this approach we could get similar results as with the standard risk analysis, but it uses more detailed methods such as probability distributions to describe the number of fatalities for next year. It is important to note that the quantitative result of the model-based risk analysis should always be presented together with a qualitative judgement of the strength of knowledge that they are based upon (Aven 2015).

Each of the aforementioned categories makes use of different tools for hazard identification and risk presentation. Some of these tools are presented in Table 1.

Table 1 Typical risk analysis tools based on Aven (2015)

Main Category	Type of Analysis	Tools
Simplified risk analysis	Qualitative	Use of brainstorming sessions and group discussions. Risk might be presented on a coarse scale, for example, low, moderate or high, making no use of formalized risk analysis methods.
Standard risk analysis	Qualitative or quantitative	Use of hazard and operability study (HAZOP), structured what-if technique (SWIFT), fault trees & event trees (without calculating probabilities). Use of checklists for identifying hazards/threats. Coarse risk analysis. Risk matrices are often used to present the results.
Model-based risk analysis	Primarily quantitative	Use of techniques such as event tree analysis and fault tree analysis to calculate risk.

As per Aven (2015), the selection of the category depends on several factors like resource and time availability and also the intention of the risk analysis. In a forward approach, the risk analysis identifies all possible initiating events together with their relevant consequences. While in a backward approach the risk analysis focuses on the identification of the initiating events or situations that are identified as important in the analysis. The first approach presents a more complete risk picture at the expense of more time and resources, while the second approach requires fewer resources but requires considerable experience and competence.

The checklist approach makes use of certain characteristics of the problem at hand to define the category of risk analysis to use. An example of these characteristics could be (in the situation of the tunnel construction industry) the gradient, length or type of tunnel to be constructed. Where different combinations of these characteristics would indicate the most relevant risk analysis category to use. (Aven 2015)

Another tool for the selection of the adequate risk analysis method is the risk-based approach. This is based on the assessment of three aspects: expected consequences, uncertainties (such as variation and lack of knowledge) and frame conditions (such as limitations). A crude assessment of the mentioned aspects is carried out by the system owner, risk experts and system experts, the results of each aspect in categorized in low, medium or high and founded on the 'risk level' the risk analysis category is selected. (Aven 2015)

2.4.2 Risk assessment

Once the problem is defined and the category of risk analysis selected, the risk assessment can be started. The joint process of carrying out a risk analysis and a risk evaluation is what is defined as a risk assessment. (Rausand 2011, Aven 2015).

A bow tie diagram is a model that is typically used for conducting risk assessments. In this model, the initiating event is located in the middle, the part corresponding to the causes and preventive barriers (risk analysis) is presented by the left side and the consequences and mitigating barriers (consequence analysis) are covered by the right side. Ref. Figure 2 below.

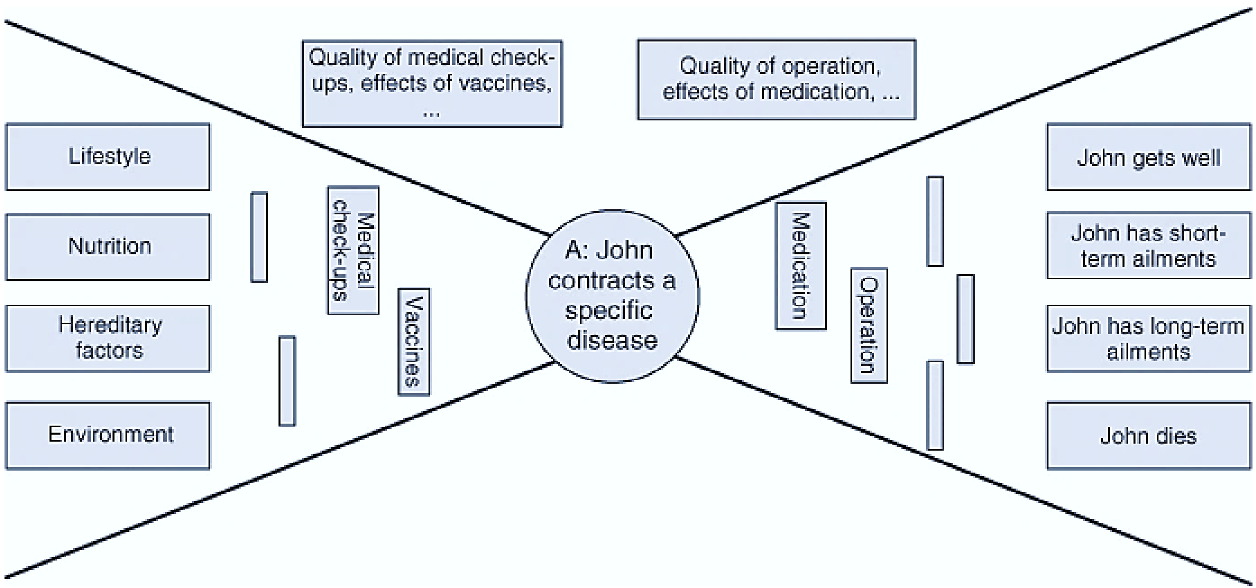

Figure 2 Bow tie example (Aven 2015)

2.4.2.1 Risk Analysis

Aven (2011) defines risk analysis as the systematic use of available information to identify risk sources, causes and consequences of these sources, and describe risk.

There are two types of risk analysis: Qualitative and Quantitative. The type of risk analysis to be used depends on the category of risk analysis selected (Ref Table 1).

A **qualitative risk analysis** uses words and/or descriptive scales to describe the frequency of the hazardous events identified and the severity of the potential consequences that may result from those events. The scales may be adapted to fit the circumstances, and different descriptions may be used for different categories of risk (Rausand 2011).

A **quantitative risk analysis** uses numerical values for frequencies, consequences and severities. The system is decomposed into subsystems and components (e.g. valves, pumps), up to a point where enough data is available for most of the components of the resulting model (Rausand 2011). An example of a quantitative risk analysis would be to use a fault tree analysis and calculate the probability that the top event will occur.

The first step of the risk analysis is the identification of initiating events or hazard identification.

As per Rausand (2011), the goals of the hazard identification are:

- To identify all the hazards and hazardous events that are relevant during use, misuse and interactions with the system
- Describe the characteristics, form and quantity of each hazard
- Describe when and where in the system the hazard is present
- Identify under what conditions the hazard could lead to a hazardous event and which pathways the hazard may follow

- Identify potential hazardous events that could be caused by the hazard (or in combination with other hazards)
- Make operators and system owners aware of the hazards and potential hazardous events

Techniques such as Failure modes and Effect Analysis (FMEA), Hazard and Operability study (HAZOP), Structured What-IF Technique (SWIFT), fault tree analysis can be applied for the hazard identification process. They are discussed in more detail in Aven (2015).

The following step after the identification of initiating events is to perform a **cause analysis**. Here, the goal is to study what is needed for the initiating events to occur (causes), what the frequency of the hazardous event is and how each cause impacts such frequency. Depending on the type of risk analysis, different methods can be used for this such as cause and effect diagrams, fault tree analysis, Bayesian networks and Markov methods among others. (Rausand 2011)

Next, as per Aven (2015), for each initiating event, an analysis is carried out addressing the possible consequences the event can lead to (**consequence analysis**). These consequences can be of varying dimensions or attributes. In this step, possible accident scenarios that can take place after a specified hazardous event has occurred are determined, barriers that reduce the impact of the possible consequences are identified, possible end events and their probabilities are determined/described and the frequency of each accident scenario is assigned/calculated. Commonly used tools are event tree analysis, event sequence diagrams, cause-consequence analysis and others. (Rausand 2011)

Finally, the **risk picture** can be presented. A risk picture attempts to provide an overview of the hazards/threats that may arise from an activity (e.g.: operation of a system) together with the possible consequences. The hazards/consequences may be accompanied by uncertainty measures such as probabilities and, depending on the situation, it should also present the background knowledge and strength of knowledge for these numbers.

Sensitivity and robustness analyses are typically included in this section to show to what extent the results are dependent on important conditions and assumptions and what it takes for the conclusions to be changed Aven (2015). In other words, to evaluate how robust the risk analysis conclusions are if some main assumptions were to change.

The degree to how well the factors described in this chapter are presented in the risk picture will highly depend on the premises used in the risk analysis, and the main premise is risk itself. Depending on the definition of risk utilized (ref. section 2.2), the final picture will vary in completeness. Is risk defined as expected values, then it may oversee the extreme outcomes with severe consequences. Or maybe risk is seen as the combination of probabilities and consequences, but then, what about the background knowledge and related uncertainties?. A factor like this can be a tipping point for the decision-makers when deciding what safety measure to implement or if it is even worth to implement them.

2.4.2.2 Risk Metrics

There are several metrics available for describing risk. Risk matrices, PLL/FAR values, F-N curves and risk contours are among the most commonly used within the field and will be briefly described in the following sections.

- Risk Matrix

According to Rausand (2011), a (standard) risk matrix is a tabular illustration of the frequency and severity of hazardous events or accident scenarios. In a risk matrix, different categories are created for probabilities (frequencies) and consequences (severities). Then the risks are allocated in the matrix based on the evaluation of these two aspects.

Figure 3 below presents an example of a standard risk matrix, where the y axis represents the probabilities, which are divided into categories from A to E (in the case of this example), and the x axis represents the consequences, which are also divided into categories from 1 to 5 (in the case of this example).

The white boxes with numbers represent the evaluated risks and the different color zones indicate the acceptance criteria. Depending on the location of the risk within the different zones risk-reducing measures shall be taken or not. The red zone indicates unacceptable risk and therefore requires risk-reducing measures, yellow indicates that additional risk-reducing measures should be considered and green indicates that the risk is within the tolerable level.

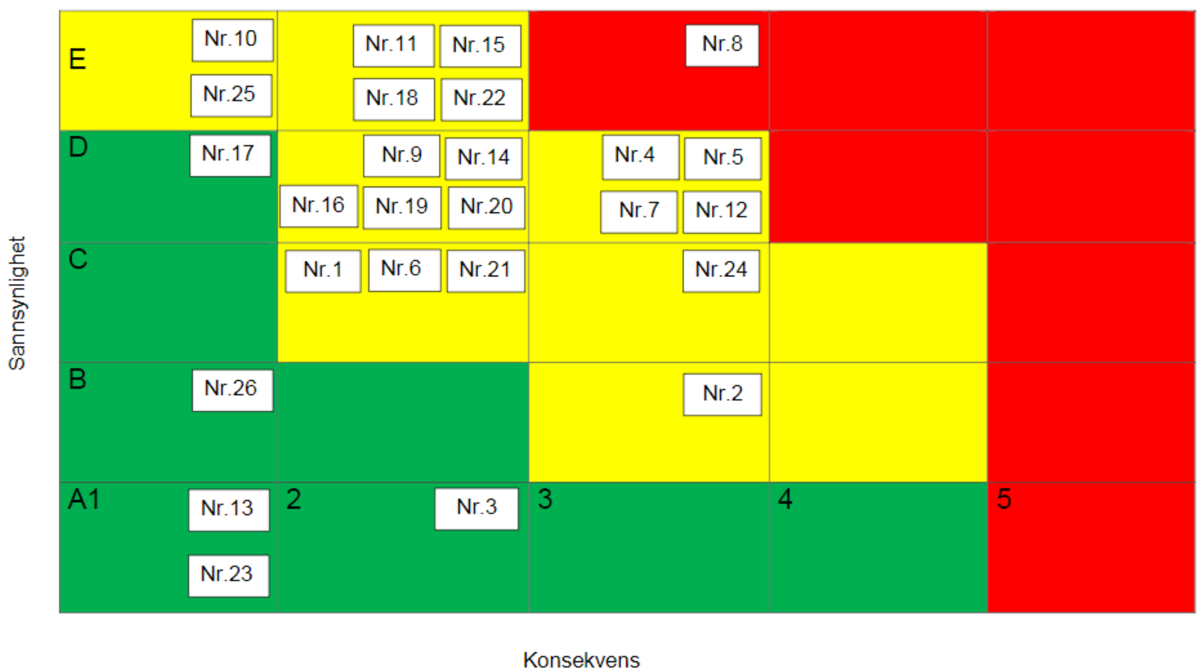

Figure 3 Standard risk matrix (ROS Sandnes kommune, appendix ref. 20)

The standard risk matrix as presented above only considers two elements which are probabilities and consequences. In light of this, a risk matrix variant was created to include a third element which is the strength of knowledge (SoK). This variant was introduced by Aven (2014) and in this thesis is referred to as an expanded risk matrix.

As per the example presented in Figure 4 below, it can be seen that the presentation is very similar to that of the standard risk matrix, but it additionally includes a ranking to represent the strength of knowledge. The risks are then allocated in the expanded matrix similarly as done in the standard one, and they are marked in white, grey or black as per the SoK ranking in the legend.

Figure 4 Risk matrix example reflecting the strength of knowledge based on Aven (2014) and ROS Sandnes kommune (appendix ref. 20)

- Localized individual risk and risk contours

Localized individual risk or LIRA, is defined as per Rausand (2011) as the probability that an average unprotected person who is permanently present at a specific location, is killed in a period of one year due to an accident at a hazardous installation. LIRA values and their geographical characteristic are used to produce risk contours. Risk contours are then a way to illustrate risk in a geographical location (mainly on land facilities).

An example of LIRA and the risk contour is presented in Figure 5 below, it shows a geographical location of a part of a facility compounded by storage tanks filled with hazardous materials. Three contours (zones) are then established on the location map to indicate the location risk in that specific area. Each area is delimited by a color that represents a given location risk value as per the legend to the right side of the map.

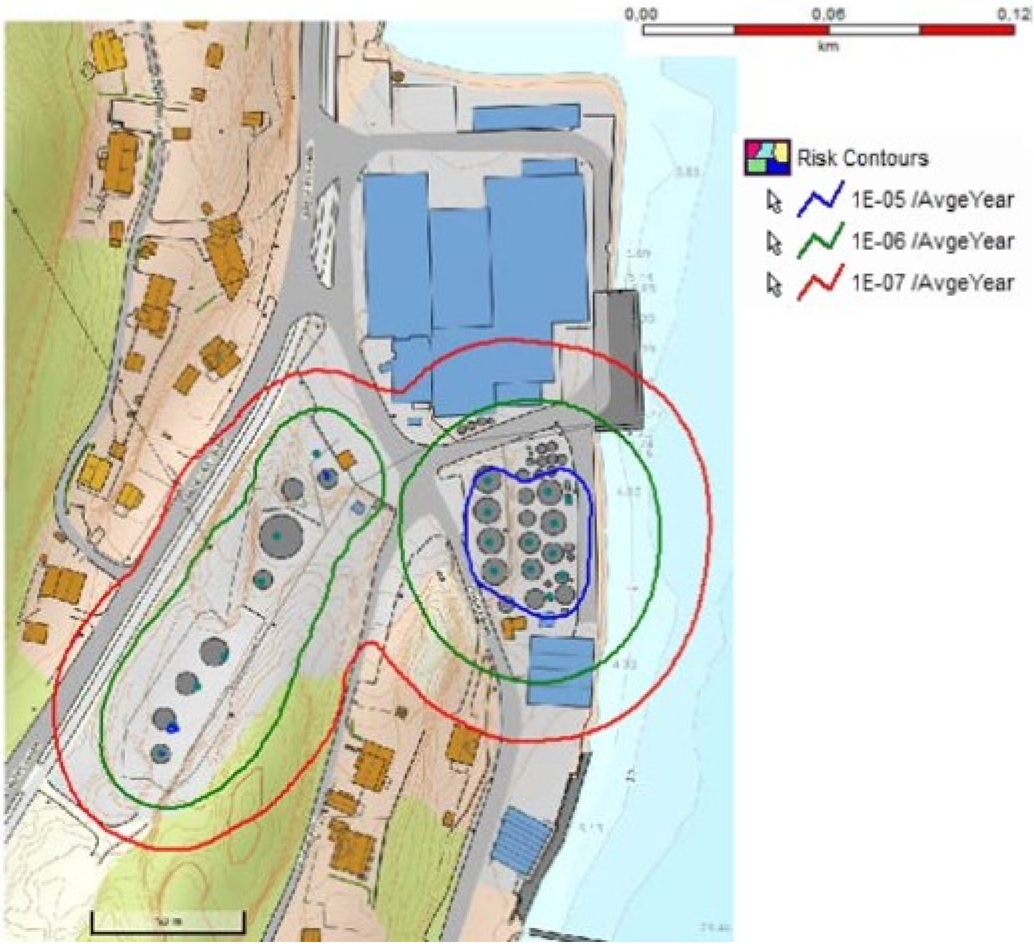

Figure 5 LIRA and risk contour example

- Potential loss of life and fatal accident rate values

The Potential Loss of Life or PLL, is a metric that indicates the expected number of fatalities during a year (Aven 2015). Furthermore, also as per Aven (2015), the Fatal Accident Rate or FAR is defined as the expected loss of life per 100 million hours of exposure.

- F-N curve

As per Aven (2015), an F-N curve is a way to describe risk related to loss of lives in large scale accidents, where F is the frequency of accident events with N fatalities.

Figure 6 below shows an example of an F-N curve. On the y axis, the frequency (average number) of accident events per unit of time (in this case per year) is presented and the x axis indicates the number of deaths per accident. The blue line represents the risk level of the facility and it indicates the frequency of accidents that may cause 1 through 10 thousand fatalities. The red and light brown lines show the tolerance limits or risk acceptance levels.

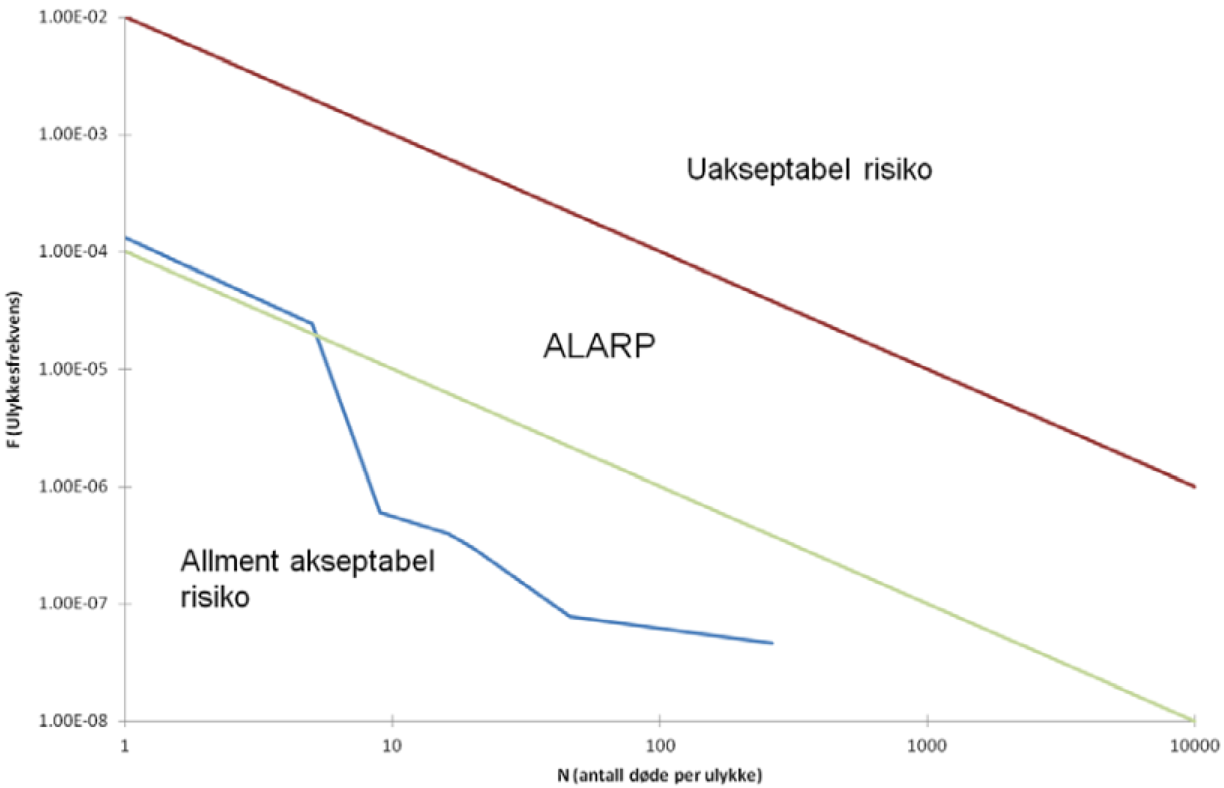

Figure 6 F-N curve example (Risk Assessment of oil and gas storage depot in Tananger area, appendix ref. 31)

2.4.2.3 Risk evaluation

The next step of the risk assessment is risk evaluation. The purpose is to compare the results produced by the risk analysis with the risk evaluation criteria defined during the planning phase. During this phase, the risk analysis results are re-visited to make sure that the correct risk levels are assigned to each risk, especially considering the level of uncertainty behind the assessments. This is important because the risk levels direct the identification of treatments and provide essential decision support for the management (Refsdal, Solhaug et al. 2015).

Further on, the risk levels are evaluated and categorized, the use of risk matrices is a common tool when doing this. During the risk evaluation, it is also important to consider the risk aggregation, as some risks that have been regarded as separate, could be instances of the same risk and therefore should be ‘aggregated’ and evaluated as one risk. An example could be an asset being harmed by more than one incident or an incident that harms more than one asset.

Finally, risks can be grouped according to relationships such as shared vulnerabilities or threats. By placing together risks that may benefit from a common treatment it can facilitate the identification of treatments that give the best effect for the least cost (Refsdal, Solhaug et al. 2015). It is also in this phase where potential preventive barriers are identified together with their efficiency, both single and combined.

2.4.3 Risk treatment

Risk treatment is the final phase of the risk analysis process, here, decisions are made related to the risk-reducing measures. Management plays an essential role as they review and judge the results of the risk assessment together with all uncertainties, assumptions and other industry aspects to the make the final decision related to which measure(s) implement. Normally the effect that the risk-reducing measures have on the overall risk is monitored for further evaluation and use (Rausand 2011).

As per ISO (2018), some options for treating risk can involve:

- Avoiding the risk
- Removing the risk source
- Changing the likelihood
- Changing the consequences
- Sharing the risk (e.g. buying insurance)
- Retaining the risk by informed decision

Following the selection of the risk treatment options, an implementation plan must be developed. It should contain at least the rationale for selection of the treatment options, the roles and responsibilities, actions and resources required, performance measures and the deadlines. Each activity established in the execution plan must be monitored and reviewed.

Lastly, there should be an appropriate level of reporting in order to communicate the risk management activities through the organization. Reporting will also serve as new information for future decision-making and improvement of risk management activities.

3 METHOD AND DATA

This chapter includes the research methodology of the thesis. The author outlines the strategy, methods and criteria used for collecting data. It is also described how the preparation of such data is performed and finally presents the individual descriptions.

The present is an empirical work, as it uses observations of data (in this case risk assessments) to draw the conclusions. (Aven 2018).

The strategy prepared to perform the research is outlined in a general way by the following sequence:

- Set the criteria for collecting the data.
- Collect and categorize relevant risk assessments.
- Prepare the collected data for evaluation.
- Set the premises for the evaluation.
- Evaluate the collected data.
- Compare the risk definition against the risk description and summarize the result.

All the activities indicated in the sequence above are developed in the coming chapters (3.1 through 4.1).

3.1 Criteria for collection of data

The use of risk assessments is widely spread throughout numerous industries, however, many of them are of private access. Some of them are converted into public access, but this normally happens after a few years. Due to this, only risk assessments that are publicly available were collected. This conforms the biggest limitation of the present research.

In the case of this research, the data collected was considered as relevant if it was performed in a span of 15 years between 2004 and 2019. The higher limit of 2019 is established as a consequence of the argument in the previous paragraph, while the lower limit of 2004 is to try to ensure that the data used is as recent as possible.

The majority of the data collected was from companies/organizations located in Norway, of which many have long experience in the application of such methodologies. However, in some instances assessments from other countries were included, especially if considered that they could contribute to the objective of the thesis.

As previously mentioned, there are many types of industries that apply risk assessments within their risk management strategy. In this work, the data considered was limited to three sectors/industries. The idea behind this is to produce more significant and relevant conclusions given the limited amount of data that is evaluated within the timeframe of the work. The three sectors selected were the following: tunnel construction, municipality planning and oil and gas. All of them of high importance for the country.

Online search engines were used to find and collect the data (specifically Google and Bing). The main keywords used for this task were, in Norwegian, 'risikovurdering', 'risikoanalyse', 'kvantitativ', 'kvalitativ', 'tunnel', 'kommune', 'olje', 'gass', 'enkel', risikovurderingskjema', ‘LNG’, ‘brann’, ‘samfunn’, ‘SJA’ and combinations of these, and in English ‘risk assessment’, ‘risk analysis’, ‘quantitative’, ‘qualitative’, ‘tunnel’, ‘municipality’, ‘oil’, ‘gas’, ‘simplified’, ‘LNG’, ‘fire’ and combinations of these.

In order to produce more representative conclusions, risk assessments were collected for each of the categories and types of risk analysis methods presented by Aven (2015).Ref. section 2.4.1. The idea was to collect approximately fifteen risk analyses per sector/industry, evenly divided among each category of risk analysis and with a combination of both qualitative and quantitative types.

Considering the big amount of work involved for collecting, describing and evaluating all the data in addition to the time constraints for the execution of the work, an acceptable data sample size was set between forty (40) to fifty (50) risk assessments. The final sample size in this research was of forty two (42) risk assessments.

Another important criterion for the selection of data is that each risk assessment must contain a clear definition of risk. An effort was made to fulfill this condition as much as possible and it was achieved to a large extent, however, in some situations (for instance when searching for simplified risk assessments) it was found to be rather difficult to find data meeting these criteria. In such cases, risk assessments were still collected and evaluated as if benefits the final result and completeness of the thesis.

For the case of the Oil & Gas industry, after an exhaustive search, no data was found available when it comes to simplified risk assessments. An assumption of this is that this type of documentation is prepared as part of internal HSE routines and is mainly kept within the company’s systems, being therefore not released to the public.

3.2 Data preparation

Before starting with the evaluation, the risk analyses were grouped into three levels. The first level is the sector/industry, the second level risk analysis category and the third level type of risk analysis method. See Figure 7 below for an illustration of the levels.

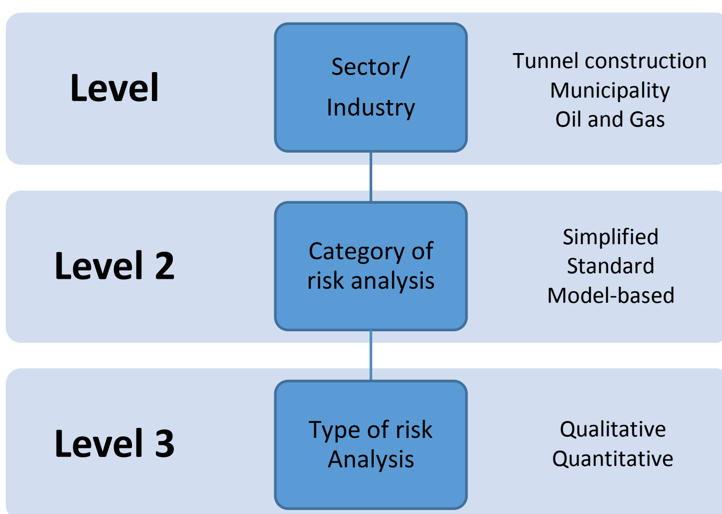

Figure 7 Levels for organization of data

3.3 Premises for description of data

The risk assessments were evaluated in a qualitative manner with the goal of interpreting the ideas behind the contents of interest. The description of each piece of data (risk assessment) consists of the following parts: topic and background, risk definition and risk description.

First, in the topic and background section, general information of the risk assessment is presented. Generally, the identifying number in the data register, the title, the year of execution, the location, a short description of the assessment and the main tools used for hazard/consequence identification and probability estimations are the points of interest of this part.

Next, the risk definition section presents the concept of risk used in the assessment. This could be, for instance, a clear quotation from the documentation terminology or an extraction/interpretation from an explanatory paragraph within the document. The definition is then classified according to the theory in chapter 2.2.

Finally, the risk description section evaluates how risk is described in each risk assessment using as a reference the general description of risk presented by Aven (2015). He explains that a description of risk must contain the elements (A', C', Q, K) where:

- A' identified events of interest (unwanted events)
- C' identified consequences that characterize C
- Q measure of uncertainty of C' (typically probability)
- K background knowledge on which C' and Q are based (models and data used, assumptions, etc.)

A way to describe A', is to present the unwanted events that will be part of the assessment. These may be identified by brainstorming sessions, checklists, HAZID's, previous risk assessments among other methods.

The identified consequences C' are the outcomes of interest upon the occurrence of the unwanted events A'. These can be recognized qualitatively or by the use of models such as event trees. The severity of the identified consequences is of interest in many risk assessments, due to this and for evaluation purposes, the consequences are also classified into **severity intervals** and **precise severities**. Where precise severity means that a severity value is given to each consequence instead of a severity interval.

The measure of uncertainty Q is typically described as a probability (P) in the risk assessments. Because of this, the term used in the coming evaluation to describe uncertainty will be P. In addition, for the purpose of the evaluation, the probability P is classified into **probability intervals** and **precise probabilities**. By precise probabilities, it is meant that a probability value is provided instead of an interval.

One of the ways in which background knowledge, K, can be included in the risk picture is by indicating the basis that has been used in order to come to the conclusions presented in the assessment. This basis could be judgements made by experts, historical data or reports, models and/or simulations among others.

If historical statistics, databases, frequencies or similar are used, a reference should be made to the sources, the period of data collection should be specified. In addition, the actual datasets or other information utilized during the assessment can be included in the appendices. The evaluation will be done based on how well these factors are presented in the assessments.

Based on the above, the scale used for evaluating background knowledge is as follows:

Low level of detail – references to some of the background information is made though not consistently.

Medium level of detail – the assessment indicates the sources and timeframes of the data used for the analysis.

High level of detail – the assessment indicates the sources and timeframes of the data used for the analysis. In addition, it also presents the datasets used as part of the report.

Variable level of detail – this category applies for risk assessments where all the background knowledge used comes from experience and expert judgement. Here the level of detail is only conditional on the level/validity of the expert's competence.

Limitations and assumptions made during the execution of the risk analysis. In this way, awareness is created in the end-user(s) of the report and can take relevant measures or additional considerations.

Another important item that will be captured as part of the evaluation is the risk metric used in the assessments to present/describe the results. These can be risk matrices, PLL/FAR, individual risk values, FN curves, risk contours among others. According to the glossary of the society for risk analysis (Aven, Ben-Haim et al. 2018), the use of such risk metrics can be linked to the different definitions of risk. For instance, a risk assessment that makes use of risk matrices for describing risk supports the use of the definition of risk R=(P&C), as such matrices effectively present a combination of probability and consequences.

In the same way, the use of PLL/FAR values supports the definition of risk R=(E) as these values represent the expected loss of lives in one year/100 million hours exposed respectively. Therefore, mapping the risk metrics used in the risk assessments will be of support in the development in the analysis of the results and further discussion.

3.4 Collected data

In Appendix 8 a list of the collected risk assessments is presented including sources and the unique reference numbers that have been assigned for easier identification throughout the thesis.

3.5 Review/Description of real risk assessments

3.5.1 Tunnel construction sector

3.5.1.1 Risk assessment of 'Follo' tunnel

Ref no: 01 **Location:** Norway **Year:** 2015 **Category:** Standard **Type:** Qualitative

- Topic and background

This risk assessment is carried out to present the risk level and necessary risk-reducing measures for the construction activities (concrete and electrical) related to the overall rehabilitation of the 'Follo' tunnel.

- Risk definition

As per chapter 1.6 of the assessment, "risk is defined as a function of probability and consequence". According to section 2.2.2, this falls within the R=(P&C) concept.

- Risk description

A'= unwanted events were identified by workshops and a generic checklist from the applicable construction regulations (byggeherreforskriften). Also, the construction leader contributed with additional unwanted events specific to the project.

C'= the consequences considered are those that affect life/health and/or cause material costs. Life/health affecting consequences are categorized into intervals as follows: very little consequences (small injury), little consequences (personal injury with absence ≥ 1 day and <10 days), medium consequences (personal injury with absence ≥ 10 days), big consequences (Serious personal injury with lasting damage) and very big consequences (death).

Material costs affecting consequences are also categorized into intervals as follows: very little consequences (<20kNOK), little consequences (20 – 250kNOK), medium consequences (250k NOK – 2m NOK), big consequences (2-50m NOK) and very big consequences (> 50m NOK).

P= consequences are categorized into probability intervals as follows: unlikely (one occurrence in more than 100 years), moderately likely (Once occurrence between 10 and 100 years), likely (one occurrence in one to 10 years) and very likely (More than one occurrence per year)

K= judgements made base on expertise from project leaders and construction leaders. Also by following regulatory requirements, handbooks, fire strategy documentation relevant for the tunnel. Low level of detail is presented with regards to data utilized as background knowledge.

3.5.1.2 Risk assessment of 'Eidsvoll' tunnel

Ref no: 02 **Location:** Norway **Year:** 2006 **Category:** Standard **Type:** Qualitative

- Topic and background

A new tunnel was planned to be built parallel to the existing Eidsvoll tunnel. This risk assessment was performed to map the risk related to the construction, operation and maintenance phases related to the building of the new tunnel.

- Risk definition

As per chapter 2.2 of the assessment: "Risk is defined as a function of probability and consequence". According to section 2.2.2, this falls within the R=(P&C) concept.

- Risk description

A'= unwanted events were identified from a pre-defined set of scenarios connected to the construction and the operation phases. For the construction phase, the focus was on the following scenarios: machines or other equipment clashing with personnel, blast accidents, fire-related to tunnel work, leakage of materials dangerous to health and environment and traffic accidents. For the operation phase, the focus was on pedestrians in the tunnel, objects in the lanes, accidents with/without personal injuries, vehicle accidents, fire in the tunnel, failure in the tunnel technical equipment and leakage of dangerous materials.

C'= consequences that have an impact on both life/health and environment are considered in the assessment. They are categorized into intervals as follows: harmless, a certain danger, dangerous, critical and catastrophic.

Life/health intervals are defined respectively as per the above mentioned categories as no personal injuries, few personal injuries, few but serious personal injuries, one dead/up to 5 serious person injuries/up to 100 evacuated and more than one dead/over 5 serious person injuries/over 100 evacuated respectively

Similarly, environmental consequences as none or almost none consequence, minor environmental damage, extensive environmental damage, serious and dangerous environmental damage and very serious and long term environmental damage.

P= probability intervals are used to describe the frequency of the consequences. The intervals are the same for both life/health and environment consequences, these are: very rare (less often than once every 100 years), rare (once between 10-100 years), can happen (once between 1-10 years), often (once or more per year), very often (ten or more occurrences per year).

K= the event's probability category and consequence class are assessed and determined based on historical statistics and experience from similar tunnel facilities. When data is not available estimates are assigned. Detail regarding data gathered from historical statistics not available. Regarding experience from similar tunnels, it is indicated that all unwanted events between June 2005 and June 2006 were reviewed and classified, the data is included in the report as an appendix. Overall medium level of detail of background knowledge.

3.5.1.3 Risk assessment of 'Stad's' ship tunnel

Ref no: 03 **Location:** Norway **Year:** 2012 **Category:** Model-based **Type:** Quantitative

- Topic and background

A ship tunnel is planned to be built to connect Molde fjord and Kjødepollen. The risk assessment is performed in order to evaluate the risk level of what would be the world's first ship tunnel.

- Risk definition

Chapter 1.3 of the assessment states that: "the risk analysis assumes that the calculated risk is a function of probability (expected frequency) for a given event and expected consequence of this event if it occurs". According to section 2.2.2, this falls within the R=(P&C) concept.

- Risk description

A'= the assessment focuses only on unwanted events related to ship stranding, ship sinking, ship collisions and fire.

C'= the consequences considered in the assessment are those related to personal risk (in this case only number of deaths) and environment risk (exposure of natural resources to eventual emissions from ship accidents).

P= precise probabilities are calculated for the consequences, these are presented as a yearly probability average. Expected deaths are calculated per year and per 100000 ship crossings. Probabilities with regards to impact to environment are estimated based on the expected amount of accidents, accident types and type/size of the ship involved.

K= use of data from AIS (Automatic Identification System) register is used for the analysis of ship traffic, data from years 2008-2010 was utilized. Accident and navigated distance statistics per type of ship and Norwegian accident statistics used. Reference to these databases is presented in the assessment. Medium level of detail of background knowledge.

3.5.1.4 Risk assessment of 'Ljoteli' tunnel

Ref no: 04 **Location:** Norway **Year:** 2016 **Category:** Standard **Type:** Qualitative

- Topic and background

There is a big avalanche danger in the Ljoteli area, a solution to achieve good level protection for this road is then to build a tunnel. Two possible solutions have been proposed, therefore, this risk assessment is made to support the decision between the two alternatives and provide the necessary risk-reducing measures.

- Risk definition

Although the risk assessment does not present a clear definition of risk, based on the risk evaluation made in chapter 5.2, it is noted that the focus is kept on evaluating the severity of the consequence and the probability. Therefore, it is assumed that the risk definition used in the assessment is that of chapter 2.2.2, where risk is the function of probability and consequences.

- Risk description

A'= unwanted events identified by the use of a supporting table (checklist) from the Norwegian road directorate as a guideline. This table considers the most typical unwanted events for road tunnels such as traffic accidents, fires, leak of dangerous goods, and vehicle stop among others.

C'= the consequences considered are those that threaten life/health to humans. They are categorized into minor damage, severe damage, one death, more than one death.

P= probabilities are assigned qualitatively based on experience and accident frequencies. They are categorized into: very rare (once every 30 years), rare (once every 10-30 years), often (once every 1-10 years) and very often (at least once every year).

K= use of a model for calculating the accident frequencies based on technical data input from tunnel characteristics, etc. Probabilities and severity of consequences are assigned by experience, historical databases and previous in-depth analyses of tunnel accidents. In most cases, during the evaluation of the risks, it is referred to the source of the historical information/statistics, including the period where the statistics were considered. Also, the documentation containing the data used is included in the references of the assessment. Medium-high level of detail of background knowledge.

3.5.1.5 Risk assessment of 'Sørfold' tunnels

Ref no: 05 **Location:** Norway **Year:** 2016 **Category:** Standard **Type:** Qualitative

- Topic and background

The existing tunnels between Megården and Mørsvikbotn do not fulfill the minimum safety requirements. It has been decided to build eleven new tunnels that comply with the requirements. A risk assessment has been made to highlight the risk level of implementing such a solution and to present eventual risk-reducing measures. Due to the big amount of tunnels (11), they were categorized into three groups. The premise was to group the tunnels with similar characteristics (big/small lengths and gradient)

- Risk definition

As per chapters 3.1.2, 3.2.2 and 3.3.2 of the assessment, risk is defined as a function of probability and consequences. According to section 2.2.2, this falls within the R=(P&C) concept.

- Risk description

A'= unwanted events identified for each group via HAZID and guidelines from the Norwegian road directorate. Some of these events are different types of traffic accidents and fires.

C'= consequences considered are those that impact life/health. They are categorized into light injury, serious injury and death.

P= probabilities are categorized by intervals for each of the consequences. The intervals are: very rare (once in 200+ years), rare (once in 11-100 years), often (once in 2-10 years), very often (at least once per year).

The assessment also presents a summary of the probabilities and consequences per group. It assesses the number of accidents with personal injuries in general and then indicates the portion of these accidents with serious and light injuries. When doing this, it also presents frequency categories based on average values. For example, from the category of rare (once in 11-100 years), a new category is created for the summary value giving once in six years as a result.

K= assessments are done based on the evaluating group's competence, technical information of the tunnels, use of handbooks and historical statistic data on recorded incidents in road tunnels over the past 20-30 years. No reference to documents, databases nor datasets used. Low level of description of background knowledge.

3.5.1.6 Risk assessment of 'Gundvanga' tunnel

Ref no: 06 **Location:** Norway **Year:** 2013 **Category:** Standard **Type:** Qualitative/Quantitative

- Topic and background

Upon rehabilitation of 'Gundvanga' tunnel, a risk assessment was performed to support the decision-making between the different upgrade proposals. This assessment states that they use qualitative analysis with expert statements but they also make use of quantitative analysis to model and determine the risk picture.

- Risk definition

A definition of risk is not presented in the assessment, however, it is assumed the use of risk as expected values given the fact that within the assessment, uncertainty is presented as a frequentist probability for each consequence based on the results of the model.

- Risk description

A'= the unwanted events considered in the risk analysis are those related to traffic accidents, fires and transport of dangerous goods.

C'= only consequences that cause personal injury/death are considered in the assessment. These are number of deaths per year, number of injuries per year and number of accidents per year.

P= precise probabilities for all the combinations of the consequences/unwanted events are calculated and presented. This is done by means of a model setting as inputs the technical conditions for each of the upgrade proposals.

K= there is a great deal of information and data that forms the basis of this risk assessment. It uses as basis Norwegian rules, regulations and standards, survey of the existing tunnel, historical accident data. Follows tunnel risk assessment methodology literature. Makes use of information on transport of dangerous goods in tunnels, fire and smoke studies in tunnels among others. All sources of background knowledge are presented in detail in the reference list including the applicable period for data collection. Medium-high level of background knowledge description.

3.5.1.7 Risk assessment of 'Kvarv-Kalvik' tunnels

Ref no: 07 **Location:** Norway **Year:** 2016 **Category:** Standard **Type:** Qualitative

- Topic and background

In a later development stage of the construction of the 'Sørfold' tunnels (ref 3.5.1.5), it was decided that due to geotechnical reasons, two of the tunnels would be combined into one longer tunnel. Therefore, a new risk assessment was carried out to cover only this part of the project which represents a change of design/conditions.

- Risk definition

As per chapter 3.1.2 of the assessment, risk is defined as a function of probabilities and consequences. This falls within the R=(P&C) concept according to section 2.2.2.

- Risk description

A'= unwanted events were identified via HAZID meetings. The focus was kept on those that could lead to personal injury/death.

C’= consequences of the unwanted events were categorized into light injury, serious injury and death.

P= the consequences are assigned into different probability intervals as follows: very rare (one occurrence in more than 100 years), rare (one occurrence in 11-100 years), often (one occurrence in 2-10 years) and very often (at least one occurrence per year).

K= the background knowledge for this assessment is supported by expert judgements, regulations. Use of handbooks and historical statistic data on recorded incidents in road tunnels over the past 20-30 years. No reference to documents, databases nor datasets used. Low level of description of background knowledge.

3.5.1.8 Risk assessment of ‘Ulsberg –Vindåsliene’ tunnels

Ref no: 08 **Location:** Norway **Year:** 2018 **Category:** Standard **Type:** Qualitative

- Topic and background

The purpose of this risk assessment is to map the risk picture in the ‘Ulsberg’ and the ‘Vindåsli’ tunnels in the ‘Rennebu’ and ‘Midtre Gauldal’ municipalities, with regard to personal safety and propose risk-reducing measures.

- Risk definition

Risk is not defined in the risk assessment. However, chapter 9 states the following “A semi qualitative evaluation is done of the probabilities and consequences” then it follows that the assessment bases itself in risk as a function of probabilities and consequences. This falls within the R=(P&C) concept according to section 2.2.2.

- Risk description

A’= unwanted events that can result in personal injury/death are the focus of the analysis. The applicable unwanted events for the tunnels in question are traffic accidents, fire, leakage of dangerous goods and rock falling (from cuts at tunnel mouths)

C’= consequences are categorized by intervals as follows: slight injury, serious injury, one to four deaths, five to twenty deaths and more than fifty deaths.

P= probabilities are assigned to the consequences also in intervals. These intervals are: extremely rare (less than one occurrence in 1000 years), very rare (one occurrence in 101-1000 years), rare (one occurrence in 11-100 years), often (one occurrence in 2-10 years) and very often (at least one occurrence per year).

K= checklist from the road directorate guidelines was used during HAZID for the identification of unwanted events. Technical information of the tunnels, tunnel regulations and handbooks, historical statistics, fire studies of vehicles inside tunnels.

An own chapter in the assessment is dedicated to talking about uncertainty around the assessment. It is explained that even though historical statistics can give an indication of future events the fact that an event has not happened before, it may still occur in the future. In addition, it is mentioned that even with lots of background knowledge, there is always uncertainty over the results and an example of what they consider the biggest uncertainty is:

humans and human behavior. Reference to reports of historical statistics for fire in tunnels included in the assessment including the collection period. Low-medium level of description of background knowledge.

3.5.1.9 Risk assessment of 'Niagara' tunnel

Ref no: 09 **Location:** Canada **Year:** 2005 **Category:** Model-based **Type:** Quantitative

- Topic and background

Upon the construction of a 10,5km long tunnel to carry water from the Niagara River above the falls, under the city of Niagara Falls, to Sir Adam Beck 1 and 2 generating stations a quantitative risk assessment was conducted for the design and construction phases of the project.

- Risk definition

As per chapter 1.3 of the assessment: "risk is expressed as the combination of the likelihood of an event occurring over a specified time frame, and the consequence if the event occurs". This falls within the R=(P&C) concept as described in section 2.2.2.

- Risk description

A'= a full list of unwanted events was identified in a previously performed Qualitative risk analysis. From this list, the expert's panel selected the events to be considered in the quantitative risk analysis based on an established set of premises that mainly focus on increase of cost in the project and increased duration of the project (delays).

C'= two consequences are considered for each unwanted event. These are impact on project cost and impact on project schedule. Mean values are presented together with lowest and highest values (interval) based on the results of the probability distributions. The units used are dollars and weeks respectively.

P= precise probabilities for each consequence were calculated by means of Monte Carlo simulations and the probability distribution of possible outcomes (such as log-normal distribution for cost and plan delays)

K= expert judgement, input from previous qualitative risk assessment and simulations. Method for modelling and detailed model calculation output is included in the assessment as an appendix. No other detail is presented regarding sources of data or explanation for the selection of probability distributions for use in the model. Low-medium level of description of background knowledge.

3.5.1.10 Risk assessment of 'E-39 Rogfast' tunnel

Ref no: 10 **Location:** Norway **Year:** 2014 **Category:** Model-based **Type:** Qualitative/Quantitative

- Topic and background

The construction of the E39 Rogfast tunnel was in the planning phase, a risk assessment was made back then based on the technical specifications. Later, these technical specifications were modified and the new tunnel design will have a new maximum gradient of 5,15%. Also, the total length of the tunnel is increased. Due to this, the existing risk analysis was updated.

- Risk definition

In chapter 1.3 of the assessment, it is stated that "Risk is measured, among other things, by fire frequency and the number of people killed". Therefore it is assumed that risk is defined as probability and consequences. Definition as per chapter 2.2.2.

- Risk description

A'= unwanted events analyzed in the assessment are as follows: traffic accidents (which do not develop into fire), fire and explosion accidents (including those that have evolved from traffic accidents), emissions/leakage of hazardous substances or gases (FG accidents), floods, (water intrusion / flood), landslides and closing due to technical failure.

C'= the consequences considered in the assessment are categorized into: Deaths, accidents and fires.

P= a model (TRANSIT) is used for calculating the number of deaths per year, the amount of injured per year and amount of accidents per year. These are calculated for the total tunnel and also for the segments.

K= data used as background information is presented in the assessment. It includes technical design of the tunnel, sources, periods, locations, references and snapshots of the data sets. It also describes why the selected data was utilized. High level of detail.

3.5.1.11 Risk assessment of 'Skálafjord' tunnel

Ref no: 11 **Location:** Faroe Islands **Year:** 2006 **Category:** Model-based **Type:** Quantitative

- Topic and background

Upon the construction of the 'Skálafjord' tunnel, two technical solutions were considered. One includes two separate tunnels and the other one includes one tunnel with a T solution. A risk assessment was performed to serve as support for the decision-makers.

- Risk definition

In chapter 4.8 of the assessment, it is stated that the acceptance criteria used in the assessment is based on FN-curve (F for frequency and N for the number of fatalities). It is then assumed that the definition of risk being used is R=(P&C) as described in chapter 2.2.2 of the theory.

- Risk description

A'= unwanted events are those that can lead to loss of life/health of people. Events such as fire and traffic accidents.

C'= the only consequence evaluated is the number of deaths

P= probabilities are calculated by means of event trees and models for the consequence in each scenario.

K= system description and data used as input to the models are presented in the assessment. Datasets of historical accident data are also included with sources and timeframes. Assumptions behind the models are highlighted and presented in a table. All data input to the model is included in the appendix. High level of detail.

3.5.1.12 Risk assessment of 'Gudvanga' tunnel (2)

Ref no: 12 **Location:** Norway **Year:** 2016 **Category:** Simplified **Type:** Qualitative

- Topic and background

A simplified risk assessment was performed before initiating construction activities for upgrading the tunnel.

- Risk definition

Risk itself is not defined, however when identifying, assessing and describing the risk three aspects are considered: critical activities, what can go wrong and (risk-reducing) measures.

- Risk description

A'= unwanted events are identified in a meeting upon reviewing the activities to be performed. Events considered are danger of collision, aggressive and unaware (lack of attention) drivers and misunderstandings during column driving.

C'= the focus is kept on what can go wrong (unwanted events) and mitigation measures rather than on the consequences. However, it is noted that some of the consequences considered are those that negatively impact the life/health of the persons involved and the tunnel users.

P= no probabilities assigned

K= a short description of the area and the tunnel is presented in the assessment. Brainstorming session carried out with all the personnel that will be involved in the activity. As the main knowledge comes from experience/expertise/competence of the personnel involved, the detail level of the background knowledge highly depends on this factor. No considerations are presented regarding the strength of knowledge.

3.5.1.13 Risk assessment of 'Fretheim' tunnel

Ref no: 13 **Location:** Norway **Year:** 2017 **Category:** Simplified **Type:** Qualitative

- Topic and background

A simplified risk assessment was performed before initiating the following activities in the tunnel: setup of traffic signs, personnel on the side of the road, stopping traffic, setup and control of column driving.

- Risk definition

No formal definition of risk is presented in the assessment, however, it is explained that the following questions are considered when assessing risk: what can go wrong, what can be done to prevent it and what can be done to reduce the consequences in case it happens.

- Risk description

A'= the unwanted events evaluated are those related to the activities that will be executed. These are danger of collision, inattentive drivers, setup and control upon column driving.

C'= consequences are categorized into small (1), medium (2) and big (3) by the assessor group.

P= probabilities are categorized into small (1), medium (2) and big (3) by the assessor group.

K= background knowledge comes mostly from the experience that the personnel involved in the work has, as a result, the level of detail is highly dependent on this. No considerations are presented regarding strength of knowledge.

3.5.1.14 Risk assessment of 'Onstad' tunnel

Ref no: 14 **Location:** Norway **Year:** 2017 **Category:** Simplified **Type:** Qualitative

- Topic and background

A simplified risk assessment was performed before initiating the following activities: setup of traffic signs, traffic indicating personnel by the side of the road, stopping traffic, setup and control of column driving.

- Risk definition

No formal definition of risk is presented in the assessment, however, it is explained that the following questions are considered to assess risk: what can go wrong, what can be done to prevent it and what can be done to reduce the consequences in case it happens.

- Risk description

A'= the unwanted events evaluated are those related to the activities that will be executed. These are danger of collision, inattentive drivers, setup and control upon column driving.

C'= consequences are categorized into small (1), medium (2) and big (3) by the assessor group.

P= probabilities are categorized into small (1), medium (2) and big (3) by the assessor group.

K= background knowledge comes mostly from the experience that the personnel involved in the work has, as a result, the level of detail is highly dependent on this. No considerations are presented regarding strength of knowledge.

3.5.1.15 Risk assessment of 'Bømlafjord' tunnel

Ref no: 15 **Location:** Norway **Year:** 2017 **Category:** Simplified **Type:** Qualitative

- Topic and background

A simplified risk assessment was performed before initiating the following activities: setup of traffic signs and use of lifting equipment inside the tunnel.

- Risk definition

No formal definition of risk is presented in the assessment, however, it is explained that the following questions are considered to assess risk: what can go wrong, what can be done to prevent it and what can be done to reduce the consequences in case it happens.

- Risk description

A'= the events evaluated are those related to the activities that will be executed, these are collision with working personnel, collision of lifting equipment, blockage of emergency vehicle and fires in cars.

C'= consequences are categorized into small (1), medium (2) and big (3) by the assessor group.

P= probabilities are categorized into small (1), medium (2) and big (3) by the assessor group.

K= background knowledge comes mostly from the experience that the personnel involved in the work has, as a result, the level of detail is highly dependent on this. No considerations are presented regarding strength of knowledge.

3.5.1.16 Risk assessment of 'Lyderhorn' tunnel

Ref no: 16 **Location:** Norway **Year:** 2017 **Category:** Simplified **Type:** Qualitative

- Topic and background

A simplified risk assessment was performed before initiating the following activities: setup of traffic signs, manual control of traffic and work inside the tunnel.

- Risk definition

No formal definition of risk is presented in the assessment, however, it is explained that the following questions are considered to assess risk: what can go wrong, what can be done to prevent it and what can be done to reduce the consequences in case it happens.

- Risk description

A'= the events considered in the assessment are collision and accidents related to the traffic and working personnel inside the tunnel.

C'= consequences are categorized into small (1), medium (2) and big (3) by the assessor group.

P= probabilities are categorized into small (1), medium (2) and big (3) by the assessor group.

K= background knowledge comes mostly from the experience that the personnel involved in the work has, as a result, the level of detail is highly dependent on this. No considerations are presented regarding strength of knowledge.

3.5.2 Municipality sector

3.5.2.1 Risk assessment fire and rescue, 'Rogaland' fire department

Ref no: 17 **Location:** Norway **Year:** 2018 **Category:** Standard **Type:** Qualitative

- Topic and background

A risk assessment was carried out to provide an updated overview of risk and challenges in the region that the Rogaland fire department is expected to prevent and/or manage.

- Risk definition

In chapter 1.3.1 of the assessment, it is stated that the definition of risk used is as follows "Risk refers to uncertainty about and severity of the events and consequences (or outcomes) of an activity with respect to something that humans value". The assessment further explains that such definition includes the uncertainty inherent in the risk concept and captures the subjective dimension of risk as a phenomenon. Definition as per chapter 2.2.3.

- Risk description

A'= the most frequent events occurring in the municipalities that conform the county were selected. Based on that, unwanted events that were part of the following categories were the main focus: natural events, fire in buildings, other fires and accidents, fire and accidents in industrial facilities, fire in tunnels and parking facilities, transport accidents and fires in accidents.

C'= consequences for each unwanted event are presented especially from the life/health perspective, however, the focus is not only kept on the consequences itself but on how the municipality will be able to react based on the current situation, training, equipment and overall preparedness level.

P= probabilities are not assigned to the consequences. However, it presents historical data for similar events/consequences to give an idea to the end-user. The assessment then proceeds to describe, based on the current situation, how well prepared the fire department is if a similar event were to occur in the county.

K= the background knowledge upon which the assessment is based comes from meeting with emergency leaders in all the municipalities, other municipal risk analyses, national statistics, reports and experience. The historical data sources are presented in the assessment, some of these include the period of data collection but not all. Medium level of detail when describing background knowledge.

3.5.2.2 Risk assessment fire and rescue, 'Østre Adger' fire department

Ref no: 18 **Location:** Norway **Year:** 2018 **Category:** Standard **Type:** Qualitative

- Topic and background

Østre Adger fire brigade is a collaboration between the municipalities of Arendal, Froland, Tvedestrand, Vegårshei, Risør, Gjerstad and Åmli. This risk assessment is performed to identify the risk and vulnerability of serious accidents and fires in these regions.

- Risk definition

As per the list of abbreviations in the assessment: "risk is an assessment of whether an event can occur, what the consequences will be and the uncertainty associated with them". This falls within the definition as per chapter 2.2.3, R=(C&U).

- Risk description

A'= diverse unwanted events under the following categories are analyzed: fire, accidents, natural events and others.

C'= Consequences considered in the assessment are those that impact the life/health of persons, environment and cultural value, material value/cost and community. The severity of the consequences for all the perspectives mentioned above is categorized into insignificant, less severe, serious, very serious and extremely serious.

P= 'Probabilities for each of the consequences are categorized into intervals as follows: extremely likely (several times in a year), very likely (once per year), likely (once in a 1-9 year interval), less likely (once in a 10-49 year interval), unlikely (less often than once in 50 years).

K= background information comes from historical statistics, key analyzes and reports such as other fire services' risk assessments, county risk assessment, professional knowledge and other experiences from events both locally, regionally and nationally are used. For incidents that occur less frequently, or which have not yet occurred, the probability assessments are based on discussion and on the expertise of the actors involved. Snapshots from the datasets of the different databases used are presented together with periods of collected data. Also, all databases and other data sources utilized are included in the reference list. High level of detail when presenting background knowledge.

3.5.2.3 Risk assessment of 'Sola' municipality

Ref no: 19 **Location:** Norway **Year:** 2012 **Category:** Standard **Type:** Qualitative

- Topic and background

Sola municipality conducted a risk and vulnerability analysis in order to map, systematize and assess the likelihood of adverse events that may occur and how they may affect the municipality.

- Risk definition

As per chapter 3.1 of the assessment: "Risk is a result of the likelihood (frequency) and consequences of adverse events". This falls within the R=(P&C) concept as described in section 2.2.2.

- Risk description

A'= the events considered are those related to natural events (avalanches, extreme weather) and those that affect human and businesses (fire, water supply, contamination)

C'= the focus is kept on consequences that have an impact on the life/health of persons, environment, material value/cost and community. The severities of the consequences for all the perspectives mentioned above are categorized into no consequence, low, medium, high and catastrophic.

P= probabilities for the consequences are presented as intervals. These are categorized as: excluded from happening (one occurrence between 100 and 1000 years. 0-3%), low (one occurrence in 10-100 years. 4-10%), medium (one occurrence in 5-10 years. 11-40%), high (one occurrence in 1-5 years. 41-97%) and guaranteed to happen (more than one occurrence per year. 98-100%).

K= use of regulations and guidelines, statistic history when available, otherwise assessments made based on expert judgements. The source of the background data is presented for most of the risks some even provide the period of collection of data. A few of the risks present snapshots with the actual data set utilized. Medium-high level of detail of background information.

3.5.2.4 Risk Assessment of 'Sandnes' municipality

Ref no: 20 **Location:** Norway **Year:** 2019 **Category:** Standard **Type:** Qualitative

- Topic and background

A risk assessment was performed in the Sandnes municipality to map, systematize and assess the likelihood of adverse events that may occur and how these may affect the municipality.

- Risk definition

As per the definitions list presented in the assessment: "Risk is an assessment of whether an event can occur, what the consequences will be and uncertainty in relation to this". This falls within the definition as per chapter 2.2.3, R=(C&U).

- Risk description

A'= on the basis of interdisciplinary expertise from the two working groups, the undefined hazard and undesirable events were identified. A list of 26 unwanted events was made related to natural disasters, accidents, contamination, life/health and impact to cultural sites.

C'= consequences considered are those that have an impact on life/health, stability, nature and environment ad material value. Consequences are categorized into five severity categories, however, it is not explained what each category entails nor its limits.

P= probabilities for the consequences are divided by categories, each category represents an interval. These are as follows: very low (less than one occurrence in a 100 years. <0,1%), low (once in 100-1000 years. 0,1%-1%), medium (once in 50-100 years. 1%-2%), high (once in 10 to 50 years. 2%-10%), very high (more often than once in 10 years. >10%).

K= database data is taken from previous incidents in municipalities or where a similar incident has taken place. Knowledge based on the competence of each service area, company, government and organization have also been used. Relevant physical data, statistics, threat assessments and other risk assessments. The assessment presents references and electronic links to the actual documentation used as basis. Medium level of detail when describing background knowledge.

3.5.2.5 Risk Assessment of 'Troms' county

Ref no: 21 **Location:** Norway **Year:** 2016 **Category:** Standard **Type:** Qualitative

- Topic and background

The risk assessment is performed as part of country requirements towards municipalities. With the purpose of having a platform to prevent undesirable incidents and strengthen the coordination of regional work on social security, emergency preparedness and crisis management.

- Risk definition

As per chapter 1.2.1, "An assessment of the risk of an incident must say something about the likelihood that it will occur and what consequences it may have". This definition falls within the R=(P&C) concept as described in section 2.2.2.

- Risk description

A'= unwanted events were analyzed based on the three following categories: natural events, major accidents and intended incidents.

C'= the consequences considered in the assessment are those that have an impact in life/health of population, nature and environment, economy and stability of the municipality. These are categorized by severity into: very small, small, medium, big and very big

P= probabilities were assigned to the consequences are categorized in intervals as follows: very low (one occurrence in 400 or more years), low (one occurrence in 100-400 years), medium (one occurrence in 50-100 years), high (one occurrence in 10-50 years) and very high (more than one occurrence in 10 years)

K= the background of each unwanted event is described including previous relevant occurrences and statistics. These are presented with the sources, years and for some events snapshots of the historical dataset used are included. Medium-high level of detail when describing background knowledge.

3.5.2.6 Risk Assessment of ice impacts from the windmill park in the 'Roan' municipality

Ref no: 22 **Location:** Norway **Year:** 2009 **Category:** Model-based **Type:** Quantitative

- Topic and background

Certain combinations of temperature, humidity and wind speed may result in ice formation on wind turbines. Because of this, a risk assessment was performed in a windmill park in the Troms municipality to assess the risk picture and evaluate possible risk-reducing measures upon ice formations falling on first (workers of the park), second (visitors to the park) and third parties (reindeer farmers and other persons in the vicinity).

- Risk definition

As per footnote 6 of chapter 5.4 of the assessment, "risk is defined as risk x consequence". This definition falls within the R= (P&C) concept as described in section 2.2.2.

- Risk description

A'= the assessment revolves around one main unwanted event which is ice being dropped from the blades of the windmills

C'= the consequences considered are those that may cause deaths towards first (workers of the park), second (visitors to the park) and third persons (reindeer park and other persons in the area)

P= probabilities are calculated in the model as individual risk (LIRA). This term is defined in the assessment as: "the likelihood for death of single individuals who are exposed to an accident event". The area around each windmill is divided into categories as per the calculated

LIRA values. In addition, the assessment presents probabilities per category groups (first, second and third person)

K= details how the model was set up, how calculations were made and where input data comes from. Presents sources, types and periods of data used. It also makes use of existing assessments for similar scenarios as guidelines and follows governmental requirements. Medium-high level of detail.

3.5.2.7 Risk Assessment of expansion of zinc plant in the 'Odda' municipality

Ref no: 23 **Location:** Norway **Year:** 2019 **Category:** Standard **Type:** Qualitative

- Topic and background

Boliden AS has plans to expand its zinc plant. This expansion includes new process equipment, a new sulfuric acid plant and an electrolysis hall. The plant is located approximately 2-3 km from the center of Odda municipality. As a municipal requirement, a risk assessment is performed to present the risk picture and evaluate possible risk-reducing measures connected to the expansion of the plant.

- Risk definition

According to chapter 1.3 of the assessment, "risk is an expression of the combination of probability and consequence of an unwanted event". This definition falls within the R=(P&C) concept as described in section 2.2.2.

- Risk description

A'= unwanted events applicable for this case were identified by the use of checklists from official guidelines and expert judgement. The focus was kept on unwanted events related to natural disasters, internal facility hazards, infrastructure, intended actions (sabotage, terrorism) and isolated accidental events in the plant area.

C'= the consequences are assessed in terms of "Life and health", "Stability" and "Material values". All these were categorized into: very small consequence (no personal injury, no damage nor loss of stability, <100k kroner), small consequence (personal injury, insignificant damage or loss of stability, material damage between 100k and 1 million NOK) medium consequence (serious personal damage, short term damage or loss of stability, material loss between 1 and 10 million NOK), big consequence (one death, damage or loss of stability of some duration, material loss between 10 and 100 million NOK) and very big consequence (more than one death, long term damage or loss of stability, material loss >100 million NOK)

P= Probabilities are assigned into intervals and categorized as follows: unlikely (one occurrence in 1000 or more years), moderately likely (one occurrence in 100-1000 years), likely (one occurrence in 10-100 years), very likely (one occurrence in 1-10 years) and extremely likely (more than one occurrence per year)

K= Assessment based on existing knowledge, experience and professional knowledge. Reference list to all background documentation used is included in the assessment including source and year. Medium level of detail of background knowledge.

3.5.2.8 Risk Assessment of marine route change due to modifications in Bodø airport

Ref no: 24 **Location:** Norway **Year:** 2019 **Category:** Model-based **Type:** Quantitative

- Topic and background

Due to the major modifications to be done in the Bodø airport, there will be conflict between the airport lights and the marine route lights. There are two main marine routes in the area: Hernesskagleia and Svartoksleia with the former passing closer to the airport area than the latter. It has been proposed to close the Hernesskagleia route and transfer the traffic to the Svartoksleia route. Therefore a risk assessment was performed to evaluate the effectivity of such risk-reducing measure.

- Risk definition

In chapter 4.1 of the document, it is stated that "the risk assessment mainly consists of a frequency analysis for estimating the expected number of accidents". Based on this statement it is assumed that they define risk as R=(C&P) as described in chapter 2.2.2 of the theory.

- Risk description

A'= the unwanted events considered in the assessment are those related to navigation risks and impact on the environment due to increased emissions caused by the longer route.

C'= the consequences evaluated in the risk assessment are grounding, collision and emissions to the environment.

P= probabilities for all consequences are calculated using a model. These values are presented as average yearly values.

K= Use of AIS to evaluate marine traffic in the area. Indicates and justifies why the data parameters were selected/used. Indicates and explains the source used for calculating traffic prognosis. Datasets included as part of the assessment in Appendix A. Medium-high level of detail.

3.5.2.9 Risk assessment of social security when establishing NOKAS facility in Stavanger

Ref no: 25 **Location:** Norway **Year:** 2005 **Category:** Model-based **Type:** Quantitative

- Topic and background

A risk assessment has been carried out to assess the social safety of establishing NOKAS's facilities in Stavanger. This risk assessment was presented as a support documentation to determine whether NOKAS will receive the final completion certificate by the municipality, and what risk-reducing measures should be investigated and implemented.

- Risk definition

As per Appendix A of the assessment, risk is defined by three dimensions: unwanted event, probability and consequence. This falls within the R=(C&P) definition as described in chapter 2.2.2.

- Risk description

A’= unwanted events considered are those that can impact life/health of third parties. Events such as attack on value transport truck, use of explosives to enter the facility, take hostages to enter the facility, among others were part of the assessment.

C’= the consequences considered in the assessment are incidents with injured persons, incidents with dead persons and incidents with five or more people killed (major accident).

P= probabilities are presented by calculating the outcomes of the event trees for each scenario.

K= all the statistics and historical data used in the assessment are included in the references with sources and timeframes. Data used and justification for its use are presented and described in the assessment. Datasets used are included in the appendices. High level of detail.

3.5.2.10 Risk assessment for the upgrade of a chemical facility in 'Færder' municipality

Ref no: 26 **Location:** Norway **Year:** 2018 **Category:** Model-based **Type:** Quantitative

- Topic and background

The chemical plant wants to expand its storage capacity of flammable products. As a result, a risk assessment was made with the purpose of calculating the risk for third persons in connection with the operation of the production plant.

- Risk definition

As per chapter 3.1 of the assessment, "risk is defined as a function of the probability and consequence". This falls within the R=(C&P) as described in chapter 2.2.2.

- Risk description

A’= the unwanted events focus on events that may pose a risk to personnel at the plant and third persons. These are collisions, leakages and sabotages. HAZID methodology used to identify relevant events.

C’= consequence considered are loss of lives. These are calculated by use of software tools in number of deaths per year.

P= probability calculations are made based on the historical guidelines and description of the facility.

K= historical data on leakages and weather is included in the references with sources and timeframes. The technical information of the facility is presented. Medium level of detail.

3.5.2.11 Risk assessment for change of detail regulation for ‘Rambergneset’ municipality

Ref no: 27 **Location:** Norway **Year:** 2017 **Category:** Simplified **Type:** Qualitative

- Topic and background

This simplified risk assessment was performed upon the change of detail regulation of the Rambergneset area due to the construction of new cabins.

- Risk definition

The assessment does not present a formal definition of risk. However, it is specified that the aspects evaluated are which undesirable events may occur, how likely they are, the consequence of such events and the measures that can counteract the risk and extent of damage

- Risk description

A'= the unwanted events of interest are identified with the help of a checklist. These are noise/pollution from traffic, traffic accidents, avalanches, landslides, floods and high voltage lines.

C'= consequences are categorized into harmless, slightly dangerous, dangerous, critical and catastrophic.

P= probabilities are categorized into: rare, unlikely, moderate likely, likely, very likely and almost certain

K= a rough description is presented for each unwanted event, it also explains the current situation and characteristics of the surroundings. Low level of detail of background knowledge.

3.5.2.12 Risk assessment for area planning in 'Jentoftbukta, Sør-Varanger' municipality

Ref no: 28 **Location:** Norway **Year:** 2013 **Category:** Simplified **Type:** Qualitative

- Topic and background

This simplified risk assessment was performed upon the review of the area regulation in Sandnes municipality

- Risk definition

The assessment does not present a formal definition of risk. However, it is specified that the aspects evaluated are which undesirable events may occur, how likely they are, the consequence of such events and the measures that can counteract the risk and extent of the damage.

- Risk description

A'= the unwanted events of interest are identified with the help of a checklist. These are noise/pollution from traffic, traffic accidents, avalanches, landslides, floods and high voltage lines.

C'= consequences are categorized into harmless, slightly dangerous, dangerous, critical and catastrophic.

P= probabilities are categorized into: rare, unlikely, moderate likely, likely, very likely and almost certain.

K= a rough description is presented for each unwanted event, it also explains the current situation and characteristics of the surroundings. Low level of detail of background knowledge.

3.5.2.13 Risk assessment for area planning of a salmon facility in 'Nordkapp' municipality

Ref no: 29 **Location:** Norway **Year:** 2011 **Category:** Simplified **Type:** Qualitative

- Topic and background

This simplified risk assessment was performed upon the review of area planning with regards to the salmon facility in Nordkapp municipality.

- Risk definition

No formal definition of risk is presented in the assessment.

- Risk description

A'= the unwanted events of interest are identified with the help of a checklist. These are related to natural events, infrastructure and project-specific risks.

C'= no consequences are presented. However, a comparison is made between the current situation and the requirements from the authorities to determine if further measures must be taken.

P= probabilities are not used in the assessment, rather, a view of current situation vs authority requirements is presented.

K= background knowledge documented for some of the unwanted events. A few precious reports are referenced to. Low level of detail.

3.5.2.14 Risk assessment for the new house zoning plan in 'Luster' municipality

Ref no: 30 **Location:** Norway **Year:** 2017 **Category:** Standard **Type:** Qualitative

- Topic and background

A new zoning plan was being prepared to lay the framework for further development of housing on Luster municipality. A risk assessment was then performed with the purpose of providing an overall and representative representation of the risk of injury to third person, life and health, material values and the environment in the zoning plan.

- Risk definition

Chapter 1.4 of the assessment defines risk as "Expressions for the combination of probability and consequence of an undesirable event". This definition is consistent with the R=(P&C) concept as described in chapter 2.2.2 of the theory.

- Risk description

A'= unwanted events were identified with the help of a checklist. The events evaluated are those related to natural disasters, life/health of persons, culture and nature and loss of infrastructure.

C'= consequences that affect are categorized into very small, small, medium, big and very big.

P= probabilities are categorized into unlikely, moderate likely, likely, very likely and extremely likely.

K= each unwanted event is briefly described and evaluated. Historical data is presented for many of the events including sources and time periods. Other documentation used is also included in the reference list with sources and dates. High level of detail.

3.5.3 Oil and gas sector

3.5.3.1 Risk Assessment of oil and gas storage depot in Tananger area. (Shell Norway)

Ref no: 31 **Location:** Norway **Year:** 2015 **Category:** Model-based **Type:** Quantitative

- Topic and background

An upgrade of a storage depot facility in Tananger was planned. In this location petrol, diesel and jet fuel products are to be stored. The products are unloaded from ships at the dock and transported through an import line to the tanks themselves where they are stored. A risk assessment has been made to ensure that the risk level to first (facility workers), second (visitors to the facility) and third persons (other persons in the vicinity of the facility) is acceptable.

- Risk definition

In chapter 1.6 of the assessment, it is stated the following: "The probability and consequence for the various identified events are then combined to calculate the risk picture". Therefore it is assumed that the definition of risk that is used is P=(C&P) as described in chapter 2.2.2.

- Risk description

A'= the hazard identification was performed based on the system description and the area-specific details. This work led to a list of possible potential hazards. Only unwanted events that may result in the release of hazardous or combustible materials and which result in the danger of first, second or third person were considered

C'= consequences analyzed are those that end up in loss of lives for first, second and third persons.

P= Based on the results from the models (fault trees), fire and explosion simulations, weather statistics and assumptions, precise probabilities are calculated for outcome combinations (leakages, fires and explosions in different parts of the facility) and for each one of the three groups (deaths).

Finally, a total FAR level for the facility is calculated for each group based on the individual results.

K= detailed presentation of the setup of the model. The technical design specifications of the facility were reviewed. Specifies the data sources used as input in the model together with the sources. Medium-high level of detail of background knowledge description.

3.5.3.2 Risk Assessment of expansion Norwegian special oil storage facility

Ref no: 32 **Location:** Norway **Year:** 2019 **Category:** Model-based **Type:** Quantitative

- Topic and background

Norwegian Special Oil (NSO) department (Bamble) is a receiving and treatment plant for contaminated water and waste oil. In 2019, it was planned to expand the plant with several tanks for storing oil. When expanding the plant, it was required to get a new approval for handling hazardous substances. For this, a risk assessment was made in order to establish contingency zones around the facility.

- Risk definition

As per chapter 2.2 of the assessment, the definition of risk used is that of individual risk which the assessment defines as: "the likelihood that an individual may be exposed to a fatal accident over a period of time (here one year)". It is then assumed that the risk definition used in this assessment is the one described in chapter 2.2.1, R=(E).

- Risk description

A'= prior to the hazard review, ISO standard checklist was evaluated to include only those hazards that were considered relevant to the facility. The focus was to identify hazards with major accident potential and to identify which safety systems and barriers are at the facility that could reduce the likelihood of incidents or limit the extent of incidents.

C'= the consequences evaluated are those related to the end results of possible leakages on different parts of the facility, these are: no consequences, flash fire and pool fire.

P= probabilities for each consequence upon leakages on different parts of the facility are presented by the use of several tools. In some cases probabilities are taken from guidelines or historical reports on failure frequencies, in other cases, such as emission calculations, model has been used.

K= data used for the analysis is referenced in the assessment including sources and periods. Also, for the case of weather in the area climate database was used and snapshot of the data is presented. Medium-high level of detail.

3.5.3.3 Risk Assessment of Pembina propane export terminal facility

Ref no: 33 **Location:** USA **Year:** 2015 **Category:** Model-based **Type:** Quantitative

- Topic and background

Pembina Marine Terminals Inc. proposed to construct and operate a liquid propane export terminal in Portland, Oregon, the Pembina Portland Propane Terminal. A quantitative risk assessment was then performed for the facility to assess the risk and implement necessary measures to mitigate risk.

- Risk definition

As per the definition table in the assessment: "Risk is the combination of likelihood and consequence of accidents. More scientifically, it is defined as the probability of a specific adverse event occurring in a specific period or under specified circumstances". This definition falls within the R=(P&C) concept as described in section 2.2.2.

- Risk description

A'= unwanted events were identified by reviewing the overall plant process flow diagrams. The unwanted events are small leak, medium leak, big leak and rupture on different plant equipment.

C’= the unwanted events are processed through event tree models to evaluate the potential hazard zones to the levels of concern. Both flammable and explosive outcome consequence zones are calculated (e.g., flammable concentration, thermal radiation, or overpressure).

P= by using event tree probabilities are calculated for each one of the possible consequences.

Then the total risk is estimated by considering the consequences, the likelihood of each event occurring and the resulting impacts. Finally, the risk is presented as Individual Risk in the form of Location Specific Individual Risk (LSIR) and Societal Risk in the form of Potential Loss of Life (PLL).

K= the assessment presents all the background data used for the work in Appendix I. All assumptions, data sources, explanations and data sets are presented. High level of detail when describing the background knowledge.

3.5.3.4 Risk Assessment of marine shipping through the Embridge northern gateway

Ref no: 34 **Location:** Canada **Year:** 2010 **Category:** Model-based **Type:** Quantitative

- Topic and background

This risk assessment examines the probability of certain events occurring en route to the marine terminal or during marine terminal transshipment and the likelihood of an event causing an uncontrolled release of oil, condensate, or bunker.

- Risk definition

In chapter 2.2 of the assessment it is stated the following: "Based on the frequency and consequence assessment and the forecast annual number of tanker calls at the Kitimat Terminal, the risk of an incident or spill occurring is estimated". Based on this statement, it is assumed that the definition of risk used in the assessment is R=(C&P) as defined in chapter 2.2.2 of the thesis.

- Risk description

A’= the focus was kept on the unwanted events that could lead to collision with other vessels, powered grounding, drifting grounding, foundering, fire and/or explosion. Hazid sessions were carried out to identify possible causes.

C’= for each unwanted event, the consequences and their severities were categorized into: minor damage, major damage and total loss.

P= probabilities were calculated for each scenario and each consequence (minor, major and total loss) all adding up to 100%

K= Route details, historical average ship statistics, weather statistics and other data are presented. These include the datasets, sources and timeframes. High level of detail.

3.5.3.5 Risk assessment of new LNG terminal and biogas tank

Ref no: 35 **Location:** Norway **Year:** 2017 **Category:** Model-based **Type:** Quantitative

- Topic and background

A risk assessment was carried out to identify the risk towards third parties due to the construction of a new LNG facility in the Sapsborg area. The assessment also covers the installation of a Biogas tank for intermediate storage.

- Risk definition

As per chapter 8.1 of the assessment, "in this analysis, the risk is presented as probabilities (frequencies) of deaths related to LNG management". Even though the official definition used in the assessment is R=(C&P), they also refer to the R=(C&U) concept and make some considerations regarding the uncertainties behind the risk evaluation performed.

- Risk description

A'= unwanted events considered are those that can end up in flammable concentrations of natural gas outside the facility. Also events including fire and explosions that cause dangerous situations outside the factory. These are collision with tanker trucks, unloading leakages, leakages from storage tanks or evaporation processes, leakage from biogas tank and other external events.

C'= consequences are considered are the number of third party deaths per accident.

P= probabilities are calculated for each of the unwanted events by means of simulations and modelling.

K= leakage statistics are collected from different databases. These are presented in the reference list. The basis for modelling ignition frequencies and effect on the population is described. Data sources for calculating the effect on population and gas characteristics are presented and evaluated in the assessment. Other data used as background information is included in the reference list including sources and timeframes. Medium level of detail.

3.5.3.6 Risk assessment of a CO2 storage and export facility

Ref no: 36 **Location:** Norway **Year:** 2019 **Category:** Standard **Type:** Qualitative

- Topic and background

Upon the installation of a new facility for receiving, storing and exporting CO2, a risk assessment was performed to map the risk picture of the facility in the area.

- Risk definition

As per chapter 2 of the assessment, "Risk = Probability x Consequence => Combination of probability and impact of an event". This is consistent with the R=(C&P) definition from chapter 2.2.2.

- Risk description

A'= the following categories were studied to identify the unwanted events: extreme weather, floods, landslides, construction, contamination, transport, operation related, fire and explosions, emergency and security (i.e.: sabotage)

C'= the consequences considered are those that have an impact on life/health, stability and material damages. These are categorized into: harmless, a certain danger, serious, critical and catastrophic.

P= probability intervals are presented to assess uncertainty. These are categorized into: unlikely (one or less occurrence in 5000 years), very low (one occurrence in 1000-5000 years), low (one occurrence in 200-1000 years), likely (one occurrence in 20-200 years) and very likely (one or more occurrence in 20 years)

K= historic weather data regarding sea level and wind velocity/direction are presented in the document. These include sources, dates, references and datasets. Statistics for the amount of sea/land traffic in the area has been taken from previous reports reference in the document. Data for CO2 leakage has been taken from previous reports, referenced in the assessment. Medium level of detail.

3.5.3.7 Risk assessment of a new LPG storage facility

Ref no: 37 **Location:** Norway **Year:** 2013 **Category:** Standard **Type:** Qualitative

- Topic and background

The Høvringen treatment plant is planning to replace the existing oil tanks with an LPG tank. The fuel in these tanks is used as reserve energy when the facility's own energy production is not enough. A risk assessment was then made to present a risk picture related to the operation and maintenance of the new LPG tank and related equipment.

- Risk definition

In chapter 1.4 of the assessment, risk is defined as "an expression for the combination of probability and consequence of an unwanted event". This is consistent with the R=(C&P) definition from chapter 2.2.2.

- Risk description

A'= unwanted events identified are those related to leakage (during all phases of operation), sabotage and terror, fire, falling loads, floods, collision of load trucks and eventual break down of other parts of the installation.

C'= the consequences considered are those that affect personal life/health and that have a negative effect on the external environment. These are categorized into: very small consequence (no personal injury, insignificant environment impact), small consequence (personal injury, local environment impact), medium consequence (serious personal injury, regional environment impact with one year recovery), big consequence (one death, regional environment impact with 10 years recovery) and very big consequence (several deaths, irreversible environment damage)

P= probabilities are categorized into intervals as follows: small probability (less than one occurrence in 1000 years), moderate probability (one occurrence in 100-1000 years), very probable (one occurrence in 10-100 years) and extremely probable (one or more occurrence per year).

K= an own chapter with reference to all the background information used as basis for the assessment is included. The title, date and source of the documentation are specified. Also, a site survey of the installations was carried out. A technical description of the facility and design criteria for the new tank is presented. Low-medium level of detail.

3.5.3.8 Risk assessment of an LNG bunkering terminal at Mongstad

Ref no: 38 **Location:** Norway **Year:** 2017 **Category:** Standard **Type:** Qualitative

- Topic and background

Upon building a new LNG bunkering terminal at Mongstad, a risk assessment was performed to present a risk picture of the facility towards the external environment and the vicinity.

- Risk definition

In chapter 2.1 of the assessment, it is stated that "the evaluation of the scenarios was based on the probability of leakage, the leakage volume and the toxicity of the gas". Further, in chapter 7.3 it is mentioned that "the risk potential of an unwanted event is evaluated qualitatively based on the expected probability and consequence". Therefore it is assumed that the definition of risk used is R=(P&C) as described in chapter 2.2.2 of the theory.

- Risk description

A'= the only unwanted events consider is leakage of liquid methane.

C'= the consequences considered are those that affect the environment in the vicinity. They are categorized into: no effect, small effect, moderate effect, significant effect, serious effect and very serious effect.

P= the probabilities are described in intervals as follows: extremely rare, very rare, rare, moderately likely and likely.

K= previous risk assessments of similar facilities have been used as background information. Also, technical description of the facility and the gas in question are used. All these are presented in a reference list with dates. Low level of detail.

3.5.3.9 Risk assessment of Australia pacific LNG pipeline project

Ref no: 39 **Location:** Australia **Year:** 2010 **Category:** Standard **Type:** Qualitative

- Topic and background

Upon the construction, operation and maintenance of an LNG pipeline in Australia's side of the Pacific Ocean, a risk assessment was performed. The goal is to map the risks related to these activities and possible risk-reducing measures.

- Risk definition

In chapter 22.2 of the assessment, it is stated that "the system of risk management applied makes use of the concepts from ISO 3100:2009: Risk management - Principles and guidelines". Based on this, it is assumed that the risk definition in use is that of ISO as described in chapter 2.2.8 of the theory.

- Risk description

A'= unwanted events considered are those which can have a negative impact on life/health, material costs and environment.

C'= consequences analyzed are injury/death of persons, fire, explosions, leakage, impact on the environment.

P= no probabilities are indicated in the assessment. Instead, a qualitative description of each unwanted event and possible consequences is made.

K= within the risk description of each unwanted event, historical data is presented and put into context. Reference is made to the timeframe and the sources. Risk level is assigned to each consequence qualitatively. Medium level of detail.

3.5.3.10 Risk assessment of a new service station

Ref no: 40 **Location:** Australia **Year:** 2017 **Category:** Standard **Type:** Qualitative

- Topic and background

The purpose of this Risk Assessment is to report on the compliance of the Hazardous Chemical storage, and the fuel dispensing system at this new facility as required by the current National and relevant State Acts.

- Risk definition

As per chapter 5 of the assessment, risk is defined as the combination of consequence (severity) and frequency. This falls into the R=(P&C) concept as described in chapter 2.2.2 of the theory.

- Risk description

A'= unwanted events considered are those that may affect people, property and environment.

C'= consequences are categorized into five levels between very low and extreme impact.

P= probabilities are categorized into five levels between very low and extreme impact.

K= safety datasheets of all the dangerous goods are included in Appendix C. Detail plan of the station are included in appendix B. Low-medium level of detail.

3.5.3.11 Risk assessment of methanol tank facility

Ref no: 41 **Location:** Norway **Year:** 2017 **Category:** Model-based **Type:** Quantitative

- Topic and background

A risk assessment was performed in a methanol tank facility in order to calculate the risk for third persons and to evaluate the danger distance that the activities in the plant generate.

- Risk definition

In chapter four of the assessment, it is stated that "the risk associated with the activities at the plant is a combination of frequency and consequence". This follows the risk definition presented in chapter 2.2.2 where R=(P&C).

- Risk description

A'= the unwanted events considered in the report are those that can lead to fire and/or explosions and toxic gas concentration. There are mainly leakages, ship collision during import/export, sabotages and escalation of events.

C'= the consequences analyzed are those that may affect the life/health of third parties. By means of simulations, the extent of the effect is calculated for toxic gas concentrations, heat damage and explosive gas concentrations.

P= frequencies are calculated for each consequence upon the different unwanted events. Based on this, a total probability is calculated for the year.

K= description of the system is presented, geographical location, historical weather data. Assumptions made are included in the report. Uncertainties behind the assessment are described. Sources, authors and timeframes of documentation and frequency reports are added in the references. Medium level of detail.

3.5.3.12 Risk assessment of a biogas facility at Eldøyane

Ref no: 42 **Location:** Norway **Year:** 2019 **Category:** Model-based **Type:** Quantitative

- Topic and background

Sunnhordaland Natural Gas plans to build a biogas plant for the production of biomethane where the source for the production is organic waste. A risk assessment was carried out to help provide a basis for determining the area restrictions in the form of consideration zones around SNG's planned facility.

- Risk definition

As per chapter 1.5 of the assessment, risk is defined as: "the combination of the probability that an event occurs and the consequence of this". This follows the risk definition presented in chapter 2.2.2 where R=(P&C)

- Risk description

A'= unwanted events considered are leakages among a specific part of the process at the facility.

C'= the consequences evaluated are those that can lead to death as a result of a fire or explosion in the facility. The severity of this is calculated based on simulations of the different scenarios.

P= probabilities are calculated for all the possible consequences. These are calculated following the event trees and frequency data from guidelines from the authorities.

K= a description of the system is available in the assessment. Sources of the data used are presented in the reference list. Frequency and weather data use is presented in the assessment. High level of detail.

4 RESULTS

This chapter presents the results of the data evaluation. The idea is to present a summary table and use the information contained in it as basis to prepare and present different charts and figures. This is done with the aim of providing the reader with a view of the results that is easier to understand. It is important to note that the results shown in chapters 4.2 to 4.5 are presented in isolation from each other. The results and the relation between them will be discussed in chapter 5.

4.1 Summary of the evaluation

In this section an evaluation summary of all the collected risk assessments is presented (Table 2 below).

Table 2 Data evaluation summary

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description A'	C'	P	K	Risk metric
01	Tunnel	Risk assessment of 'Follo' tunnel	Std.	Qual.	2015	Norway	R=(P&C)	Use of checklist and expert knowledge	**Severity intervals**. Very small, small, medium, big and very big	**Probability intervals.** Unlikely, moderately likely, likely and very likely	**Low level of detail.** Not much information on data sources	**Standard Risk matrix**
02	Tunnel	Risk assessment of 'Eidsvoll' tunnel	Std.	Qual.	2006	Norway	R=(P&C)	Unwanted events were identified and presented for both construction and operation phases.	**Severity intervals.** Consequences that impact life/health and environment. Harmless, a certain danger, dangerous, critical and catastrophic	**Probability intervals.** Very rare, rare, can happen, often, very often	**Medium level of detail.** Sources and timeframes included for some of the data used	**Standard risk matrix**
03	Tunnel	Risk assessment of 'Stad's' ship tunnel	Model	Quant.	2012	Norway	R=(P&C)	Focuses only in unwanted events related to ship stranding, ship sinking, ship collisions and fire	Consequences related to person risk (no. of deaths) and environment risk (exposure, emissions from ship accidents).	**Precise probabilities.** Expected deaths per year and per ship crossings. Expected impact to environment based on amount, type and size of ships.	**Medium level of detail.** Sources and timeframes included for data used, databases referenced to.	**Expected consequences** Table with expected accidents and deaths
04	Tunnel	Risk assessment of 'Ljoteli' tunnel	Std.	Qual.	2016	Norway	R=(P&C)	Considers traffic accidents, fires, leak of dangerous goods, and vehicle stop among others	**Severity intervals** Consequences that threaten life/health to humans. Categorized into minor damage, severe damage, one death, more than one death.	**Probability intervals.** Categorized into: very rare, rare, often and very often	**Medium level of detail.** Data sources, timeframes, databases included in the references.	**Standard risk matrix**

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description A'	Risk Description C'	Risk Description P	Risk Description K	Risk metric
05	Tunnel	Risk assessment of ‘Sørfold’ tunnels	Std.	Qual.	2016	Norway	R=(P&C)	Identified via HAZID and guidelines. Some of the events are different types of traffic accidents and fires	**Severity intervals.** Consequences that impact life/health. Categorized into: light injury, serious injury and death.	**Probability intervals.** Very rare, rare, often, very often	**Low level of detail.** Not much information on data sources	**Standard risk matrix**
06	Tunnel	Risk assessment of ‘Gundvanga’ tunnel	Std.	Qual./Quant.	2013	Norway	R=(E)	The unwanted events considered are those related to traffic accidents, fires and transport of dangerous goods	Consequences that cause personal injury/death are considered. These are no. of deaths per year, no. of injuries per year and no. of accidents per year	**Precise probabilities.** For all the combinations of the consequences /unwanted events are calculated and presented	**Medium level of detail.** Data sources, timeframes, databases included in the references.	**Expected consequences** Table with expected accidents, injured, deaths and fires per year.
07	Tunnel	Risk assessment of ‘Kvarv-Kalvik’ tunnels	Std.	Qual.	2016	Norway	R=(P&C)	Identified via HAZID meetings. Focus was kept on those that could lead to personal injury/death.	**Severity intervals.** Consequences were categorized into light injury, serious injury and death	**Probability intervals.** Very rare, rare, often and very often	**Low level of detail.** Not much information on data sources	**Standard risk matrix**
08	Tunnel	Risk assessment of ‘Ulsberg – Vindåsliene’ tunnels	Std.	Qual.	2018	Norway	R=(P&C)	Events that can result in personal injury/death are the focus. Traffic accidents, fire, leakage of dangerous goods and rock falling.	**Severity intervals.** Slight injury, serious injury, one to four deaths, five to twenty deaths and more than fifty deaths.	**Probability intervals.** Extremely rare, very rare, rare, often and very often	**Low level of detail.** Reference is made to a limited part of the data sources.	**Standard risk matrix**
09	Tunnel	Risk assessment of ‘Niagara’ tunnel	Model	Quant.	2005	Canada	R=(P&C)	Focuses on unwanted events that can cause increase of cost for the project and increased duration of the project (delays).	Two consequences are considered for each unwanted event: impact on project cost and impact on project schedule.	**Precise probabilities**. Calculated for each consequence of each unwanted event.	**Medium level of detail.** Model methodology is explained, no detail on data sources or selection of probability distributions.	**Expected consequences.** Tables with expected cost increase and project delays.

								Risk Description				
Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	A'	C'	P	K	Risk metric
10	Tunnel	Risk assessment of ‘E-39 Rogfast’ tunnel	Model	Quant.	2014	Norway	R=(P&C)	Unwanted events are traffic, fire and explosion accidents, emissions of hazardous substances or gases , floods, landslides and closing due to technical failure	Consequences are categorized into: Deaths, accidents and fires.	**Precise probabilities.** Calculated as amount of deaths per year, amount of injured per year and amount of accidents per year	**High level of detail.** Presents technical design of the tunnel, sources, periods, locations, references and snapshots of the data sets. Also describes why the selected data was utilized	**Expected consequences.** Tables with amount of deaths, injuries, accidents and fires.
11	Tunnel	Risk assessment of 'Skálafjord' tunnel	Model	Quant.	2006	Faroe Islands	R=(P&C)	Unwanted events that can lead to loss life/health of people. Events such as fire and traffic accidents.	Consequence evaluated is the loss of life (no. of deaths)	**Precise probabilities.** Calculated by means of event trees and models for the consequence in each scenario.	**High level of detail.** System description, historical data and datasets used as input to the models presented in the assessment. Assumptions and data used to the model is included in the appendix.	**Expected consequences.** FN curve, PLL tables
12	Tunnel	Risk assessment of Fretheim tunnel	Simpl.	Qual.	2017	Norway	Not available	Unwanted considered are danger of collision, aggressive and inattentive drivers, misunderstanding during column driving.	Focus is kept on what can go wrong and mitigation measures rather than consequences. Still, some of the consequences are those that life/health of the persons involved and the tunnel users.	No probabilities assigned	**Variable level of detail.** Background knowledge from the personnel involved in the work. No information regarding strength of knowledge.	Risk list
13	Tunnel	Risk assessment of Onstad tunnel	Simpl.	Qual.	2017	Norway	Not available	Unwanted events evaluated are related to the activities executed. These are	**Severity intervals.** Consequences are categorized into small (1), medium	**Probability intervals.** Categorized into small (1),	**Variable level of detail.** Background knowledge comes	Probability and consequence categories are multiplied to

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description A'	C'	P	K	Risk metric
								danger of collision, inattentive drivers, setup and control upon column driving.	(2) and big (3) by the assessor group."	medium (2) and big (3) by the assessor group."	from the experience of the personnel involved. No info regarding strength of knowledge is presented."	calculate a risk level (value)
14	Tunnel	Risk assessment of Bømlafjord tunnel	Simpl.	Qual.	2017	Norway	Not available	The unwanted events evaluated are related to the activities executed. These are danger of collision, inattentive drivers, setup and control upon column driving.	**Severity intervals.** Consequences are categorized into small (1), medium (2) and big (3) by the assessor group."	**Probability intervals.** Categorized into small (1), medium (2) and big (3) by the assessor group."	**Variable level of detail.** Background knowledge comes from the experience of the personnel involved. No information regarding strength of knowledge is presented."	Probability and consequence categories are multiplied to calculate a risk level (value)
15	Tunnel	Risk assessment of Lyderhorn tunnel	Simpl.	Qual.	2017	Norway	Not available	The events evaluated are related to the activities executed, these are: collision with working personnel, collision of lifting equipment, possible blockage of emergency vehicle and car fires	**Severity intervals.** Consequences are categorized into small (1), medium (2) and big (3) by the assessor group."	**Probability intervals.** Categorized into small (1), medium (2) and big (3) by the assessor group."	**Variable level of detail.** Background knowledge comes from the experience of the personnel involved. No information regarding strength of knowledge is presented."	Probability and consequence categories are multiplied to calculate a risk level (value)
16	Tunnel	Risk assessment of Fretheim tunnel	Simpl.	Qual.	2017	Norway	Not available	The events considered in the assessment are collision and accidents related to the traffic and working personnel inside the tunnel	**Severity intervals.** Consequences are categorized into small (1), medium (2) and big (3) by the assessor group."	**Probability intervals.** Categorized into small (1), medium (2) and big (3) by the assessor group."	**Variable level of detail.** Background knowledge comes from the experience of the personnel involved. No information regarding strength	Probability and consequence categories are multiplied to calculate a risk level (value)

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description A'	C'	P	K	Risk metric
											of knowledge is presented."	
17	Munic.	Risk assessment fire and rescue, 'Rogaland' fire department	Std.	Qual.	2018	Norway	R=(C&U)	Unwanted events within the following categories: natural events, different types of fires and transport accidents.	Focus kept on life/health perspective consequences and on how the municipality will be able to react based on current situation, training, equipment and overall preparedness level.	Probabilities are not assigned to the consequences. However, it presents historical data for similar events/consequences to give an idea to the end user.	**Medium level of detail.** Some of the data is presented in the assessment including the data periods.	Does not use matrix or tables. Describes qualitatively the overall picture.
18	Munic.	Risk assessment fire and rescue, 'Østre Adger' fire department	Std.	Qual.	2018	Norway	R=(C&U)	Unwanted events categories are: fire, accidents, natural events and others.	**Severity intervals.** Life/health, environment and cultural value, material cost and community. Categorized into insignificant, less severe, serious, very serious and extremely serious.	**Probability intervals.** Extremely likely, very likely, likely, less likely, unlikely	**High level of detail.** Background information presented with sources and timeframes. Justification of selected data. Data sets are included as snapshots. In addition all data is included in the references.	**Expanded risk matrix**
19	Munic.	Risk assessment of 'Sola' municipality	Std.	Qual.	2012	Norway	R=(C&P)	The events considered are those related to natural events and those that affect human and businesses (fire, water supply, contamination)	**Severity intervals.** Consequences that impact on the life/health, environment, material cost and community. Categorized into no consequence, low, medium, high and catastrophic	**Probability intervals.** Categorized into excluded from happening, low, medium, high and guaranteed to happen	**Medium-high level of detail.** Sources for most data is presented in the assessment. Snapshots of data sets for some of the risks are also presented.	**Standard risk matrix**

								Risk Description				
Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	A'	C'	P	K	Risk metric
20	Munic.	Risk Assessment of 'Sandnes' municipality	Std.	Qual.	2019	Norway	R=(C&U)	Unwanted events related to natural disasters, accidents, contamination, life/health and impact to cultural sites	**Severity intervals.** Consequences that impact life/health, stability, nature, environment and material value. Five categories, not explained what each category entails nor its limits	**Probability intervals.** These are as follows: very low, low, medium, high, very high	**Medium level of detail.** Historical data and previous risk assessments used. References to the data is made in the assessment	**Standard risk matrix**
21	Munic.	Risk Assessment of 'Troms' municipality	Std.	Qual.	2016	Norway	R=(C&P)	Unwanted events were analyzed based on the three following categories: natural events, major accidents and intended incidents	**Severity intervals.** Those impact life/health, nature and environment, economy and stability. Categorized into: very small, small, medium, big and very big	**Probability intervals.** Categorized into: very low, low, medium , high and very high	**Medium level of detail.** Information of the background data for each unwanted event is available in the assessment. Incl. timeframes, sources and snapshots of datasets for some risks.	**Standard risk matrix**
22	Munic.	Risk Assessment of ice impacts from the windmill park in the 'Roan' municipality	Model	Quant.	2009	Norway	R=(C&P)	One main unwanted event which is ice being dropped from the blades of the windmills	Consequences that may cause deaths towards first (workers of the park), second (visitors to the park) and third persons (reindeer park and other persons in the area)	**Precise probabilities.** Described as individual risk (LIRA). Presents probabilities per category groups	**Medium level of detail.** Describes model setup and where input data comes from. Presents sources, types and timeframes of data used.	**Expected consequences.** Risk levels (contours) around each windmill

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description A'	C'	P	K	Risk metric
23	Munic.	Risk Assessment of expansion of zinc plant in the 'Odda' municipality	Std.	Qual.	2019	Norway	R=(C&P)	Unwanted events related to natural disasters, internal facility hazards, infrastructure, intended actions (sabotage, terrorism) and isolated accidental events in the plant area.	**Severity intervals.** Consequences assessed in terms of life/health, stability and material values. Categorized into: very small, small, medium, big and very big.	**Probability intervals.** Categorized into: unlikely, moderately likely, likely , very likely and extremely likely	**Medium level of detail.** Refers to background documentation used including sources and timeframes.	**Standard risk matrix.** Also presents a qualitative description of each risk
24	Munic.	Risk Assessment of marine route changes due to modifications in Bodø airport	Model	Quant.	2019	Norway	R=(C&P)	Unwanted events considered in the assessment are those related to navigation risks and impact on environment	Consequences evaluated in the risk assessment are grounding, collision and emissions to environment.	**Precise probabilities.** Calculated for all consequences using a model. Values are presented as average yearly values.	**High level of detail.** Indicates why the data parameters were used. Indicates and explains the source used for calculating traffic prognosis. Datasets included as part of the assessment in Appendix A	**Expected consequences.** Probability tables for the consequences
25	Munic.	Risk assessment of social security when establishing NOKAS facility in Stavanger	Model	Quant.	2005	Norway	R=(C&P)	Unwanted events considered are those that can impact life/health of third parties	Consequences considered are: incidents with injured persons, incidents with dead persons and incidents with five or more people killed (major accident)	**Precise probabilities.** Presented by calculating the outcomes of the event trees for each scenario	**High level of detail.** All statistics and historical data are included in the references with sources and timeframes. Data used and justification is presented. Datasets included in the appendices	**Expected consequences.** Probability tables including probabilities for each consequence

								Risk Description				
Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	A'	C'	P	K	Risk metric
26	Munic.	Risk assessment for upgrade of chemical facility in 'Færder' municipality	Model	Quant.	2018	Norway	R=(C&P)	Unwanted events that pose a risk to personnel at the plant and third persons. These are collision, leakages and sabotages	Consequence considered are loss of lives. Calculated by use of software tools in no. of deaths per year	**Precise probabilities.** Calculations are made based on the historical guidelines and description of the facility	**Medium level of detail.** Historical data on leakages and weather included in the references with sources and timeframes. Tech. information of the facility presented.	**Expected consequences.** Risk levels (contours) with no. of deaths per year
27	Munic.	Risk assessment for change of detail regulation for Rambergneset	Simpl.	Qual.	2017	Norway	Not available	The unwanted events of interest are identified with the help of a checklist. These are: noise/pollution from traffic, traffic accidents, avalanches, landslides, floods and high voltage lines.	**Severity intervals.** Consequences are categorized into harmless, slightly dangerous, dangerous, critical and catastrophic.	**Probability intervals.** Categorized into: rare, unlikely, moderate likely, likely, very likely and almost certain	**Low level of detail.** Rough description is presented for each unwanted event, also explains the current situation and characteristics of the surroundings.	**Not used**
28	Munic.	Risk assessment for area planning in Jentoftbukta, Sør-Varanger municipality	Simpl.	Qual.	2013	Norway	Not available	The unwanted events of interest are identified with the help of a checklist. These are: noise/pollution from traffic, traffic accidents, avalanches, landslides, floods and high voltage lines.	**Severity intervals.** Consequences are categorized into harmless, slightly dangerous, dangerous, critical and catastrophic.	**Probability intervals.** Categorized into: rare, unlikely, moderate likely, likely, very likely and almost certain	**Low level of detail**. Rough description is presented for each unwanted event, also explains the current situation and characteristics of the surroundings	**Not used**
29	Munic.	Risk assessment for area planning of a salmon facility in Nordkapp municipality	Simpl.	Qual.	2011	Norway	Not available	The unwanted events of interest are identified with the help of a checklist. These are related to natural events, infrastructure and project specific risks	No consequences are presented. Comparison made between the current situation and the requirements to determine if further measures must be taken	Probabilities are not used in the assessment, rather, a view of current situation vs authority requirements is presented	**Low level of detail**. Background knowledge documented for some of the unwanted events. A few precious reports are referenced to	**Not used**

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description A'	Risk Description C'	Risk Description P	Risk Description K	Risk metric
30	Munic.	Risk assessment for the new house zoning plan in 'Luster' municipality	Std.	Qual.	2017	Norway	R=(P&C)	Unwanted events identified with the help of a checklist. These are related to natural disasters, life/health of persons, culture and nature and loss of infrastructure	**Severity intervals**. Consequences that affect are categorized into very small, small, medium, big and very big	**Probability intervals**. Probabilities are categorized into unlikely, moderate likely, likely, very likely and extremely likely	**High level of detail** Unwanted events briefly described and evaluated. Historical data presented for many of the events incl. sources and time periods. Other doc. used included in the ref. list with sources and dates	**Standard risk matrix**
31	O&G	Risk Assessment of oil and gas storage depot in Tananger area. (Shell Norway)	Model	Quant.	2015	Norway	R=(C&P)	Unwanted events that result in the release of hazardous or combustible materials and which result in the danger of first, second or third person were considered	Consequences analyzed are those that end up in loss of lives for first, second and third persons.	**Precise probabilities.** Calculated for outcome combinations (leakages, fires and explosions in different parts of the facility) and for each one of the three groups (deaths).	**High level of detail.** Explains setup of model. Presents the data sources used in the model including the sources.	**Expected consequences.** FN-curves, PLL/FAR tables and risk level (contours)
32	O&G	Risk Assessment of expansion Norwegian special oil storage facility	Model	Quant.	2019	Norway	R=(E)	Focus was to identify hazards with major accident potential	Consequences evaluated are: no consequences, flash fire and pool fire	**Precise probabilities.** For each consequence upon leakages on different parts of the facility are presented by use of several tools	**Medium level of detail.** Data used is presented in the references incl. year and sources. Weather dataset is presented. Gives considerations reg.uncertainties.	**Expected consequences.** Risk levels (contours), frequency/proba bility tables

								Risk Description				
Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	A'	C'	P	K	Risk metric
33	O&G	Risk Assessment of Pembina propane export terminal facility	Model	Quant.	2015	USA	R=(C&P)	Unwanted events are small leak, medium leak, big leak and rupture on different plant equipment.	Flammable and explosive outcomes are considered.	**Precise probabilities.** For each of the possible consequences.	**High level of detail.** All assumptions, data sources, explanations and data sets presented in Appendix I. It presents considerations regarding uncertainties.	**Expected consequences.** PLL tables, risk levels (contours)
34	O&G	Risk Assessment of marine shipping through the Embridge northern gateway	Model	Quant.	2010	Canada	R=(C&P)	Unwanted events that could lead to collision with other vessel, powered grounding, drifting grounding, foundering, fire and/or explosion	**Severity intervals.** Categorized into minor damage, major damage and total loss.	**Precise probabilities.** Calculated for each scenario and each consequence (minor, major and total loss) all adding up to 100%	**High level of detail.** Route details, historical average ship statistics, weather statistics and other data is presented. These include the datasets, sources and timeframes	**Expected consequences.** Probability tables, normalized per nautical miles.
35	O&G	Risk assessment of new LNG terminal and biogas tank	Model	Quant.	2017	Norway	R=(C&P)	Unwanted events that can end up in flammable concentrations of natural gas, fire and explosions outside the facility. Collision with tanker trucks, leakages and other external events.	Amount of third party deaths per accident.	**Precise probabilities.** Calculated for each of the unwanted events	**Medium level of detail.** Data sources presented in the references including timeframes. Also refers to the (C&U) definition and uncertainties.	**Expected consequences.** FN-curves and risk levels (contours)

								Risk Description				
Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	A'	C'	P	K	Risk metric
36	O&G	Risk assessment of a CO2 storage and export facility	Std.	Qual.	2019	Norway	R=(C&P)	Unwanted events: extreme weather, floods, landslides, construction, contamination, transport, operation related, fire and explosions, emergency and security (i.e.: sabotage)	**Severity intervals.** Consequences that have impact on life/health, stability and material damages. Categorized into: harmless, a certain danger, serious, critical and catastrophic	**Probability intervals.** Categorized into unlikely, very low, low, likely and very likely	**Medium level of detail.** Refers to sources and timeframes of weather, sea traffic and CO2 leakages data used in the assessment.	**Standard risk matrix**
37	O&G	Risk assessment of a new LPG storage facility	Std.	Qual.	2013	Norway	R=(C&P)	Unwanted events related to leakages, sabotage and terror, fire, falling loads, floods, collision of load trucks and eventual break down of other parts of the installation	**Severity intervals.** Those that affect person life/health and that have a negative effect on the environment. Categorized into: very small, small, medium, big and very big	**Probability intervals.** Categorized into: small, moderate, very probable and extremely probable	**Medium level of detail.** Source, timeframes and titles of the data used is presented. Survey and technical description is also included	**Standard risk matrix**
38	O&G	Risk assessment of an LNG bunkering terminal at Mongstad	Std.	Qual.	2017	Norway	R=(C&P)	Leakage of liquid methane	**Severity intervals.** Consequences that affect the environment in the area. Categorized into no effect, small, moderate, significant, serious and very serious	**Probability intervals.** Categorized into extremely rare, very rare, rare, moderately likely and likely	**Low level of detail.** Previous risk assessments used for information are referenced to. Technical description of the facility is also presented.	**Standard risk matrix**
39	O&G	Risk assessment of Australia pacific LNG pipeline project	Std.	Qual.	2010	Australi a	R=ISO	Unwanted events which can have negative impact on life/health, material costs and environment	Consequences analyzed are injury/death of persons, fire, explosions, leakage, impact on environment	No probabilities are indicated in the assessment	**Medium level of detail.** Historical data presented and put into context. Ref. is made to the timeframe and the sources	Risk list categorizing risks into low, medium and high

Ref no.	Sector	Title	Cat.	Type	Year	Loc.	Risk def.	Risk Description: A'	Risk Description: C'	Risk Description: P	Risk Description: K	Risk metric
40	O&G	Risk assessment of a new service station	Std.	Qual.	2017	Australia	R=(C&P)	Unwanted events considered are those that may affect people, property and environment	Consequences are categorized into five levels between very low and extreme impact	Probabilities are categorized into five levels between very low and extreme impact	**Medium level of detail.** Safety datasheets of all the are included in Appendix C. Detail plan of the station are included in appendix B	**Standard risk matrix**
41	O&G	Risk assessment of methanol tank facility	Model	Quant.	2017	Norway	R=(P&C)	Unwanted events that can lead to fire, explosions and toxic gas concentration. These are mainly leakages, ship collision during import/export, sabotages and escalation of events.	Consequences analyzed are those that affect life/health of third parties. The extent of the effect is calculated for toxic gas concentrations, heat damage and explosive gas concentrations	**Precise probabilities.** Frequencies are calculated for each consequence. Based on this, a total probability is calculated for the year	**Medium level of detail.** Description of the system, geography, and weather data is presented. Sources, authors and timeframes of documentation and frequency reports in the references	**Expected consequences.** Individual risk and risk contours
42	O&G	Risk assessment of a biogas facility at Eldøyane	Model	Quant.	2019	Norway	R=(P&C)	Unwanted events considered are leakages among a specific part of the process at the facility	Consequences that can lead to death as a result of a fire or explosion in the facility. Severity of is calculated based on simulations.	**Precise probabilities.** Probabilities are calculated for all the possible consequences.	**High level of detail.** A description of the system is available. Sources of the data used is presented in the reference list. Frequency and weather data used is presented in the assessment.	**Expected consequences.** Risk contours

4.2 Risk definition

This section and Figure 8 below present the results on how risk was defined in the collected data. This is the formal definition of risk given in each of the assessments. Datasets presented are taken from Table 2, columns two (2), four (4), and eight (8).

From the figure below it is seen that throughout the three sectors in question (tunnel, municipality, and oil and gas) the dominant definition of risk was that which defines risk as the combination of probability and consequence R=(P&C), as described in chapter 2.2.2 of the theory. This is true for standard and model-based risk assessments.

In the same line, it was also noted that in the special case of standard risk assessments within the municipality sector, there was no overwhelmingly dominant risk definition. For this case, the total sample was of seven (7) risk assessments of which four (4) use the R=(P&C) definition and the remaining three (3) make use of the R=(C&U) definition.

Regarding the simplified risk assessments, it was found from the totality of the sample, that none of them present a formal definition of risk. This is indicated in Figure 8 below by the green 'not available' series.

Definitions such as those of expected values and ISO were found to be less used as formal definitions among the data.

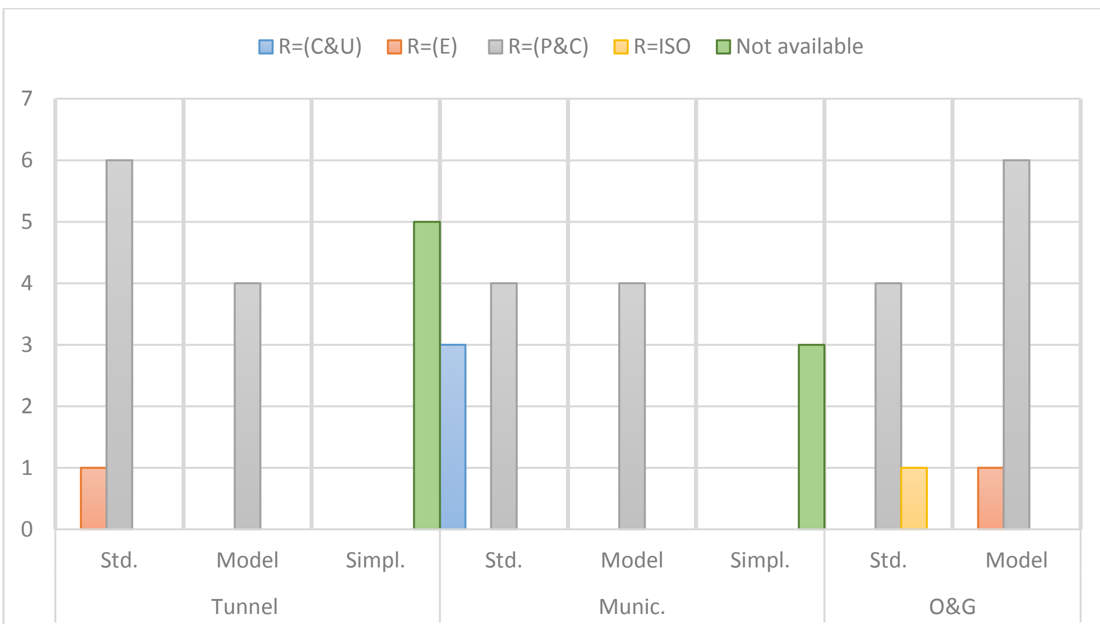

Figure 8 Risk definition (Overall)

4.3 Risk description

This section presents a comparison between the formal definition in the risk assessments and the risk description presented. The datasets for the next two figures are taken from Table 2, columns eight (8) through twelve (12).

Figure 9 groups the assessments by their formal definition of risk and presents the number of these that describe all the elements from the general description of risk presented by Aven (2015); A', C', P and K. The main take from this figure is that even considering the formal risk definition used in the assessments, a majority of them go on to describe (to varying levels of detail) all the previously mentioned elements.

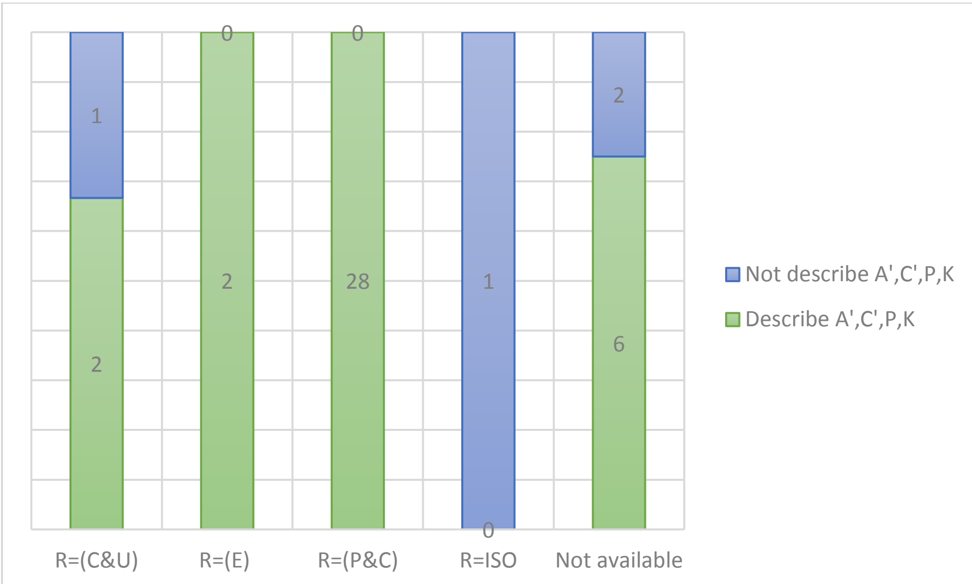

Figure 9 Description of A', C', P and K per formal risk definition

From a wider perspective, it was seen, as shown in Figure 10 below, that regardless of the formal risk definition used, at least 90 percent of the total sample data described (again to varying levels of detail) all the elements A', C', P and K.

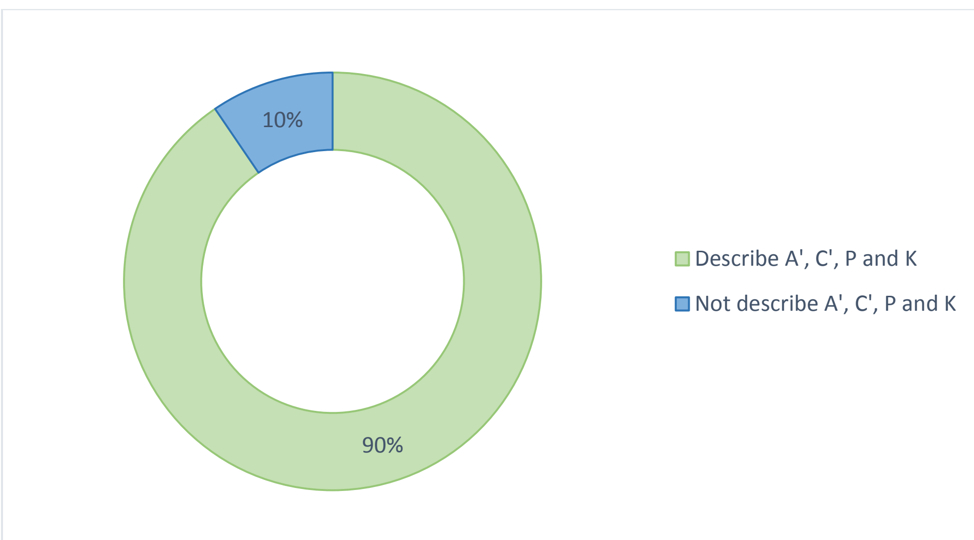

Figure 10 Description of A', C', P and K (Overall)

4.4 Risk metric

In this section and with the next two figures the results of the risk metrics are presented. Figure 11 shows the resulting risk metrics of the collected data, grouping them by sector and risk analysis category. Later, Figure 12 presents a correlation between the formal risk definition of the risk assessments and the risk metrics used. The datasets used for these figures come from Table 2, columns eight (8), and thirteen (13).

As shown in Figure 11 below, it was found that the most used risk metrics are risk matrices which reflect combinations of probabilities and consequences (severity) and metrics that reflect expected consequences (use of PLL values, risk contours, etc.).

It was also seen that risk matrices were the preferred metric when performing standard risk analyses and somewhat of preference when performing simplified risk analysis. On the other hand, the main risk metric used for model-based risk analyses are the expected consequences.

A few of the assessments did not use any type of risk metric, instead, they described the risk by words. These are identified in the figure below by the category qualitative description.

Some other risk assessments only presented a risk list where each risk was itemized and the different elements such as probability and consequences were described. No graphical visualization tools were used to present the risk picture.

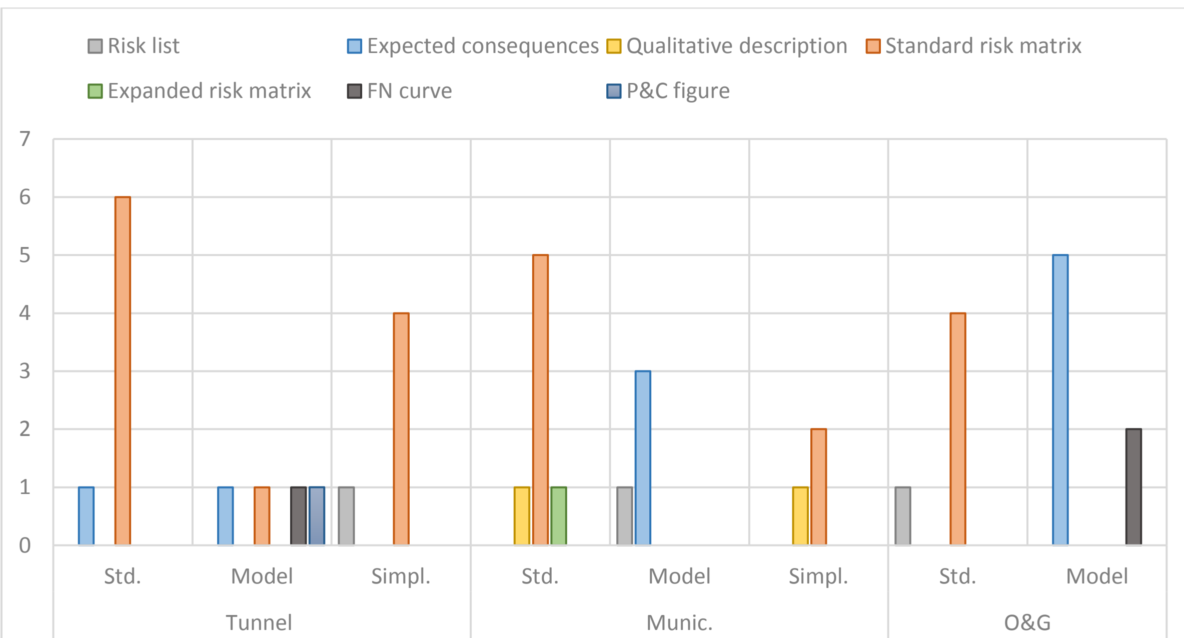

Figure 11 Risk metric (Overall)

Interesting results came to light from the data presented in Figure 12, where the formal risk definition was compared with the risk metric used. Regarding the R=(C&P) definition, the data showed that there is a big diversity of risk metrics used regardless of their appropriateness with respect to the risk definition.

From the R=(C&U) series, it is noted that one of the risk assessments makes use of standard risk matrix, another one makes use of the expanded risk matrix and the remaining one makes use of qualitative descriptions. Sense could be made out of this as different attempts to try and best describe the consequences and uncertainties, given the fact that this definition is rather recent.

For the risk assessments where the formal definition of risk was not available account for a total of eight from which the majority makes use of risk matrices followed by risk lists and qualitative descriptions.

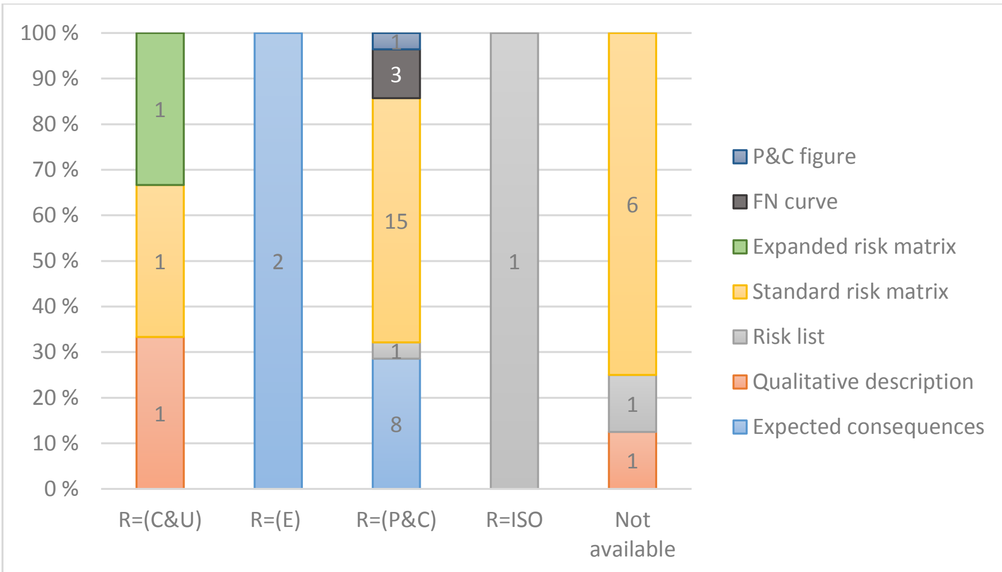

Figure 12 Risk definition vs risk metric (Overall)

For further discussion in chapter 5.3, Figure 17, Figure 18 and Figure 19 show the results from the previous figure split per sector.

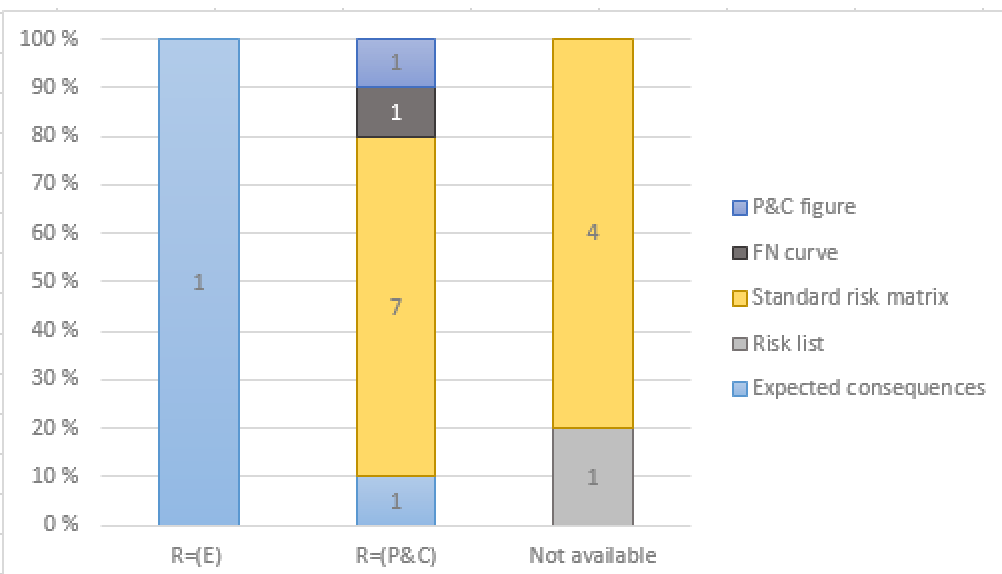

Figure 13 Risk definition vs risk metric (Tunnel)

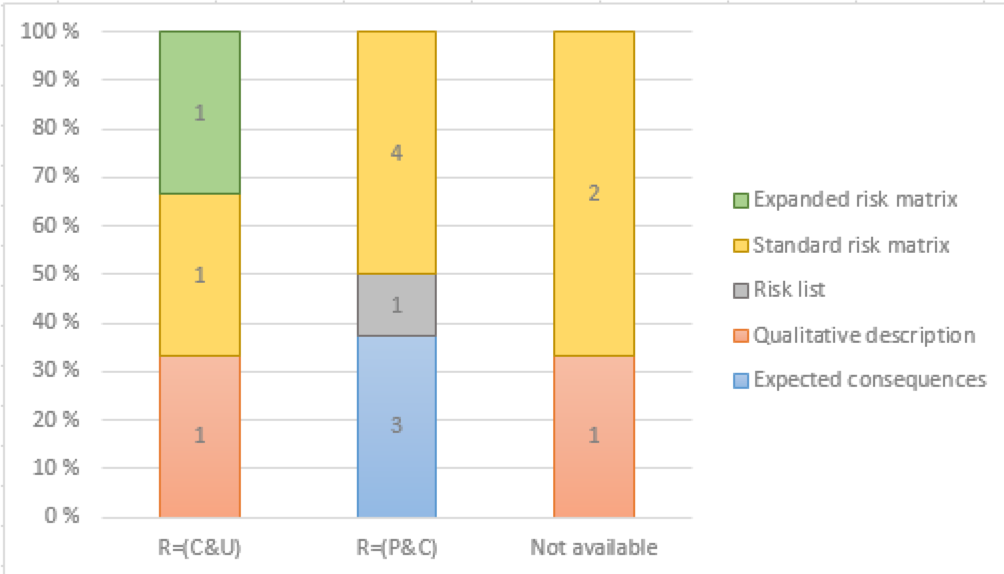

Figure 14 Risk definition vs risk metric (Municipality)

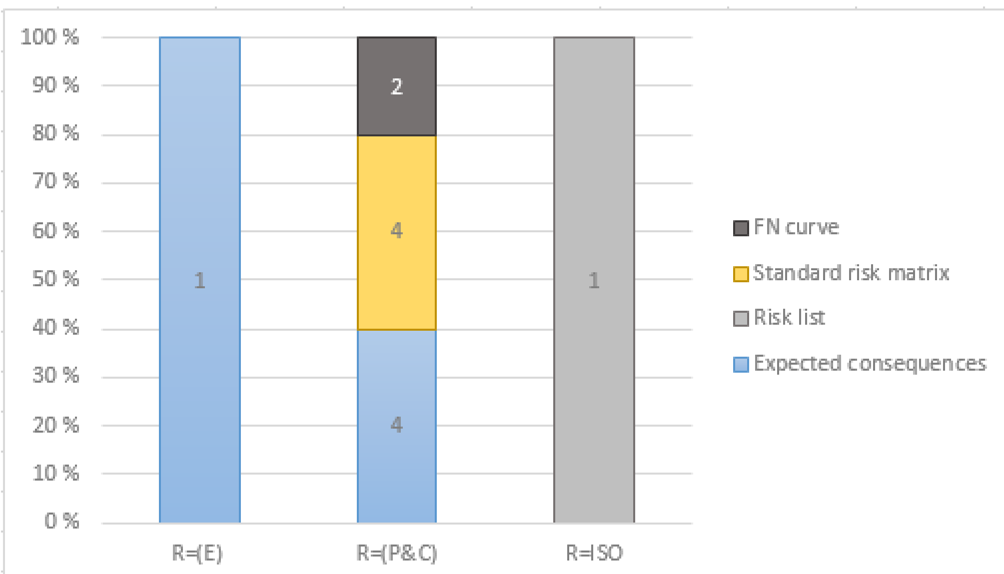

Figure 15 Risk definition vs risk metric (Oil & Gas)

4.5 Risk timelines

In this chapter, a timeline is presented to map the development of the use of the formal risk definitions in the timeframe of our dataset (2005-2019). This is the risk definition as presented in the assessments. Figure 16 presents an overall timeline including all the sectors, categories, and types of risk analysis. Figures 14, 15, and 16 show the same timeline but filtered by sectors.

From Figure 16 below, it can be seen that the R=(P&C) definition has been steadily present throughout the whole timeframe and it is still widely used in the risk analysis context. Furthermore, the R=(E) and R=ISO definitions were found to be seldom used within the collected data.

Risk assessments that did not have a formal definition of risk were removed from the figure below as they were considered as not relevant for the timeline trend.

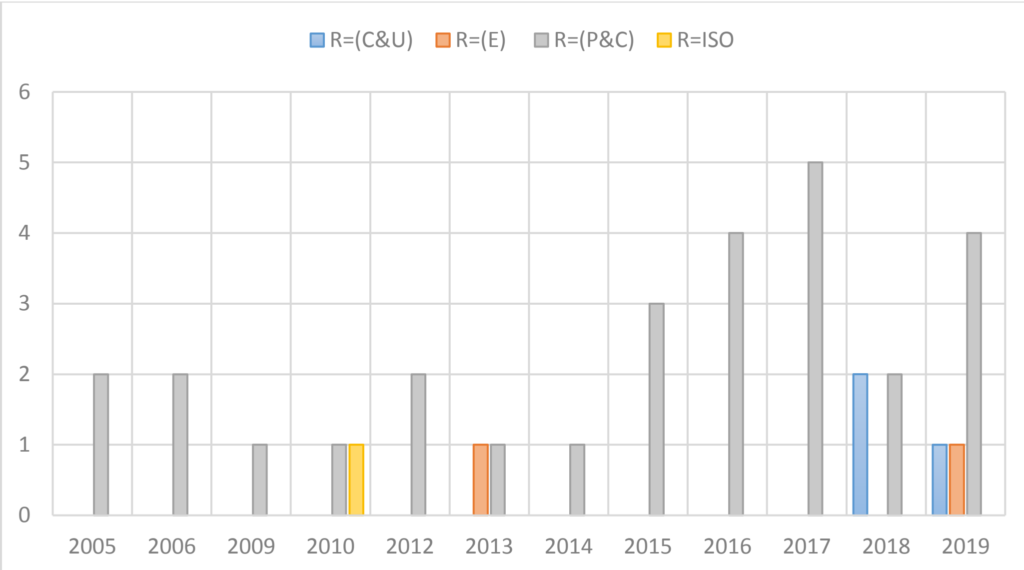

Figure 16 Risk definition timeline (Overall)

It is also noted in the figure above that the rather recent R=(C&U) concept started to get some traction as a formal risk definition in risk assessments since the year 2018 (as per the collected dataset). This is true for the municipality sector as shown in Figure 18.

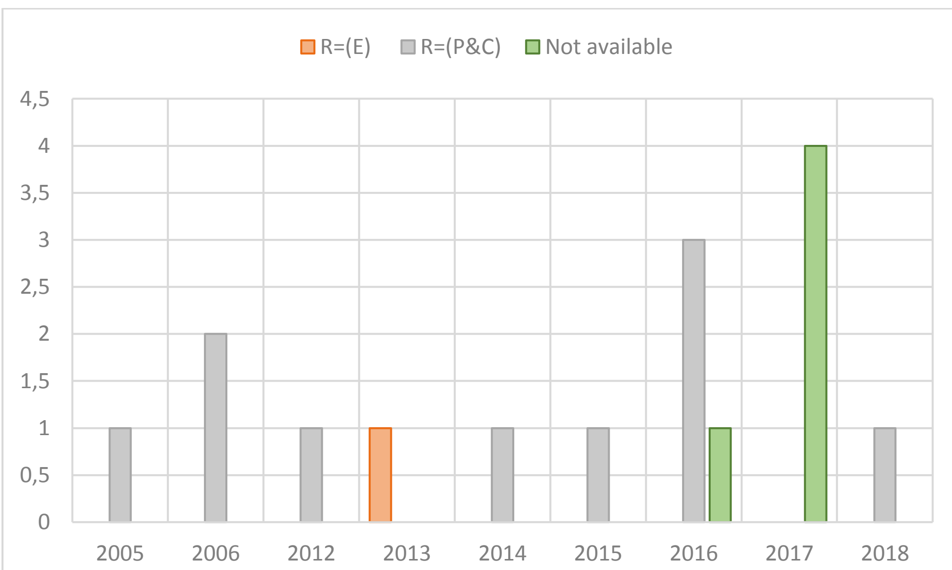

Figure 17 Risk definition timeline (Tunnel)

Further, Figure 17 and Figure 19 present a similar trend in both tunnel and oil and gas sectors with regards to the use of R=(P&C) as formal risk definition.

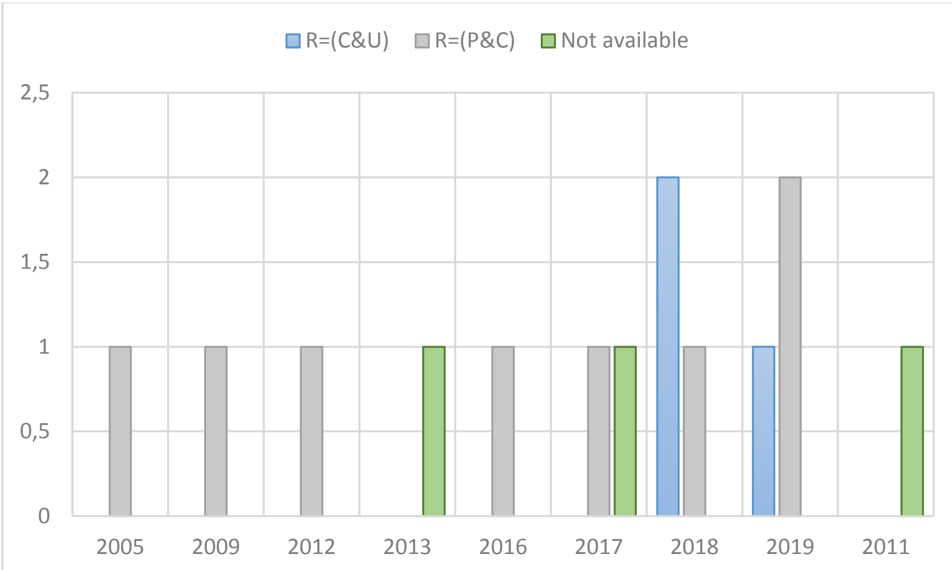

Figure 18 Risk definition timeline (Municipality)

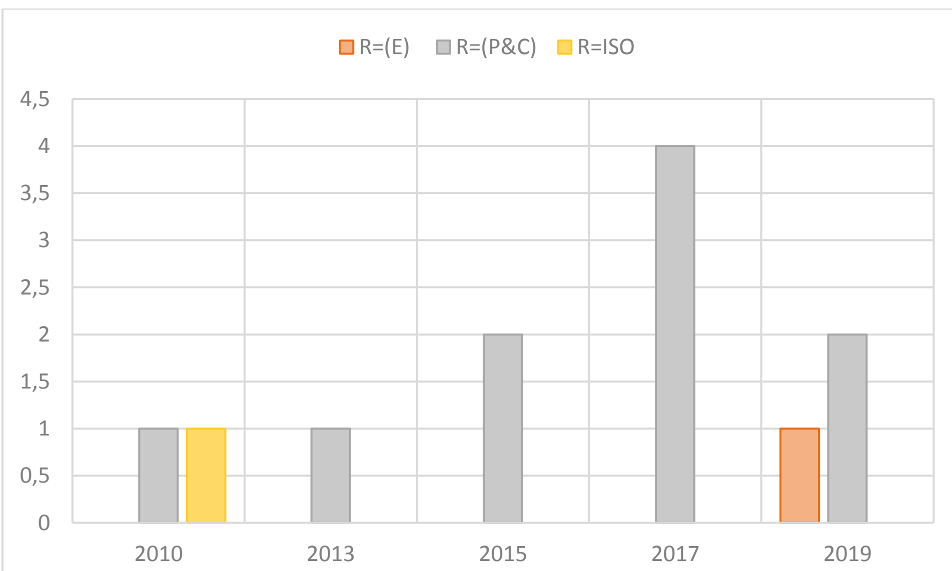

Figure 19 Risk definition timeline (Oil & Gas)

5 DISCUSSION

The approach taken for the coming chapters is to first discuss the risk definition used in the collected data, then discuss these definitions

To present a structured chapter, first, the risk definition results are evaluated against the current regulations in section 5.1. Then, the risk description results are discussed and compared for consistency against the risk definitions in section 5.2, subsequently in section 5.3, a similar comparison is made but this time between the risk metric and risk definition. Section 5.4 revolves around the evolution of the definition of risk through the last sixteen years

Finally, the main objective of the thesis is answered in section 5.5 where all the previous individual discussions are seen from a joint perspective and conclude with a brief review over the reliability and validity of the present empirical work in section 5.6.

5.1 Risk definition

The starting point of the discussion is the definitions of risk. With basis on different literature, several risk definitions of risk were presented in the theory chapter, however, the focus is kept on the concepts that are in use within the collected sample.

Within the tunnel construction sector, from a total of 16 risk assessments collected, 10 make use of R=(R&C), one makes use of R=(E), and the remaining five present no definition of risk.

The Norwegian public roads administration is the responsible authority for planning, constructing, operate, and maintain the road network in the country. As such, they also regulate the work in the tunnel construction sector. This organization is also responsible for keeping, updating and publishing the regulations, requirements and guidelines. The current regulation from the roads administration for risk management (Statens Vegvesen 2014), defines risk as "the probability that an unwanted event occurs and the related consequences".

Further in the municipality sector, out of a total of 14 risk assessments, eight use the R=(P&C) definition, three use R=(C&U) and for the remaining three risk assessments, a risk definition was not available.

The Norwegian directorate for civil protection has the responsibility for having a complete overview of the risks and vulnerabilities of the community and to protect Norway and its citizens from accidents, disasters, and other incidents. The directorate's focus is on preventing and preparing for accidents, crises and other hazards to society. An important part in the prevention of such type of incidents is risk management, and according to the current guidelines in municipality planning (Direktoratet for samfunnssikkerhet og beredskap 2014, Direktoratet for samfunnssikkerhet og beredskap 2017), risk is defined as "an assessment of whether an incident can happen, what the consequences can be and the uncertainty related to this".

Finally, in the oil and gas sector, 12 risk assessments were evaluated from which ten apply the R=(P&C) concept, one applies the R=(E) and the last one applies the R=ISO concept.

The petroleum safety authority (PTIL) is the governmental authority responsible for safety, emergency preparedness and working environment in the petroleum industry in Norway (both onshore and offshore). As per their framework regulations (Petroleumstilsynet 2015), risk is defined as “the consequences of the activity and its associated uncertainty”.

It can be then said that the regulating authorities have a big influence in directing the developments in many areas, and risk management is no exception. This is generally more beneficial as the authorities tend to prioritize the wellbeing of the society, as discussed by Abrahamsen and Aven (2012). In their paper, it is discussed that risk assessment criteria (if used) should be formulated by the authorities, as the industry would not in general focus on serving the interest of the society as a whole.

Initially, the sampled data does not seem to be completely consistent with the applicable risk definitions established by the authorities. Only the tunnel construction sector presents consistency between the risk definition used in the assessments and the definition established by the relevant authority (C&P definition). On the other hand, the risk assessments evaluated within both the municipality and oil and gas sectors predominantly used the C&P definition of risk which is not consistent with the current definition established by the respective regulating authorities, the C&U perspective. A reason for this could be that the C&U concept was introduced relatively recently in these two sectors while the authority regulating the tunnel construction has, so far, used the same (C&P) concept for a long time. This idea is further developed in section 5.4 Risk timelines.

Based on the results from Figure 8 and the previous discussion, the risk definitions that are being used, within the sectors of interest, in the last fifteen years are the R=(C&P), R=(C&U), R=(E) and R=ISO, hence only these definitions will be further discussed.

5.2 Risk description

The first part of the discussion in this section is meant to briefly revisit the consistency criteria risk definition – risk description under which each assessment was evaluated. Then, the relations between the risk definition and description in the data are discussed.

According to the explanation from chapter 2.2.2, the C&P definition of risk is the two-dimensional combination of probability and consequences. It then follows that a risk description consistent with this definition only contains these two elements, namely probability and severity of consequences.

Also, as per the explanation given in chapter 2.2.3 the C&U definition of risk, is the two-dimensional combination of consequences of an activity, ‘C’, and associated uncertainty ‘U’. Recalling from chapter 3.3, Aven (2015) states that a description of risk consistent with the C&U definition contains all the following elements:

- A’ identified events of interest (unwanted events)
- C’ identified consequences that characterize C
- Q measure of uncertainty of C’ (typically probability)
- K background knowledge on which C’ and Q are based (models and data used, assumptions, etc.)

For a risk description to be consistent with the R=(E) definition it must base itself only in expected probability values. These expected values may be presented in the form of risk indicators.

Finally, the ISO definition as explained in chapter 2.2.8 focuses on uncertainty on objectives, Aven (2014) states that this concept can be seen as a special case of the (C&U) or C definitions.

Therefore, a risk description will be deemed as consistent with the ISO definition in any one of two scenarios: a) when the description contains all the elements of a general description of risk (A', C', Q, K) as described by (Aven 2015) and b) when the description contains the events and consequences.

The results shown in Figure 9 and Figure 10 present valuable information to discuss the consistency between the formal risk definitions and the risk descriptions of the collected data. The approach was to group the risk assessments by their formal risk definition and then indicate how many of them proceeded to describe risk including the A', C', Q and K elements.

When analyzing these two figures it became clear that regardless of the formal risk definition used in the assessments and despite not acknowledging K as part of the risk description, a big majority (up to 90%) present a description of all the previously mentioned elements of a general description of risk as described by (Aven 2015). From this 90%, it was also seen that the level of detail presented when describing the background knowledge was highly variable between low, medium and high almost to 33% each. On the other hand, only 7% (9% if special case a) of ISO is considered) used the C&U definition.

Such findings may be due to the fact that, during the risk analysis process, a big number of risk analysts find themselves in the situation of not being able to communicate the results of the assessment in the desired way were they to strictly follow the boundaries set by the risk definition used in the assessment. In other words, it is done due to necessity. This necessity forces the analyst to not be consistent between the way they define risk and the way they describe it.

Further, it is argued by Aven (2014) that the risk perspective (definition) chosen, strongly influences the way risk is analyzed, hence having serious implications for risk management and decision-making. Then it follows that a risk definition that manages to cover all the risk elements under its related risk description will help the risk assessment team to accurately communicate the results of the analysis while at the same time keeping the consistency between the risk definition and the risk description.

Coming back to the results from Figure 9 and Figure 10, the remaining 10% (equivalent to four risk assessments) were split as follows:

- One assessment (ref. no 39) defined risk as ISO.

In this case, the assessment described risk by presenting unwanted events and the consequences. No probabilities were assigned but instead, a qualitative description of each unwanted event and possible consequences is made. Based on this evaluation, and following the consistency criteria for the ISO concept, more specifically the b) scenario, it can be said that the definition and description of risk are consistent.

- One assessment (ref. no 17) defined risk as C&U.

Even though this risk assessment contains the A, C' and K elements, it did not present any measure of uncertainty Q. Therefore, strictly speaking, and according to the previously mentioned criteria, the risk definition is not consistent with the risk description.

- Two risk assessments (ref. no 12 and 29) are not considered as they did not present a formal definition of risk.

5.3 Risk metric

Similarly to the previous section, the first part of the discussion in this section is dedicated to briefly revisit the consistency criteria for risk definition – risk metric under which each assessment was evaluated. Then, the relations between the risk definition and metric in the data are discussed.

According to the theory discussed in chapter 2.4.2.2, a standard risk matrix is an illustration of the frequency and severity of hazardous events or accident scenarios. An FN curve describes on the y axis the frequency (average number) of accident events per unit of time (in this case per year) and the x axis indicates the number of deaths per accident. Similarly to the FN curve, a P&C figure illustrates the probabilities on the y axis and consequences on the x axis, the main difference is that it is not strictly dedicated to accidents and fatalities (in the case of risk assessment with ref. no 9 it was used to present the probability vs the time delays and probability vs economic losses f a project). It is then considered, that a risk assessment that makes use of any of the three previously mentioned metrics (standard risk matrix, FN curve and P&C figures), can only consistent with a P&C definition of risk.

Also as per the theory presented in chapter 2.4.2.2, risk indicators such as PLL, LIRA, FAR and similar are only consistent with the R=(E) definition as all these constitute expected consequences (number of fatalities).

An expanded risk matrix as described in chapter 2.4.2.2, illustrates the frequency and severity of hazardous events or accident scenarios and also includes the background knowledge. Further, when a risk metric is categorized as ‘qualitative description’ in the figures from chapter 4.4 it means that, by using no other means than words, the assessment describes the unwanted events, probabilities, consequences and background knowledge. Therefore it is considered that a risk assessment that makes used of any of these two risk metrics (expanded risk matrix and qualitative description) is consistent with the C&U definition of risk.

Moving on to the analysis and discussion of the results, from an overall perspective and according to Figure 11, the most used risk metrics are the risk matrices, followed by risk indicators depicting expected consequences and FN curves. Risk lists, P&C figures and qualitative descriptions are used less often.

According to the theory in chapter 2.4, one of the risk metrics that is typically used in standard risk analyses are the risk matrices, likewise, the model-based risk analyses make use of risk metrics such as PLL and/or LIRA. These statements are supported by the results from Figure 11 which show that the risk metric of preference for the standard risk analysis are the risk matrices and the metric of preference for the model-based risk analyses are those relying on expected consequences.

In the tunnel construction sector, Figure 13 plots the risk definitions used in the assessment versus the risk metric. Further, it was discussed in section 5.1 that the risk definition established by the authority within the sector is the combination of probability and consequence. In line with this is was seen that:

- Ten risk assessments make use of the P&C definition of which: seven used standard risk matrices, one used FN curve and one used P&C figures these metrics are all consistent with the P&C definition. The remaining assessment used expected consequences as risk metric being this the only inconsistency of the sector.

- One assessment makes use of the R=(E) definition, also, this assessment used expected consequences as risk metric being therefore consistent.
- Five risk assessments do not present a formal definition of risk. A common point of these five is that they are all simplified risk assessments

Figure 14 plots the risk definition and risk metrics used in the data for the municipality sector. We recall that the current definition established by the authority is the combination of consequences and uncertainties (ref. section 5.1). The plotted results reflect the following:

- Eight assessments used the P&C definition of which four used standard risk matrix and one used risk list. The remaining three used expected consequences being then not consistent with the definition in use.
- Three assessments used the C&U definition of which one used the expanded risk matrix and one used a qualitative description of the risks these are then considered consistent with the C&U definition. On the other hand, the remaining assessment made use of a standard risk matrix being then inconsistent with the definition.
- Three assessments did not present a definition of risk. Similarly to the tunnel construction sector, all these three are simplified risk assessments.

The oil and gas sector, whose authority also defines risk as C&U provides the following information:

- Ten risk assessments make use of the C&P definition of which four used standard risk matrix and another two used FN curves showing, therefore, consistency with the definition. The last four used expected consequences which is not consistent with the C&P definition.
- One risk assessment used the R=(E) definition and it was consistent by using expected consequences as risk metric.
- One assessment used the ISO definition and was also consistent by using a risk list.

5.4 Risk timelines

From the results in chapter 4.2, it is clear that the predominant definition across sectors is the one described in section 2.2.2 where risk is defined, as the two-dimensional combination of probabilities 'P' and consequences 'C' (R=P&C). This is followed by the concept presented in section 2.2.3, where Aven (2007), Aven (2010), Aven (2014) and Aven and Renn (2009), define risk as the two-dimensional combination of consequences of an activity, 'C', and associated uncertainty U' or R=C&U. Very close to the R=C&U definition comes the risk as expected values and ISO concepts.

The overwhelming use of the R=(C&P) definition and the somewhat recent irruption of the R=(C&U) concept may be justified by the evolution (or lack of) of governmental guidelines and regulations for the three sectors in question.

As per the Statens Vegvesen (2014), guidelines for risk assessments, the term risk is defined as the probability that an adverse event occurs and the consequences that it may cause. Similarly, the Norwegian oil and gas industry primarily follows the NORSOK (2010) Z-013 standard which defines risk as "the combination of the probability of occurrence of a harm and the severity of that harm". Furthermore, and according to the Direktoratet for samfunnssikkerhet og beredskap (2011) law for societal safety in area and construction planning for municipalities, risk was defined by how often accidents can happen and which consequences these may have on life/health, material loss and the community itself.

Up to this point, the "official" risk definitions mentioned above for the three sectors match with the risk a combination of probability and consequence concept as presented in the theory chapter 2.2.2.

Later, between the years 2014 and 2017, the Norwegian authorities for societal safety (municipality sector) released new revisions of their guidelines. More specifically Direktoratet for samfunnssikkerhet og beredskap (2014) and Direktoratet for samfunnssikkerhet og beredskap (2017). One of the main changes within these new revisions was the inclusion of a new element to the risk definition from the 2011 revision, this element was the uncertainty (and strength of knowledge). Also, a template was introduced for the evaluation of individual risks within the risk analyses which includes the uncertainty/strength of knowledge element.

It then makes sense that, according to the results of the risk timeline shown in Figure 16, the predominant definition within the evaluated sample is R=(C&P) and that the R=(C&U) definition started as a new, more recent trend, which gains traction especially within the municipality sector.

5.5 On the consistency between risk definition and risk description

Throughout the previous discussion chapters, consistency has been discussed from two separate perspectives, a) risk description versus risk definition and b) risk metric versus risk definition. After those discussions, it becomes clear that to achieve consistency between the way risk is defined and the way risk is described, many elements need to be aligned and aiming towards the same direction. And as the findings show, this direction is generally set by the authorities who, always prioritizing the interests of the society, are in the vanguard of the development of risk management policies and guidelines.

However, the guidelines set by the authorities are only the tip of the iceberg. Below that, there may be several organizations that possibly follow international, national, or company-specific standards. In such cases, systems must be in place to ensure that all applicable requirements are in line and up to date with the latest guidelines set by the authorities. In addition, if we look beyond the papers at the organizational level, one finds many very different groups of people across different organizations who may or may not have up to date knowledge, competence or will to lead the risk analysis group in a structured way.

In the **tunnel sector,** there is a high level of consistency between the risk definition and the risk metric, however, when qualitatively describing risk, the assessments go on to describe events and consequences of interest, express the uncertainties and present the available knowledge (to varying degrees). In this case, the official risk definition as per the relevant authority has been the same for a long period (P&C).

Both **municipality and oil and gas sectors**, present a good albeit lower level of consistency between the risk definition and the risk description when compared to the tunnel construction sector. Also, similarly to the tunnel construction sector, they describe events and consequences of interest, express the uncertainties and present the available knowledge (to varying degrees). The authorities for both of these sectors recently updated the official definitions of risk from P&C to C&U with two different outcomes.

As per the trends presented in chapter 4.5, we see the effect of this change in the assessments from the municipality sector, on the other hand, no such effect was seen for the oil and gas sector. One reason for this may be the misalignment between the authority's definition of risk and the Norwegian petroleum standards (NORSOK) definition of risk as argued in chapter 5.4. In Norway, the oil and gas operators have the responsibility to ensure that the regulations are followed, this can be a very difficult task when usually a big amount of contractors with different quality levels within their risk management systems are involved.

Then, it can be said the risk definitions are deemed consistent with the risk descriptions up to a certain degree. It can be argued that across the three sectors evaluated, there is a certain level of consistency between the risk definition and the risk metric. However, the risk description is not only formed by the way the results are summarized, which, in a way is what the risk metrics are. A qualitative description of the risks conforms the main body of the risk assessments and it is there where the biggest inconsistencies are seen. As previously mentioned, the majority of the assessments described the risk following the elements A', C', P and K which are consistent with a C&U definition even when only three of the assessments from the total sample defined risk as such.

5.6 Reliability and validity of the research

Reliability and validity are concepts typically used for evaluating the quality of the research. Aven and Heide (2009) evaluate the reliability and validity of different risk analyses. In their paper, they define **reliability** as the extent to which a risk analysis yields the same results when repeating the analysis. In the same paper, **validity** is defined as the degree to which the risk analysis describes the specific concepts that one is attempting to describe.

In order to ensure the validity of this work, several measures have been taken throughout the literature review, methodology, results and discussion. The criteria for data collection has been clearly defined by specifying the sector, categories and types of risk analyses to be sampled as shown in the Levels for organization of data (Figure 7).

Since the methods for evaluation of data were specifically developed for this thesis, measurements were set in place to ensure their validity. This was done in part by ensuring that such methods are in line with established theory on the relevant fields of interest such as risk, risk management, risk analysis processes among others.

An important condition to achieve reliability is to not only define the population for data sampling but also presenting a very detailed description of the method for collecting and evaluating the data. To ensure this, key aspects such as the size of the sample, the time period of data collection, sources of the sample, and basis for evaluation of the data were described in chapter 3. Likewise, in the same chapter, each step of the sequence followed to arrive to the conclusions were presented and described in the hopes of fulfilling the reliability criteria.

Despite implementing the previously mentioned measures to achieve valid and reliable results, an important factor that may impact the results of this work was the amount of data evaluated. The size of the sample was limited by the amount of time available to finalize the work, then it follows that if a similar study were to be performed with an increased sample size the results would be more precise, however, the author opinion is that the main conclusion of the thesis would remain valid.

Looking retrospectively, throughout the execution of this work, some individual items could have been done in a slightly different manner. One such item is related to the criteria which limits the data collection to only publicly available risk assessments. This is true especially for the oil and gas sector as it could provide more insight and details on evaluation and results.

6 CONCLUSIONS AND RECOMMENDATIONS

This work has reviewed the theory, set up the criteria, collected and evaluated a data set of risk assessments from the tunnel construction, municipality and oil and gas sectors. This with the objective of evaluating, in real-life practices, whether the risk definitions used are consistent with the risk definitions presented. In this regard, the following conclusions are made.

By evaluating the resulting trends and comparing them with the relevant regulations and standards, it was concluded that the use of risk definitions in risk assessments performed within the evaluated sectors is highly influenced by the local authorities. This is normally seen as positive as, generally, the authorities main focus is to prioritize/ensure the benefit of society. However, for such an impact to be truly positive, they must go hand in hand with the latest developments from the risk science.

It was further seen that, despite the recent updates to official risk definitions made to the regulations in the municipality and oil and gas sectors, not all the risk assessments dated after such updates came to place made use of the new risk definition. It is argued that this could be due to the lack of alignment between regulation and other standards used in the industry that are not under the direct control of the authorities.

Another possible reason, of maybe more relevance for the oil and gas sector, is the high difficulty to align the risk management systems of all the contractors that typically are involved in a project with updates from authority regulations. Even more when, as previously mentioned, these regulatory updates may not necessarily be aligned with other commonly used industry standards (such as NORSOK).

In light of this, it is recommended to review the audit processes within the relevant organizations to ensure a tight follow up of the requirements. In addition, set in place special campaigns and implementation plans when updates to regulations are to enter into effect to achieve a good understanding and alignment to such updates.

As for the main objective of the thesis, the results showed that as a rule, the risk descriptions of the majority of the risk assessments evaluated, present more than just the elements contained in their respective definitions. It is argued that this could be due to the necessity of the risk analysts to express more than just was is entailed by the risk definitions in use.

It was concluded that, in general and as per the evaluated sample, the risk definitions can be deemed consistent with the risk descriptions up to a certain degree. Consistent in the sense that a good number of assessments manage to describe the elements that conform their respective risk definitions, though not completely consistent as the risk descriptions usually included more than such elements. The one exception was when the definition of risk used was the two-dimensional combination of consequences of an activity and associated uncertainty, which successfully managed to cover all the elements presented in the evaluated risk descriptions.

It is also argued that a risk definition that manages to cover all the risk elements under its related risk description will help the risk assessment team to both accurately communicate the results of the analysis while at the same time keeping the consistency between the risk definition and the risk description.

Finally, it could be of interest to expand the study done in this thesis to other sectors of society, this could be of benefit towards a better understanding of risk management practices in Norway, leading to future and continuous improvement.

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8 APPENDIX

Ref. no	Title	Source
01	Risk assessment of ‘Follo’ tunnel	https://docplayer.me/40356877-Rehabilitering-av-follotunnelen-sha-grovanalyse.html
02	Risk assessment of ‘Eidsvoll’ tunnel	https://docplayer.me/35361712-E6-dal-minnesund-risiko-og-sarbarhetsanalyse-eidsvolltunnelen.html
03	Risk assessment of ‘Stad's’ ship tunnel	https://docplayer.me/41946930-Det-norske-veritas-rapport-risikoanalyse-av-stad-skipstunnel-for-to-tunnelalternativer-kystverket.html
04	Risk assessment of ‘Ljoteli’ tunnel	https://www.vegvesen.no/_attachment/2423006/binary/1280188?fast_title=Risikovurdering+av+tunnel+%285+MB%29.pdf
05	Risk assessment of ‘Sørfold’ tunnels	https://www.vegvesen.no/_attachment/1426945/binary/1119747?fast_title=Risikovurdering+S%C3%B8rfoldtunnelene.pdf
06	Risk assessment of ‘Gundvanga’ tunnel	https://www.vegvesen.no/_attachment/507003/binary/819683?fast_title=Gudvanga+Risikoanalyse.pdf
07	Risk assessment of ‘Kvarv-Kalvik’ tunnels	https://www.vegvesen.no/_attachment/1485712/binary/1126187?fast_title=Risikovurdering+E6+Kvarv-Kalvik-tunnelen.pdf
08	Risk assessment of ‘Ulsberg –Vindåsliene’ tunnels	https://www.rennebu.kommune.no/globalassets/plankontoret/e6/e6-horing-og-offentlig-ettersyn/vedlegg-planbeskrivelse/vedlegg-23---risikoanalyse-to-tunneler.pdf
09	Risk assessment of ‘Niagara’ tunnel	http://www.rds.oeb.ca/HPECMWebDrawer/Record/411256/File/document
10	Risk assessment of ‘E-39 Rogfast’ tunnel	https://docplayer.me/49657881-E-39-rogfast-ros-analyse-tunnel-revisjon-2.html
11	Risk assessment of 'Skálafjord' tunnel	https://docplayer.me/28323278-Risikoanalyse-av-skalafjordtunnelen-forfatter-e-oppdragsgiver-e-skalafjordtunnilin-p-f-grader-denne-side-isbn-prosjektnr-antall-sider-og-bilag.html
12	Risk assessment of Gudvanga tunnel	https://vegtilsynet.com/tilsyn/tilsynsrapporter/trafikksikkerhet-ved-arbeid-i-tunneler/_/attachment/inline/8b30093c-a8b7-443d-b89a-b0c8be72847e:8815ec90aa949cc162420eb4a2a352e977299c28/Trafikksikkerhet%20ved%20arbeid%20i%20tunneler.pdf
13	Risk assessment of Fretheim tunnel	as above
14	Risk assessment of Onstad tunnel	as above
15	Risk assessment of Bømlafjord tunnel	as above
16	Risk assessment of Lyderhorn tunnel	as above
17	Risk assessment fire and rescue, ‘Rogaland’ fire department	https://www.rogbr.no/Rapporter%20og%20utredninger/Risikoanalyse%202018.pdf
18	Risk assessment fire and rescue, ‘Østre Adger’ fire department	https://www.arendal.kommune.no/oabv/_f/p2/icaa8c188-e292-4db1-a095-25cdcba45322/oabv_ros-analyse_med_scenariobeskrivelser2018.pdf
19	Risk assessment of ‘Sola’ municipality	https://www.sola.kommune.no/_f/p1/ibab86d65-12ec-4285-888b-d4bf06675fbe/risiko-og-sarbarhetsanalyse-2012.pdf
20	Risk Assessment of ‘Sandnes’ municipality	https://www.sandnes.kommune.no/globalassets/tekniskeiendom/samfunnsplan/kommuneplan-2019-2035/endelig-vedtatt/helhetlig-risiko--og-sarbarhetsanalyse-sandnes-kommune-2019-2022.pdf
21	Risk Assessment of ‘Troms’ county	https://www.fylkesmannen.no/contentassets/ad4f0b25ed9d46d49b20cadd9ce51b35/fylkesros-for-troms-2016-2019.pdf
22	Risk Assessment of ice impacts from the windmill park in the ‘Roan’ municipality	https://www.fosenvind.no/globalassets/fosen-vind/main-images/kvt_2019_r016_reb_roan_icerisk-rev2.pdf
23	Risk Assessment of expansion of zinc plant in the ‘Odda’ municipality	https://www.odda.kommune.no/Handlers/fh.ashx?MId1=347&FilId=2945

Ref. no	Title	Source
24	Risk Assessment of marine route changes due to modifications in Bodø airport	https://bodo.kommune.no/getfile.php/1322809-1573222752/Plan%2C%20bygg%20og%20eiendom/Kart%20og%20arealplaner/Arealplaner/Planprosesser/2019/Omr%C3%A5deregulering%20for%20ny%20sivil%20lufthavn%20i%20Bod%C3%B8/3%20Vedtak/Risikoanalyse%20for%20endring%20av%20farleder.pdf
25	Risk assessment of social security when establishing NOKAS facility in Stavanger	https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2461598/SINTEF%2BRapport%2BSTF50%2BA05053.pdf?sequence=2&isAllowed=y
26	Risk assessment for upgrade of chemical facility in 'Færder' municipality	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/horing--utvidelse-av-anlegg--wilhelmsen-chemicals-as---kjopmannskjar/kvantitativ-risikoanalyse.pdf
27	Risk assessment for change of detail regulation for Rambergneset	https://www.sor-varanger.kommune.no/getfile.php/3870621.652.cxqaabafxp/ROS_Planforslag+Endring+av+detaljregulering+for+Rambergneset+11.05.2017.pdf
28	Risk assessment for area planning in Jentoftbukta, Sør-Varanger municipality	https://sor-varanger.custompublish.com/getfile.php/2348429.652.bxpuabbqfu/ROS_Jentoftbukta.pdf
29	Risk assessment for area planning of a salmon facility in Nordkapp municipality	http://nordkapp.custompublish.com/getfile.php/1807326.383.wwvxdpfqyu/Risikovurdering24112011.pdf
30	Risk assessment for the new house zoning plan in 'Luster' municipality	https://www.luster.kommune.no/cpclass/run/cpesa62/file.php/def/17003533d17003536o6d5e33/vedlegg-7_ros-analyse-pdf.pdf
31	Risk Assessment of oil and gas storage depot in Tananger area. (Shell Norway)	https://docplayer.me/1520061-Risikoanalyse-av-tananger-depot.html
32	Risk Assessment of expansion Norwegian special oil storage facility	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/nso-bamble/kvantitativ-risikoanalyse-nso-bamble.pdf
33	Risk Assessment of Pembina propane export terminal facility	http://media.oregonlive.com/portland_impact/other/Pembina%20QRA%20Draft%20Report.pdf
34	Risk Assessment of marine shipping through the Embridge northern gateway	https://www.academia.edu/28481228/MARINE_SHIPPING_QUANTITATIVE_RISK_ANALYSIS_ENBRIDGE_NORTHERN_GATEWAY_PROJECT
35	Risk assessment of new LNG terminal and biogas tank	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/gassanlegg-lng-ved-borregaard-as-sarpsborg/risikoanalyse.pdf
36	Risk assessment of a CO2 storage and export facility	https://www.fedje.kommune.no/siteassets/bilder/plan-og-bygging/risiko--og-sarberheitsanalyse---northern-lights-19.02.2019.pdf
37	Risk assessment of a new LPG storage facility	https://docplayer.me/24363082-Risikovurdering-etablering-av-lpg-tank-og-rorforinger-pa-hovringen-renseanlegg.html
38	Risk assessment of an LNG bunkering terminal at Mongstad	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/mongstadbase-bunkringsanlegg-for-lng/vedlegg-2-miljorisikoanalyse-lng---bunkringsterminal-ccb-mongstad.pdf
39	Risk assessment of Australia pacific LNG pipeline project	http://eisdocs.dsdip.qld.gov.au/Australia%20Pacific%20LNG/EIS/vol-3-gas-pipeline/22-hazardandrisk.pdf
40	Risk assessment of a new service station	https://www.blacktown.nsw.gov.au/files/assets/public/public-exhibitions/da-17-01780/p-hazard-identification-and-risk-assessment-6-honeman-close-huntingwood-arcidiacono.pdf
41	Risk assessment of methanol tank facility	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/engene-tankanlegg-satre-i-hurum-kommune/risikoanalyse.pdf
42	Risk assessment of a biogas facility at Eldøyane	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/sunnhordland-naturgass-as/kvantitativ-risikoanalyse.pdf