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Summary

Elkem has got smelting plants worldwide. Five of them are located in Norway. Smelting of metal takes place in electrical arc furnaces, for example, in Elkem Thamshavn. The electrical arc occurs between furnace electrodes and furnace charge. Thereby it causes a melting (Schei, Tuset, & Tveit, 1998), (Elkem AS, 2016a).

Elkem smelting plants have many working areas with potential hazards related to the personnel which refer to current, high temperatures, amount of energy concentrations etc. Due to its industry specialty, smelting industry needs tailored standards. Therefore, a need for the implementation of the methodology appeared. It should identify critical areas that could be a starting point in the development of a standard. The assessment of working areas' criticality regarding to low voltage will be in focus in this thesis. Identification of such critical areas is an important task, since management can prioritize the areas that have been identified (Aven, 2009).

A common definition of criticality is following (Aven, 2009, p. 404):

“A system is considered critical if its failure or malfunctions may results in severe consequences”. The consequences can involve environmental damage, loss of lives, etc.

By identification of critical areas it can be identified how one can distribute resources and activities concerning investments in safety and risk reducing measures (Aven, 2009).

What kind of tool will be the best to use in this case? Is it the best to use methods that are well established as, for example, risk matrix or is it more useful to introduce other tools?

The selection of methods in many cases depends on the available historical data. By using the available data, the following sources were found:

- Information from external sources, for instance, Accident statistic from Norwegian Directorate for Civil Protection [DSB] did not contain required information.
- Data from internal sources, as Synergi Life database, were limited.

Risk matrix is a widespread tool in many companies and it is used for qualitative risk assessment. However, it is a tool with limitations (Flage & Røed, 2012). Issues related to the risk matrix, among other things are the subjective classification of the probability and consequence, the consistency between quantitative measures and risk matrix, etc. Thus, risk matrix is used to performing a crude risk analysis and cannot be used alone for decision-making.

It is questionable whether this method will be the best option for smelting industry. Thus, an alternative approach may be suggested. It is related to expected values and uncertainties in underlying phenomena and processes (Aven, 2009).

This alternative approach does not need a large amount of data and can be applied for ranking a few areas. For instance, it could be used to identify top five most critical working areas. Using of this ranking tool requires high knowledge related to smelting plants and the actual process. It is clear, that by including the uncertainty in the assessment of criticality the

accuracy of the results will be higher. Nevertheless, the approach suggested by Aven (2009) needs some adjustments before it can be used in practice. For instance, when different areas have the same type of consequences but probabilities $P(A)$ is different or when some areas have the same type of uncertainties but different probabilities. In such cases, there is not a straight way forward how to rank the actual areas.

In addition, the alternative method for identification of critical areas was introduced in 2009. Since then there have been new studies related to this approach. Goerlandt and Reniers (2015) introduce how the assessment of uncertainties can be improved. Moreover, Aven (2013) showed the different new risk perspectives, inter alia, uncertainties based risk definitions in real-life situations. The risk description done in this way has a great impact on risk management and decision-making (Aven, 2009).

In light of new research the alternative approach could be modified. The suggested improvement are as following:

- Insert the colors for assessment of risk indices expressing the expected consequences.
- Use the improved classification scheme for uncertainties.
- Include the assessment of knowledge in risk assessment.

Since the focus was to develop a method for identifying the critical areas for own workers and contractors, the results will be hypothetical.

Preface

This master thesis is written as a final part of the Master program in Risk Management at the University of Stavanger, Faculty of Science and Technology, Norway. Thesis comprises 30 credits and was completed in first half year of 2016.

My main motivation to write this thesis was an opportunity to combine my background as electrical engineer and MSc in Risk Management. I have always had a interest for heavy industries and it was is great pleasure to write for a large international company like Elkem.

In this thesis, I suggested a methodology that can be used for identifying critical areas for the smelting industry. I could fulfil my wishes when I was writing about these problems. This task is an exciting one because it is a relevant topic that would benefit greatly in practice. Working on my master thesis was both challenging and educative. I will take this experience further into my professional career.

I would like to thank all my supervisors for great collaboration and good guidance during the whole semester.

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Darya Yaduta

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LIST OF ABBREVIASJONS:

QHSE: Quality, Health, Safety, Environment

EHS: Environment, Health and Safety

A: Event

P (A): Probability of an event A

EC: Expected consequences

E [C|A]: Expected consequences given event A

DSB: Norwegian Directorate for Civil Protection

VAC: Voltage (alternative current)

NACE: Nomenclature of Economic Activities

VAC: Voltage Alternating current

DSB: Directorate for Civil Protection

[Direktorat for samfunnssikkerhet og beredskap]

FAR: Fatality Accident Rate

RM: Risk Matrix

ISO: International Organization for Standardization

API: American Petroleum Institute

NORSOK: Produces standards for petroleum-industry activities in Norway

QRA: Quantitative Risk Analysis

CSP: Crushing-Sifting- Packing

OGP: International Association of Oil & Gas Producers

FSE: Requirement about safety working by and operating electrical installation

[Forskrift om sikkerhet ved arbeid i og drift av elektriske anlegg]

FEL: Requirement about electrical low voltage installations

[Forskrift om elektriske lavspenningsanlegg]

FEF: Requirement about electrical supply installation

[Forskrift om elektriske forsyningsanlegg]

ISO 31000: Risk Management-Risk Assessment Techniques

API PR 581: Risk-Based Inspection Technology

DNV GL: The Norwegian Veritas (Norway) and Germanischer Lloyd (Germany)

[Det Norske Veritas]

ALARP: As low as reasonably practica

1. INTRODUCTION

There are many types of methods available for identification of critical areas in the industrial context. A risk analysis should provide a broad, informative and balanced picture of risk in order to give a good support for a decision-maker. In this chapter the current situation related to accidents concerning low voltage will be presented. In addition, practical utility of the development of corporative standards will be discussed in such a special industry as smelting industry.

1.1 Background

We are living in a society where many security systems, safety procedures, protective clothing etc. related to electricity, have been implemented. However, accidents with several consequences still occur. One might ask a question: When is it safe enough? Do operators have an unreal picture of hazards related to electrical current? What methods are used to assess risk in the industrial context?

Safety could be defined as *“a condition; absence of undesired events or freedom from danger and fear. This condition is not static but is affected by factors such as threats and hazards, vulnerability and value”* (Aven, 2006).

There still occurs electrical accidents which are related to both low and high voltage in various types of industries. For example, globally, in 2014 three fatalities were reported that relate to electricity in the oil and gas industry. One of the most common causes (for this type of industry) is human action, i.e. unintentional violation (by an individual or a group), improper use/position of tools/equipment/material/products (Producers, 2014a, 2014b).

In Norway, approximately 3000 people get hurt by electricity injuries every year. In 2014, an accident with one fatality was recorded during the rehabilitation of a power plant (Direktorat for samfunnssikkerhet og beredskap, 2014). Most of accidents are often caused by violations of safety regulations and by violations of instructions for complying with requirement about safety working by and operating electrical installation [Forskrift om sikkerhet ved arbeid i og drift av elektriske anlegg] (Direktorat for samfunnssikkerhet og beredskap, 2015).

An electrical accident can cause major health and economic consequences and cause other problems. Typical injuries caused by electrical accidents involve burns, cardiac arrest, neurological damage etc.

Most of the accidents occur at work according to DSB. In most cases the accidents happened because of human actions and only some were caused by material failure. People do not have a clear understanding of electrical hazards and risk which is related to them. It is often a coincidence that prevents accidents and near-accidents from becoming serious accidents (Direktorat for samfunnssikkerhet og beredskap, 2015).

Each industry has its own specific work areas and potential hazards. The smelting industry as Elkem can be good example here, where new standards could be implemented.

A standard could be defined as “*A document describing the important parts of a product, a service or a work process and provides solutions*”. For example, *how products should be produced and how systems should be described*” (Rosvold, 2015).

By using standards which relate to a process or a system it is possible to identify the quality of a product, its functional and safety requirements etc. In the other words, they help to identify all the hazards related to the production of goods or hazards which related to the equipment. Despite the existence of already established requirements: Requirement about electrical supply installations [Forskrift om elektriske forsyningsanlegg], Requirement about electrical low voltage installations [Forskrift om elektriske lavspenningsanlegg], etc (NELFO et al., 2006). However, there are some industries, i.e., smelting industry that requires establishment of some specific tailor-made standards for their specific processes, electrical arc furnaces, machinery etc.

That is why, the idea was developed in order to identify the critical working areas for own employees and contractors related to low voltage. The identification can be based on historical data. The results may be used for development of a corporative standard concerning voltage level under 1000V. Therefore, a need occurred to sample information which relates to low voltage. This information could make a basis for the development of corporate standard. The goal is to show a picture of the real risk of the existing situation.

Challenges:

- Different plants have different needs (each plant has its own areas that should be developed, including the closure of old facilities, improving the registration methodology etc.)
- Neither operators nor maintenance crew have a good overview of risk level and consequences involved (Elkem AS, 2016c).

Many people associate risk with accident statistics. Usually the information related to accident statistics is presented in the form of reports and tables showing the number of fatalities and injuries as result of accidents. Accidents are often related to one activity within different consequence categories: Loss of life, personal injuries, economical losses, etc. (Aven, 2003; Kvaløy & Aven, 2005).

Many companies used accident statistic as an important tool to obtain regular updates on the number of injuries or any other relevant reference. It has become quite common to use a different sources for registering of events, inter alia, CODAM (Database for registration of events and injuries), Synergi Life (software that is used to manage QHSE non-conformances, incidents, risk), etc. DSB publishes each year a Safety journal “Electrical safety” [Elsikkerhet] with accident statistics. In other words, the data or historical data will give the information about the safety and risk level. This information can be used to make estimates for the prediction of risk in the future (Aven, 2003).

However, usually few fatal accidents and accidents with severe damage and losses will occur in the company. Therefore, the amount of data will be a quite limited and would give a poor basis for the prediction of risk. By including the data from near-misses and deviations from the established procedures the amount of data may be increased. This is a reasonable way to do it, since such events can give the information about the possible locations where accidents

can occur. Nevertheless, such events do not give a good basis for quantifying a risk (Aven, 2003).

Due to the issues mentioned above it is necessary to introduce other methods to identify risk that can be used by other industries, i.e. smelting industry in case where the data is limited and the goal is to identify the critical areas for personnel concerning low voltage. For future studies critical areas concerning maintenance related to electrical equipment can be also taken into consideration.

The main criteria for the selection of an alternative method are:

- Results should be based on qualitative assessment of risk.
- Method can be used for identification of critical areas.
- Applicable for the smelting industry.
- The approach should introduce other risk perspectives than just probability-based.

Aven introduced in 2009 an alternative approach based on expected values and uncertainties in underlying phenomena and processes (Aven, 2009).

The applications areas alternative approach are:

- Identification of critical areas.
- Does not required a large amount of data.
- Taking to account activities with severe consequence and large uncertainties.

Obviously, the approach suggested by Aven (2009) is a better alternative than risk matrix and it is more suitable for the purpose in this thesis (see chapter 2.3). However, this concept does not include all the aspects of risk, for instance, the background knowledge (Aven, 2009). Practical implications of this method require some adaptations to be used in the smelting industry.

This thesis is organized as following.

Firstly, in Chapter 2, different risk components are introduced and the way how uncertainty can be handled.

Secondly, The risk matrix is presented as tool to visualize the risk when the amount of data is limited. In addition, the limitations which relates to the use of risk matrix will be highlighted and recommendations for further modification of the risk matrix will be made.

Thirdly, The alternative approach for ranking the working activities, including the vulnerabilities and uncertainty are introduced. Moreover, the idea of criticality will be introduced and its different ways to be interpreted.

Fourthly, The data collection will be introduced.

Fifthly, The results of the analysis will be presented.

Finally, There will be introduced discussion and conclusion with identified critical areas for personal safety. The alternative approach has some potential for improvement. Thus, in the same chapter (see Chapter 6) suggestions for improvement can be found.

1.2 Smelting industry risks (short description)

There are many aspects that can be analyzed in such type of industry. For instance, installation, process and people (Elkem AS, 2016b). Focus here was in risk related to workers and contractors. The smelting plant, i.e. Elkem Tamshavn was split into different working areas. The classification was already performed in Synergi and were used without modifications (see Chapter 1.3). These areas have different electrical hazards for personnel concerning low voltage. The summary of results is presented below in Table.1-1.

Table1-1. Hazards for operators on a smelting plant (Elkem AS, 2016b)

Areas	Some equipment operated by electrical power	Hazards for operators
Raw Materials	Harbor cranes, compressors conveyor belts, rotating	Dust formation, Long term hazardous materials (quartz), Bulk handling systems are open
Furnace	Pumps (for cooling),hydraulic systems (electrodes and gates), valves, furnace rotation drivers	Gas, pressure, heat. Furnace working Continuously. Energy concentration
Tapping area	Tapping platforms, Ladle pull cars, Rod pushing maskin	Water + hot metal can cause explosions. Tapping every 20 min
CSP	Conveys, rotary valves, crushers, packing machines	Short circuit, cutting
Recovery plant	Compressors, Turbines	Pressure, heat

1.3 Elkem Thamshavn (graphical illustration of analyzed areas)

There are five smelting plants located in Norway. It was chosen to focus on only one smelting plant: Elkem Tamshavn (Elkem AS, 2016a).

The main products from silicon plant Elkem Thamshavn is: Metallurgical silicon, Microsilica (971 grade), electrical power and steam. Thanks to the own recovery system this plant recovers 30% of consumed electricity (Elkem AS, 2016a). The plant in Thamshavn has two electrical arc open furnaces. The process of production of silicon is presented below.

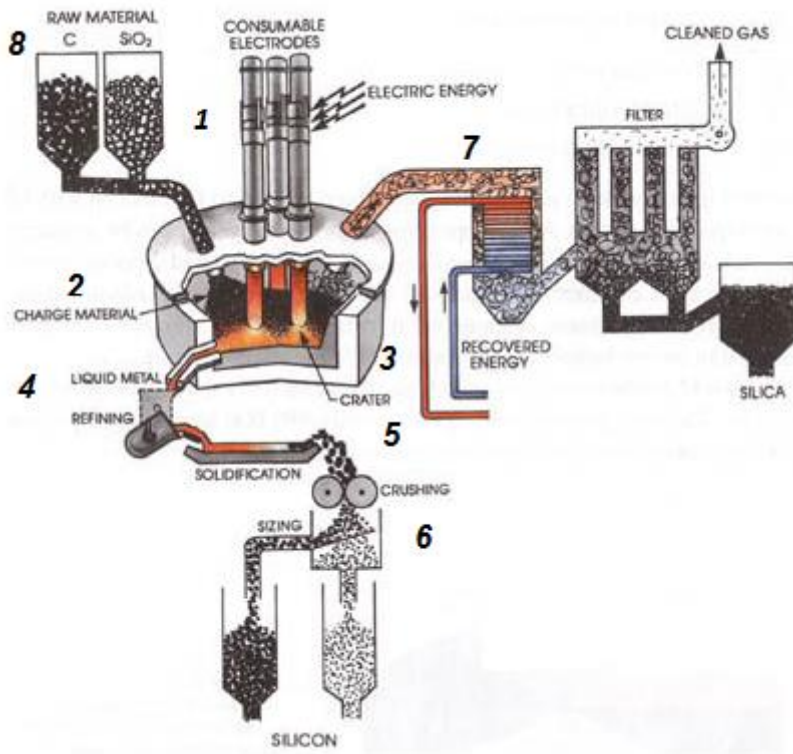


Figure 1-1. Production of silicon at Silicon plant, ("Ferro Silicon [Picture]," 2016)

- 1- Furnace house -Furnace 1- Mantel floor
- 2- Furnace house- Furnace 1- Charging floor and Furnace 2-Charging floor
- 3- Furnace house -Furnace 2- Master floor)
- 4- Furnace house -Furnace 2-Tapping hall
- 5- Furnace house- Furnace 2-Tapping-area
- 6- After treatment-Cold- Crushing-Sifting-Packaging (CSP)
- 7- Recovery plant-Boiler house
- 8- Raw material facility- Transport facility- Storage Silos to Daily silos

1.4 Issue

The following questions will be answered in this thesis:

Identification of what kind of working areas (concerning low voltage) are critical for employees and contractors with respect to:

- Health (H).
- Safety (S).

1.5 Limitations

It was not possible to focus on all Elkem smelting plants, due to various locations and individually differences of smelting plants. Elkem Tamshavn in Norway was visited during the work. Therefore, it was decided to use the data related to this plant in this analysis.

The most critical areas will be evaluated in relation to personnel safety. When an area is assigned as critical, it means critical in regard to own workers and contractors. Criticality of areas concerning voltage level covers all the activities in the plant under 1000 VAC.

A brief summary of all limitations is presented below:

- Country: Norway.
- Plant: Thamshavn.
- Data collection: Synergi Life.
- Historical data associated with electrical current under 1000V. There is a limited amount of data in the collection.
- Critical areas: Working areas.
- Future risk: related to health (H) and safety (S).

2. THEORY

Probability-based risk definitions, i.e. risk is a product of probabilities and consequences were dominant for a long time. During the last decade, the definitions of risk were expressed in terms of uncertainty (Hafver et al., 2015).

For technological applications risk matrix (RM) is an irreplaceable tool. This widely used tool for risks visualization has both a negative and a positive impact on the risk assessment (Flage & Røed, 2012). The risk will be adequately defined when the consequences and uncertainties are included.

2.1 Risk description

Risk says something about events (A) and the consequences (C) of them that can occur in the future. Examples of initiating events A are as following:

- Failure with control system (alarm conditions) in a process plant.
- Electrical power failure.
- Failure with dump valve, etc.

Risk perspectives and risk definitions have a direct impact on the method that should be taken in order to perform a risk analysis. The output risk indices from risk analysis have direct influences on any changes in the background knowledge, in assumptions and suppositions.

Thus, the risk description should be presented as (Aven, 2010):

$$Risk = (A, C, P_f^*, U(P_f^*), K) \quad (1),$$

Where

- A - Event.
- C - Consequences.
- $U(P_f^*)$ - Refers to description of uncertainty of (P_f^*) relative to true value P_f .
- P_f^* - is estimate of P_f .
- P_f - The unknown risk.
- K - Background knowledge.

2.1.1 Consequences

The consequences (C) are expressed by severity. Today it is impossible to know when these events will occur and what kind of consequences there will be. Thus, both (C) and (A) are associated with uncertainty. Probability (P) is used to express how likely it is that an event and consequences will occur (Aven, Røed, & Wienche, 2010). It should be highlighted that probability expresses the uncertainty related to occurrence of the event.

2.1.2 Probability

There are basically two possibilities to express probability according to Aven (2010).

The first one, P_f is a *relative frequency* interpretation. The underlying probability is unknown and it refers to a population which is not existing. Since the experiment is assumed to be hypothetical and to be repeated an infinite number of times. For example, assume that one will estimate the risk associated with fatalities during the operation of a plant. It can be supposed that at least 10 fatalities will occur next year. Thus, it will be defined the initiating events (such a gas leak), its consequences and losses.

The question is how should the probability be interpreted in this case?

The P_f is a property of a plant, i.e. “infinitely large population of similar plants that this particular plant belongs to” (Aven, 2010, p. 625; Kvaløy & Aven, 2005).

Bayesian probability – is another interpretation of probability as it expresses uncertainty to future events and consequences, based on background knowledge (K) of assessor and background information. In other words, this type of probability is a subjective measure of uncertainty, since it is conditional on the background knowledge (Aven, 2010).

The approach by referring to relative frequency¹ may give an inaccurate risk estimate. The Bayesian approach related to Bayesian probability, i.e. always conditional on a background knowledge and it is difficult to say how correct this probability is, since there are no references.

The need to distinguish between those two probabilities (above) is related to how outcomes from risk analyses should be interpreted. In case of relative frequency-interpreted probability, the risk description is built on a knowledge-based risk estimate. The same situation occurs when risk description is based on the one probability, i.e. the risk exists “Objectively”. Uncertainty related to A and C is unknown and depends on the assessor’s knowledge. Description of the risks performs a knowledge-based assessment of uncertainties.

The various risk definitions can be applied for both Bayesian and Frequency probability. Thus, probability is not a good tool to describe uncertainties. Uncertainties beyond the probabilities should be highlighted (Aven, 2010).

It is recommended to include the uncertainty component (U) in the risk description. By doing this the subjectivity of probabilities can be handled.

2.1.3 Uncertainties

The goal of the risk analysis is to map and to describe the risk. The initiating events will be identified, their consequences and causes, etc. Then, how these analyses should be performed and what kind risk indices should be included to achieve an informative and broad risk picture. In the previous chapter 2.1.2, uncertainty was highlighted as one of the risk indices

¹ Frequency – “Number of times the event occurs per unit of time” (Aven et al., 2010, p. 41)

that the risk analyst is faced with (Aven et al., 2010; Flage & Aven, 2009), (Flage & Aven, 2009).

Simultaneously, a proper treatment of uncertainty plays a key role, in order to give a good support for decisions. According to Flage and Aven (2009), most approaches in quantitative risk analysis/assessment (QRA) propose to relate uncertainties to calculated probabilities and expected values. The main disadvantages of this way of thinking is (Flage & Aven, 2009):

- Results from analyses are difficult to interpret.
- If large uncertainties involved, it can give inaccurate risk estimates.

Based on this interpretation one can say that “uncertainties exist in most elements of risk analysis”(Flage & Aven, 2009, p. 9). In the other words, the accuracy of the assessment is limited.

In 2009, Flage and Aven suggested a new approach as results of these two aspects above. The main idea was to present uncertainty as main component of risk. Probabilities have a function to give an epistemic-based description of uncertainties (Flage & Aven, 2009).

By epistemic-based description they means a Bayesian perspective, i.e. uncertainty related to probability expressed by assessor(s), i.e. assessment based on his/her (their) background knowledge. Flage and Aven (2009) refers to Lindley (2006) in order to point that our knowledge can hide uncertainties and not the probabilities themselves.

2.1.4 Vulnerabilities

Uncertainties are directly connected to vulnerability and they are a part of a risk picture. Vulnerability is a risk index that shows “all combinations of possible consequences and uncertainty, given that an initiating has occurred” (Aven et al., 2010, p. 33; Flage & Aven, 2009).

This analysis can give some additional information about the risk. Using of vulnerability should be done with care since redefining the initiating events may change it significantly (Aven, 2009).

2.2 Treatment of uncertainties

During the risk assessment, uncertainty factors should be taken into account. Some of uncertainty factors, which can have an impact on risk estimates: Number of assumptions, sensitivity to the relevant risk and vulnerability risk index (Flage & Aven, 2009).

The guideline is presented below how to assess uncertainty in different cases. The category classification for uncertainties starts with from L (low) and finishes with H (high). According to Aven (2008) and Abrahamsen (2015), uncertainties are defined as “factors that could cause large deviations from the expected value” (Abrahamsen, Pettersen, Aven, Kaufmann, & Rosqvist, 2015, p. 7). The conditions presented in Table 2-1 are used to decide the type of

uncertainty. Accordingly, assigned activity/area/process should meet the constitutions from one of these groups.

Table 2-1. Different types of uncertainties (Flage & Aven, 2009)

Uncertainties	Low	Medium	High
	<ul style="list-style-type: none"> - Relevant (involved) phenomena well understood. Models used are known and give results with the required accuracy. - The results prediction has a good accuracy. - Large quantities of data are available. - Agreement between experts. - The assumptions made are seen as very reasonable 	<ul style="list-style-type: none"> -Involved phenomenon is good understood. - Some data are reliable. Models that was exploited is considered as simplified (or cases between). 	<ul style="list-style-type: none"> - Relevant phenomena is not well understood/give poor predictions. - Lack of consensus between experts. - Data/information is unreliable or non-existent/irrelevant. -Assumptions is simplified too much. - Lack of disagreements between experts.

There are a lot of methods, which can be used for describing risk indices. Everything from group discussions to model-based risk analysis techniques as fault tree analysis and event three analysis. The choice depends on every single situation and the information available for the analysis (Abrahamsen et al., 2015).

In case when amount of data is not so big a risk matrix can be used for assess the risk.

2.3 Risk matrix (RM)

Risk matrix is a common tool that is used for risk evaluation in many companies. The risk matrix consist of a table with several categories of “probability», «frequency” or “likelihood” presented in columns against several categories of “consequences”, “severity” or “impact” presented in rows (or otherwise)(Cox, 2008).

For each dimension 3-5 categories are commonly used. Risk level is expressed by different colors. The green, yellow and red cells indicate low, medium and high risk (See Table 2-2). Some companies prefer to have more colors than these three. Each row-column pair ratings of probability (vertical axis) and consequences (horizontal axis) range from “VL” (very low) to “VH” (very high) (Flage & Røed, 2012).

Thus, the risk matrix is a graphical presentation of the probability (likelihood) that an event can occur and the consequence of an outcome. Consequence categories can be defined in

different terms, inter alia monetary values (Flage & Aven, 2009; Thomas, Bratvold, & Bickel, 2014).

Federal Aviation Administration Advisory Circular used this matrix for airport operators to introduce the concept of safety management systems. An example of a standard 5×5 risk matrix shows on Fig. 2-1.

Likelihood\ Severity	No Safety Effect	Minor	Major	Hazardous	Catastrophic
Frequent	Green	Yellow	Red	Red	Red
Probable	Green	Yellow	Red	Red	Red
Remote	Green	Green	Yellow	Red	Red
Extremely Remote	Green	Green	Green	Yellow	Red
Extremely Improbable	Green	Green	Green	Green	Yellow

Figure 2-1. Example of a predictive Risk Matrix for the Federal Aviation Administration, (Cox, 2008, p. 498)

There are more examples of risk matrices. In smelting industry 5×5 risk matrix is also used

Table 2-2. Risk Matrix used in Elkem (Elkem AS, 2015)

Likelihood categories (%)		Consequence categories				
		VL	L	M	H	VH
VH	90-100	Significant	Significant	Critical	Critical	Critical
H	60-90	Significant	Significant	Significant	Critical	Critical
M	20-60	Insignificant	Significant	Significant	Significant	Critical
L	20	Insignificant	Insignificant	Significant	Significant	Significant
VL	<10	Insignificant	Insignificant	Insignificant	Significant	Significant

To distinguish between two ways to describe the risk (by using RM) is a key aspect of building of the risk matrix (Aven et al., 2010):

1. Risk matrix based on expected consequence given event.
2. Risk matrix based on the consequence categories.

It is best to use the first type when a big amount of information is available. Otherwise, by showing the different consequence categories it is possible to get more nuanced risk picture (See App.B).

By using the risk matrix it is possible to rank the systems, according to priority levels. For this reason it is has a large impact on risk management. There are two ways to interpret the risk matrix (Flage & Røed, 2012):

- It is not a risk analysis method in itself. It is a tool to visualize a risk.
- It is a qualitative risk analyzing method producing a grove risk results compared to more complicated risk analysis methods.

This is illustrated in risk management² process according to Flage and Røed (2012) as presented in ISO 31000. Below is the risk management process shown in order to give an overview of the complexity of quantitative risk analysis (See Fig. 2-2). There are two opportunities to use RM here (both are marked with triangles).

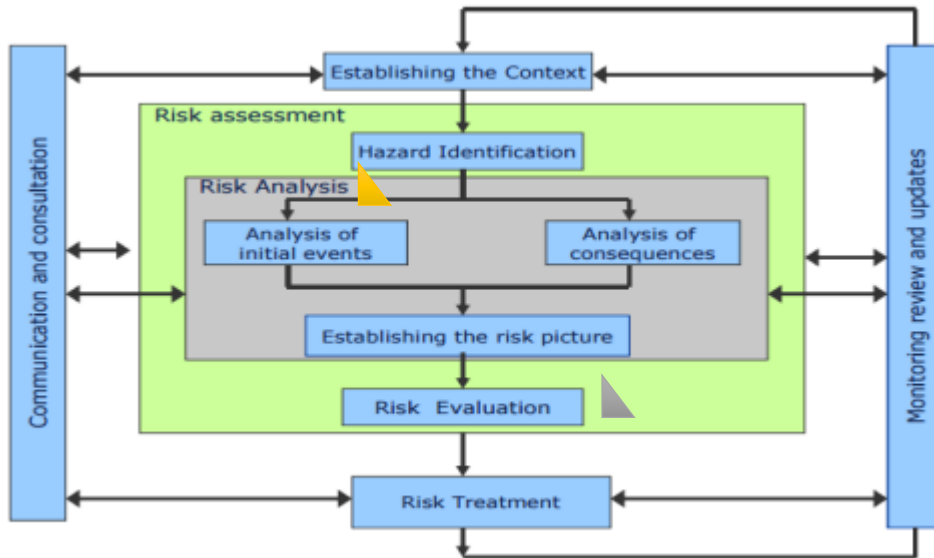


Figure 2-2. The risk management process (Falck, 2014)

A common application area for risk matrices is to visualize a risk. That is why it is important to clarify that risk matrix should be not associated with the risk analysis step on the Fig.2-2. In principle, results from two steps in risk management process can be illustrated by using of risk matrix. These areas are marked with triangles in Figure 2-2.

According to Flage and Røed (2012), the most common approach is to perform a coarse risk analysis (the area with yellow triangle, i.e. risk analysis). However, in some cases matrix is used as a part of the evaluation phase. Many professionals mean that those two application areas described by triangles which are used in risk matrices are related to each other (Flage & Røed, 2012).

The main goal of using risk matrices is to give a good support for decision making. In many companies, the risk matrices are considered to be a useful tool. Despite the fact that, risk matrix can give a dubious support to risk management. The decision maker should have clear understanding about limitation related to RM.

However, it is a fact that risk matrices are widespread and they influence decisions to large extent. In other words, it is not possible to compensate the risk matrices by other decision tools. Thus, it is reasonable to highlight all pitfalls, which are related to the using of risk matrices. The main point here is to show how this tool can be used in the appropriate manner (Flage & Røed, 2012).

² Risk management involves all measures/activities that should be done to manage a risk (Aven et al., 2010)

2.4 Challenges by using risk matrix

The method is simple and easy to understand for all the people. However, there are some issues which relate to the use of risk matrix. Nevertheless, it is widely believed that risk matrix is better than “purely random decision making” (Cox, 2008, p. 499)

Risk matrix as an element of risk management and it is recommend by different standards: NORSOK (2002), API PR 581 (2008), ISO 31000 (2009) (Thomas et al., 2014). Although wide spread of using of risk matrix, people do not always know about pitfalls or limitations related to this tool. There is not much literature which points the limitations related to the risk matrix (Cox, 2008; Thomas et al., 2014). Some authors, for example, Cox (2005), Cox (2008), Flage and Røed (2012), Thomas at el. (2014), listed several deficiencies with risk matrices.

According to Cox (2008) there are not only practical but also theoretical limitations related to the use of risk matrix. The listed issues include (Thomas et al., 2014):

- Risk-Acceptance Inconsistency.
- Range Compression.
- Centering Bias.
- Category-Definition Bias.

1. Risk-Acceptance inconsistency

From his point of view (Cox (2008), the design of risk matrix should conform to three axioms and one rule. Separation of green and red regions by yellow color in risk matrix is the main point. However, traditionally seen as categorizing of the outcomes. Cox (2008) refers to risk matrix consistency, i.e. the risk index in the yellow cell cannot be higher/bigger than any risk indices in red cells and smaller than in any of the green cells. Otherwise, the risk matrix is inconsistent (Cox, 2008; Thomas et al., 2014).

Thomas at el. (2014) pointed out that in many papers using of risk matrices violates at least one of the axioms or rule proposed by Cox (2008).

2. Range Compression

The “range compression” flaw is caused by “identical ratings to quantitatively different risk”. (Thomas et al., 2014, p. 59). This situation occurs when one converts probabilities and consequences into the scores.

3. Centering Bias

This phenomena is a typical for different people to range different situations without setting the highest level or grade. As example, let have a scale from 1 to 10. According to Thomas at el. (2014) selection of value of most people will end between 2 and 9.

4. Category-Definition Bias

The Centering-Bias is related to how different people trying to avoid extreme values during ranging in different situations. The “Bias” deficiency is strongly connected to “people actions” too. During probability assessment, quality of results can be questionable according to Thomas at el. (2014). As example, the situation when category is defines as “Very Likely”

means probability $(P) > 0.9$. For most non-professionals category “Very Likely” will be defined from 0.43 to 0.99 when they will be faced with it. This implies that definitions of categories or scores can be various among experts, i.e. lack of consistency in communication between experts. It can result in an irrational use of resources and the identified risk levels may be questionable (Thomas et al., 2014).

There is “nothing wrong” with using of risk matrix for a decision-making. The main point when one underlies the disadvantages is to show its real possibilities, which can be achieved by using the risk matrix. Risk matrix is a good tool as it can provide useful information for a decision maker. Nevertheless, it is not a complete risk analysis tool. There is a need to use other approaches to get a complete risk picture.

A broad risk picture can provide a good support for decision-maker. Management of risk should contain more complex approaches, i.e. the use of uncertainties in analysis in addition to probabilities and expected values.

2.5 The framework that include uncertainty, probability and expected consequence

The alternative approach suggested by Aven in 2009 covers uncertainties, vulnerabilities, expected consequences and probabilities. This approach is a kind of a ranking tool for critical activities.

What does it mean that the area (system) is critical?

Criticality is strongly connected to risk according to Aven (2009). Therefore, by identifying all the aspects of concern one can say that risk is adequately defined, i.e. criticality too.

A criticality measure is related to expected values. This is why there is a need to establish a ranking tool. Further, in this approach description of uncertainties related to the possible surprising consequences (outcomes) may occur in relation to the expected values. As was mentioned in Chapter 2.1. The importance of the vulnerability is one aspect of risk in the risk assessment.

A list of aspects that should be taken to account is presented below (Aven, 2009, p. 407):

- Initiating events (A) (triggers), such as short-circuiting of a furnace, leakage or a warning about an attack.
- Consequences (C) of these events, such as degraded insulation on equipment, shutdown of production, accidents.
- The values (attributes) at stake.
- Uncertainties and likelihoods, about the occurrence of the events and the consequences.

Vulnerability is one of risk components. This aspect of risk relates to (Aven, 2009, p. 407):

- Consequences of the initiating events.
- The values (attributes) at stake.

- Uncertainties and likelihoods, about the occurrence of the consequences, given the initiating events.

Risk covers both uncertainty and severity of the consequences of the activity with respect to the human value according to Aven (2009). While vulnerability related to initiating event A, formally can be considered “as uncertainty about and severity of the consequences given the occurrence of the event A”(Aven, 2009, p. 407).

A measure to express uncertainties is a probability. Another measure that was presented by this approach is measure of magnitude (size, intention, score, and intensity) or severity. Severity is just a way to define the consequences and uncertainty related to events. Number of fatalities or economical losses can express severity of consequences (Aven, 2009).

The risk perspective that presented in alternative approach concerning the following points:

1. This perspective points out that probability is not a perfect tool for expressing uncertainties.

The background information can hide a number of assumptions and/or suppositions. These assumptions can be wrong. For this reason, the probabilities, which are based on this background information, will give the wrong information.

2. Risk is more than expected values. Uncertainties should be managed too.

Furthermore, a degree of uncertainty (high or low) does not necessary mean high/low risk.

For example, assuming that two options are available (Aven, 2009):

- Alternative A describes a situation with probability distributions either 0.5 or 0.0001.
- Alternative B has probability distributions either 0.5 or 0.9999.

In addition, alternative A has a higher degree of uncertainty than alternative B.

The case describes the situation with two outcomes: 0 or 1 fatalities. The decision alternatives are respectively A or B. By considering only the provided information it looks like the alternative B has the highest risk. However, in order to decide what kind of situation has the highest criticality, it should be used different measures.

2.6 An alternative approach to identifying critical areas

The purpose of this thesis is to find a method to identify critical working areas for own employees and contractors concerning low voltage in smelting industry.

- The question is what kind approach will give a rational input to the decision-maker. Which approach will give us a broad risk picture?
- How should one manage the limitations of risk assessment?
- Could vulnerability be a basis for adequate measure of criticality?

Most of the approaches require simplifications and several assumptions in order to perform a risk analysis. Since risk will change with time, i.e. it is not an “objective state”. Decision situations are different and will depend on the purpose of the analysis.

Using the probabilities and expected consequences cannot give an adequate risk picture. Risk matrix cannot be used alone for performing this analysis (Aven, 2007, 2008). The traditional quantitative risk analysis will be not an option in this case. The data collection from internal database “Synergi Life” was limited. In other words, the use of, for example, trend analysis for identifying of critical areas is not possible in this situation, see Aven and Kvaløy (2005). In many cases instead of QRA a more qualitative approach can be better (Aven, 2008).

Identification of safety critical activities and systems it is not a simple task. There are many points that should be taken into account, including different equipment, different production areas, regions etc. In addition, there are several approaches to define the critical systems and activities. Some of these are risk based, other take into account vulnerability or include the probability dimension (Aven, 2009).

In 2009, Aven suggested an alternative approach to the identification of safety and security critical systems and activities. In this approach, the risk perspective in underlying phenomena and processes include uncertainty, probability and expected value.

The benefits of this approach is that the company's management can save time and money by distributing activities and resources only in the areas that have been identified (Aven, 2009).

In addition by including the four aspect of risk: Uncertainties, vulnerabilities, expected consequences and probabilities in risk description, it is helpful to achieve a more nuanced risk picture. Therefore, one can say that both risk and criticality is adequately defined (Aven, 2009).

2.6.1 Different interpretations of criticality

There are different interpretations of when a system or activity is critical (Aven, 2009). The most common are:

- Activity is critical if vulnerability is high.
- Activity is critical if risk is high.

High vulnerability

In this case “a system is considered critical if its failure or malfunction may result in severe consequences” (Aven, 2009, p. 404). Consequences can be expressed by economical loss, loss of life, environmental damage etc. Choosing this category requires the use of probabilities that have not been calculated properly.

High risk

This definition (measure) takes into account the probability of the initiating event, reliability importance measures, and traditional risk.

Birnbaum’s measure is one of the important reliability measures. By expressing the sensitivity of reliability (risk) with respect to the parameter the criticality measure can be defined, for example, the reliability of the safety barrier: insulation of electrical equipment can be mentioned (Aven, 2009).

Therefore, to give a good support for decision-maker the identifying of critical areas should cover both probabilities and uncertainties. Thus, using of vulnerability as critically measure should be done carefully since it depends on the definition of initiating events. On the other hand, it is not a guarantee that the critical activities will be the same if the choice will be justified by probabilities and uncertainties (Aven, 2009). It can be explained by different risk interpretations in risk assessment. Due to this reason different approaches can be used.

Aven (2009) refers to Willis (2007), who defines the risk as “expected consequences of an existent threat”(Aven, 2009, p. 405). He excludes uncertainties from risk description as opposed to Aven. This can be illustrated, for example, by risk of terrorism. The calculated expected value is not so large, but it does not exclude the events that can cause a lot of damages and fatalities. This aspect is a good example that shows hidden uncertainties in underlying phenomena and processes. According to Aven (2009) it is possible to take attention to these uncertainties by specifying the probability of an event resulting in large losses.

It seems to be difficult to implement a risk-based criticality when uncertainty is high. There is a challenge to determine the probabilities with good precision. Referring to this argument the probability is not a perfect tool to express uncertainty. The probability is based on a background information. This means that assessors’ judgment of probability can be based on many assumptions and suppositions, which can be wrong. Because of that reason the numbers (probabilities) can give a poor prediction for the decision-maker. To get a broad picture of the risk one should see beyond the numbers (Aven, 2009).

Unfortunately by measuring uncertainties with standard tools it is not possible to predict black swans. Aven (2009) refers to Taleb (2007) who presented the black swans logic, i.e. it is not possible to predict black swans because nothing in the past can point to their occurrence.

The conclusion is that in order to identify the critical areas an approach which combines both the probability and uncertainty dimension should be used. Aven (2009) suggested an approach that is especially suited for identifying critical systems. This approach covers uncertainties and severity of consequences of an activity.

2.6.2 The description of alternative approach

The alternative approach consists of 6 steps (Aven, 2009, p. 408):

1. Identify possible initiating events A.
2. Define categories of consequences C (severity classification).
3. Rank the systems according to vulnerability using $E [C | A]$, i.e. the expected consequences given the occurrence of A.
4. Assign probabilities for the events A, calculate the unconditional expected consequences, EC, by $EC = P (A) * E [C | A]$, and rank the systems according to EC.
5. Assess uncertainties in underlying phenomena and processes that could result in surprises relative to EC, and adjust the ranking based on this assessment.

To visualize the risk description from steps 4 and 5, the scheme presented in Fig. 2-4 is used. Both the components $P (A)$ and $E [C | A]$ are used for standard risk description. The X’s (risk

index) represent the risk (assessed) for to different areas (systems). Different systems are marked with symbol "✕".

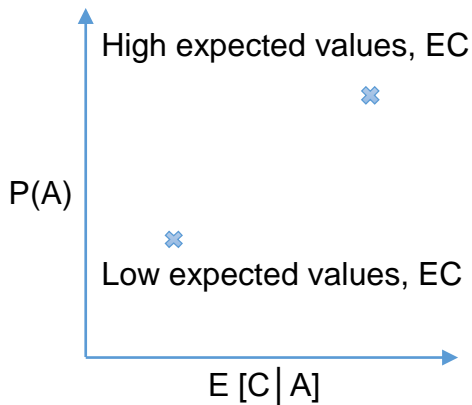


Figure 2-4. The traditional risk description (Aven, 2009, p. 408)

Before calculation of risk contribution from a specific system, some assumptions should be made. By calculating the differences in risk indices the contribution from a specific system can be expressed (Aven, 2009).

Next step expresses the risk based on the expected consequences and the assessment of uncertainties in underlying phenomena and processes. Combining these two components can give large deviations in comparison with the expected values EC. Risk description based on EC and uncertainties is presented below in Fig. 2-5.

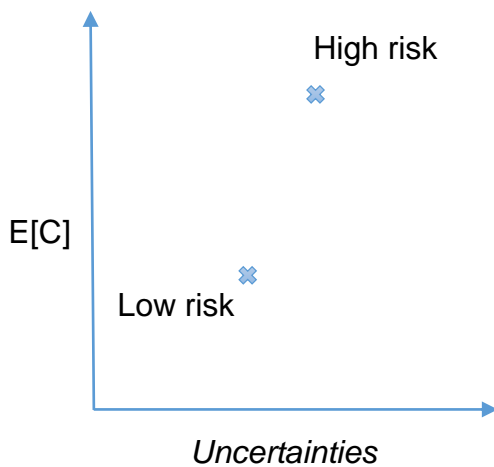


Figure 2-5. A Risk description based on untraditional components $E [C|A]$ and uncertainties (Aven, 2009, p. 408)

✕ - represents a different systems (areas).

Due to practical reasons, the following structure for describing risk categories the following categories was suggested (Aven, 2009):

1. Expected risk calculations: Low, Medium, High (Fig. 2-4).
2. Overall risk assessment: Low, Medium, High (Fig. 2-5).

The classification based on traditional risk will be a basis for establishing the structure for defining risk categories described above. This description uses the expected consequences (Aven, 2009).

The classification of risk based on uncertainty assessments needs improvement. The need for modification may be illustrated with an example.

It was assumed that, by using the expected consequences criterion the system was classified as to have a medium risk. In case, if underlying phenomena and process have a large uncertainty, the system should be reclassified to have a high risk instead of a medium one. There are a numbers of factors that can relate to uncertainties: future use and demand of systems, political events and new technology (Aven, 2009).

It is required to perform a crude analysis, in case the system will be classified by conformity with the following scheme as described above. Nevertheless, the crude analysis can be often disregarded. The reason is a performed a detailed risk analysis that may provide a basis for the classification (Aven, 2009).

Both figures Fig. 2-4 and Fig. 2-5 contain one-dimensional consequences. However, in practice, there exists many types of attributes. That is why risk description should be established as in Fig.2-4 and Fig.2-5 for each attribute. Aven (2009) suggested adding scores for different attributes in order to define the summarizing measures for these attributes.

3. DATA COLLECTION

There exist some available databases where information about accidents related to electrical accidents can be found. In most cases, such sources are not accessible to the public. In the previous chapter (see Chapter 1), some available online sources were mentioned where information related to the accident statistic can be found, inter alia, accident statistic from DSB. However, the available information was not relevant for the smelting industry. For instance, category “Industry and Raw material extraction” gives the overview of incidents that occurred in different plants across whole Norway (For more details see App A) (Direktorat for samfunnssikkerhet og beredskap, 2015). The data suitable for analysis was found in an internal database "Synergi Life", developed by The Norwegian Veritas and Germanischer Lloyd [DNV GL].(DNV GL, s.a.)

3.1 Synergi Life

The Synergi Life software is “a complete business solution for risk and QHSE management, managing all non-conformances, incidents, risk, risk analysis, audits, assessments and improvement suggestions” (Vinnem, 2014b, p. 887).

Elkem uses the events database “Synergi Life” from 2011 according to received mail 7th of June, 2016 from David Thomas Styles (Project Manager in Elkem). This software is widely used in Elkem for recording of different events. It was reasonable to use this database to work on corporate project which regards the safety of low-voltage and to base the thesis on this.

In this case, it was made an attempt to map all Health and Safety (HS)-events related to low-voltage installations (installation, operation and maintenance) from the last five years. Environment was not include due to time limitation. By using this database one should remember that there is a limited number of search outputs. Therefore, it is necessary to have predefined searching criteria.

A layout of “Synergi Life” is presented in Fig. 3-1.

Figure 3-1. Illustration of layout of database "Synergi"(DNV GL, s.a.)

This database contains various settings (see Fig.3-1), which can be helpful to perform a search of a large quantity of information. It is also possible to get in a form of Excel sheet as an output from Synergi. This is a practical feature for further work with the data

The methodology description is presented in this master thesis concerning only one smelting plant. However, it is possible to apply this method in other plants if necessary. Many searches has been made to study this database before the required criteria were established.

The search criteria used in this thesis are:

- The analyzed period: from 17.04.2011 to 17.04.2016.
- For simplicity, in a field type of case: Completed cases.
- Location: Thamshavn.
- In all fields were searching: Electrical maintenance.

The search gave 143 events related to low voltage. By reading, "the log" with events description it was concluded that in 85% of cases, the available information is not suitable for analysis, inter alia, those were events which related to collection of observed dust on electrical equipment or lack of lighting, etc.

There should be enough data in order to quantify the risk related to personal injuries and identify most critical areas for personnel. In addition, the data should be relevant for a case study. Identification of working areas (see Fig.1-1) by using Synergi started with areas where the amount of events recorded was largest. The events took place during the past five years.

The frequency could not be used for identification of areas for analysis due to low amount of registered events.

The main idea of using historical data was to identify working areas (in this case) that will be used to predict a future risks for personnel. For this reason, the selection of areas was made by the assessment of potential hazard instead of the use of frequencies. The information about the description of every event and their actual consequences was available in Synergi. The potential hazard (that can cause different consequences in other circumstances) was a main criterion for identifying of areas for future analysis.

A list of working areas that were identified by assessing potential hazard (see Fig.1-1 in Chapter 1.3):

1. Furnace house - Furnace1-Mantel floor.
2. Furnace house - Furnace1 and Furnace 2 - Charging floor.
3. Furnace house – Furnace 2-Master floor.
4. Furnace house – Furnace 2-Tapping hall.
5. Furnace house – Furnace 2-Tapping area.
6. After treatment- Cold-CSP-Crushing-Sifting-Packing.
7. Recovery plant- Boiler house.
8. Raw material facility- Transport facility- Storage Silos to Daily silos.

Furnace 1 and Furnace 2 were not done at random. The selection was based on the recovered historical data information.

4. RESULTS

Up to now, the framework was introduced in order to identify the critical areas in smelting industry for personnel. In this chapter, the focus will be provided on practical implementation of two methods and then the results will be presented. Eight areas as described in chapter 4.1 were the input for the analysis and they were identified by using historical data. The prediction of risk for personnel is based on the identification of electrical hazards related to each area. The results from the risk matrix i.e. identified critical areas for personnel will be further ranked by an alternative approach.

4.1 Consequence categories and probabilities

A 5×5 risk matrix was used for risk assessment in eight areas in the smelting plant (see Table 2-2). The categories for consequences and probabilities were predefined since it was used RM suggested in risk instructions from Elkem. X-axis represents consequence categories and Y-axis expresses probability (%).

Consequence categories varies from VL (very low) to VH (very high). The consequence spectrum for an event varies from insignificant consequences to death. It is uncertain what the consequences there will be. Probabilities shows how likely it is that the consequences will be as, for example, is shown in the Table 4-1 (Aven et al., 2010). The risk is high if both probability and consequence is VH.

Dividing consequences and probabilities into 5 different groups is based on Safety instruction from Elkem (2015) and Brukerguide for FSE and NEK EN 50110-1:2005 see Table. 4-1 and 4-2 below.

Table 4-1. Division of consequence categories into 5 categories (NELFO et al., 2006),(Elkem AS, 2015)

Risk attribute	Definition	Consequence				
		Non Hazardous	Hazardous	Critical	Very critical	Disastrous
		VL	L	M	H	VH
Health	Working environment and health for own workers and contact workers	Health issues without any sickness absence or permanent deterioration of health	Short term absence < 16 days. No permanent health issues	Long term absence > 16 days. Permanent health issues	Permanent deterioration health and reduced ability to work and/or partly disable	100% disabled or death
Safety	Employee safety for own employees, contact workers and neighbors of unit	Minor injury, no treatment required	Minor injury, treatment required	Injury with medical treatment and/or absence, but no permanent damage	Injury with permanent damage/disability	Injury with serious permanent disability or fatality

The categories from Table 4-2 was used for assignment of the probability that an undesired event will occur during the next year. It is not always easy to assign the probabilities in form of numbers. Due to this fact that it was decided to add the group of probabilities described by words .

Table 4-2. Division of probabilities into groups (Elkem AS, 2015),(NELFO et al., 2006)

Probability*	Unlikely	Less likely	Likely	Very likely	Extremely likely
Events occur	VL	L	M	H	VH
%	<10	20	20-60	60-80	90-100

For simplicity, since the background knowledge was limited, the risk attributive “Health” and “Safety” were combined in one group.

4.2 Alternativ way for using of risk matrix

By using historical data the working areas which should be examined were identified in the plant (see Fig.1-1).

The main assumptions were used:

- The plant is running under normal conditions.
- Operators will be working at the same time when the event occurs.

The alternative way to use the risk matrix means that further treatment of the identified areas was performed separately for each area. Each area is exposed to different types of risks. It depends on the amount of equipment, type of equipment, location of operators when an event will occur, etc. For technical details, see Fig.4-1 and Fig.4-2. This way to perform the risk assessment is used in Norwegian Public Road Department (Rambøll, 2009).

First, All risks related to 8 predetermined areas were decided, i.e. different types of events were identified that can occur in one specific area.

Second, These events were collected in one table. The results is illustrated in Table 4-3.

Finally, a ranking of areas was performed according to the risks to which personnel may be exposed. Visualizing of risks (see Fig.4-3) by using risk matrix was done with basis on expected consequence given undesirable event, $E [C | A]$, where C is a consequence and A is an initiating event (for more details see App.B).

The results of ranking are presented in Table 4-4. By coloring shown various risk categories from L (low) to H (high). Respectively, the area that contains most of “H”-risk was assigned as the most critical.

Further, a brief description of all eight areas and identified events according to various equipment were introduced. David Thomas Styles (Project Manager in Elkem Technology) was contacted in regard to give in an appropriate manner a brief description of working areas in Elkem smelting plant. The information was received by email the 7th of June 2016.

4.2.1 Furnacehouse-Furnace 1- Mantel floor

Generally:

Elkem Tamshavn has 2 electrical arc furnaces.

Mantel floor - the area that is on the top of the furnace (see Fig. 4-1). This is the area where furnace electrodes are maintained during furnace operation. It represents a particular risk to personnel with regards to electric shock hazard, i.e. an area that consists of mechanical arms, which has responsibility to electrodes movements. In addition, there are lot water-cooling cables.

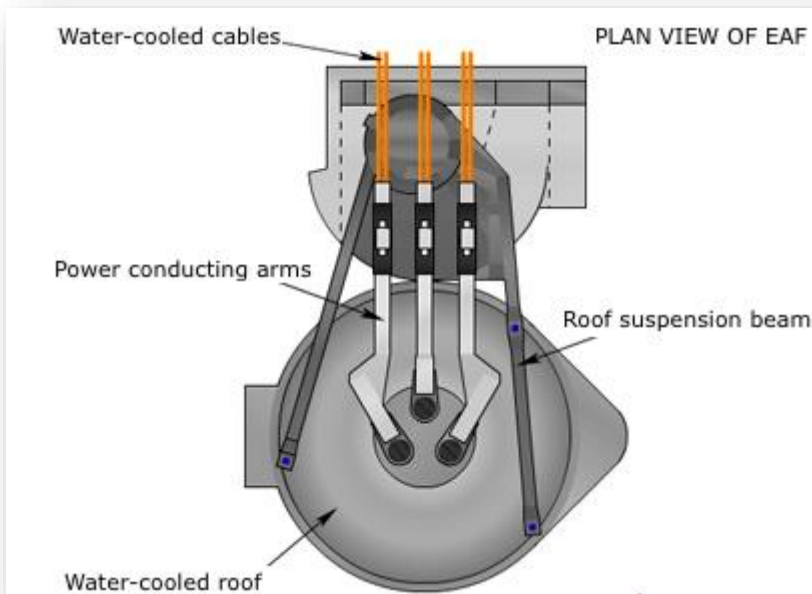


Figure 4-1. Plan view of Electrical Arc Furnace (EAF), ("Electrical Arc furnace Schematic [Picture]," 2010)

Identified events:

- Safety switch does not work.
- Failure with insulation.
- The emergency stop does not work.

4.2.2 Furnace house-Furnace 1 and Furnace 2- Charging floor

Generally:

Charging floor area is related to charging of the furnace. The process is very important since production goes on continuously. The furnace is open and electrodes move in vertical and horizontal planes during furnace regulation and electrode feed. Below on Fig. 4-2 is the section view through furnace presented. The view of a closed furnace is shown in regard to

clarify the types of the equipment that is involved in a smelting process. Moreover, corresponding initiating events, that can occur in this area.

Identified events:

- Safety switch does not work.
- Pump/Compressor stops working.
- Failure of remote control.
- Failure with insulation.
- Short circuit, for example, around furnace.
- Dust.
- The emergency stop does not work.

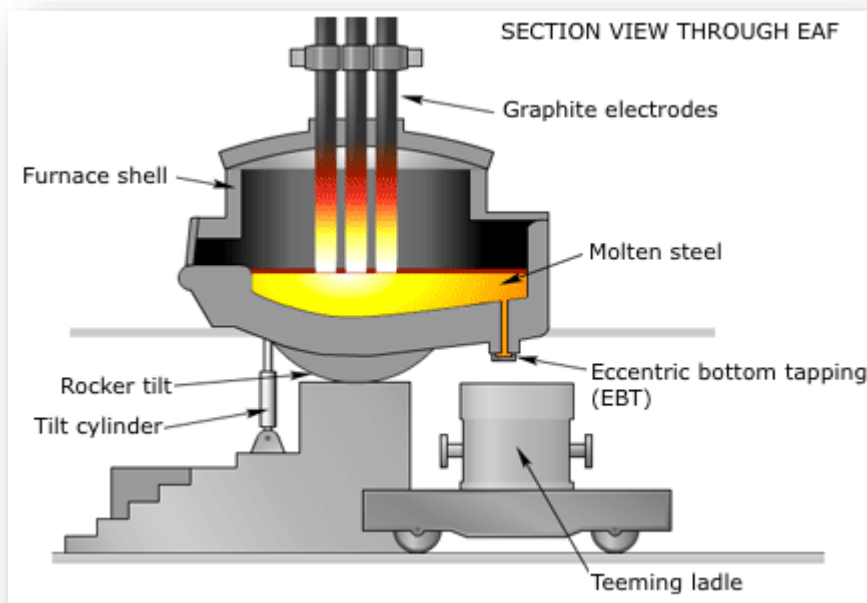


Figure 4-2. Section view through EAF ("Electrical Arc furnace Schematic [Picture]," 2010)

4.2.3 Furnace house – Furnace 2- Master floor

Generally:

The Master floor belongs to the area that covers the bottom of the furnace. There is a lot of equipment that is located in this area, inter alia, Pumps (for cooling), hydraulic systems (electrodes and gates), valves, furnace rotation drivers, etc.

Initiated events:

- Safety switch does not work.
- Pumps/Compressors stops working.
- Failure with insulation.
- Short circuit, for instance, due to the failure with insulation.

- The emergency stop does not work.

The main problem in this area from the low voltage point of view is the shock risk that can exist, from time to time due to the furnace pot (crucible) voltage exceeding 50 VAC. It can happen due to metal leaking through the furnace lining and making contact with the furnace shell.

4.2.4 Furnacehouse-Furnace 2-Tapping hall

Generally:

The tapping hall is one of the most dangerous areas in the plant regarding the amount of energy concentration, hot metal, etc. The worst situation might happen when water meets hot metal. This can cause an explosion (Elkem AS, 2016b).

In practice, there are two operators during the process. One of them drives ladle to a casting area, while the other one uses a remote controlled crane to fill the cast form.

Identified events:

- Safety switch does not work.
- Failure of the remote control.
- Failure with insulation.
- Short circuit, f.exp. around furnace.
- Overfilling of an ladle.
- The emergency stop does not work.

4.2.5 Furnace house – Furnace 2 – Tapping area

Generally:

Tapping the furnace occurs several times during the day. In addition, there is a need to take some quality samples during the tapping. The tapping process is not completely automated, i.e. ladles should be replaced, a tapping hole should be cleaned, etc.

This area is perhaps one of the most significant with regards to operator's risk related which relates to low voltage electric energy. The furnace shell represents intermittently a contact hazard. The surface can exceed 50 VAC and it has been recorded as high as 200 VAC. This voltage is monitored and operators are warned by an optical alarm when shell voltage exceeds 50 VAC. It is important to note that this happening does not interrupt the furnace operation.

There is also an electric lance in this area, which is directly connected to one of the furnace transformers. Operators are protected from electric shock by their work area being isolated from any ground potential.

Identified events:

- Safety switch does not work.

- Failure with insulation.
- Short circuit, f.exp, around furnaces.
- Overfilling of a ladle.
- The emergency stop does not work.

4.2.6 After treatment -Cold- Crushing-Sifting-Packaging (CSP)

Generally:

The CSP-area contains fewer risks in comparison to Tapping area (4.1.5.) or Tapping hall (4.1.4). Nevertheless, there is some electrical equipment here, which can cause operators' injuries, for example, conveyors, rotary valves, crushers, packing machines etc.

Identified events:

- Safety switch does not work.
- Failure with insulation.
- Pumps, compressor stops working.
- Failure of the remote control.
- Dust.
- Short circuit.
- Wires falls on conveyor belt.

4.2.7 Recovery plant - Boiler house

Generally:

In this area (boiler house), pressure and temperature is the most important factor and it should be monitored.

Identified events:

- Safety switch does not work.
- Pumps/Compressor stops working.
- Failure with cooling system.
- Deviations in measurement of temperature
- Deviations in measurement of flow.

4.2.8 Raw material facility- Transport facility- Raw material facility-Transport facility- Storage Silos to Daily silos

Generally:

This area does not require a constant presence of an operator. Despite the fact that some of the equipment is located at harbor cranes, compressors conveyor belts, etc.

Identified events:

- Safety switch does not work.
- Pumps/Compressor stops working.
- The emergency stop does not work.
- Wire(s) falls on conveyor belt.

4.2.9 Summary of the identified events

In the table below (Table 4-3) the identified risks in the plant are shown based on the limited knowledge of the plant and the processes, which takes place there. For simplicity, the identified risks were assigned the following ID: A1, A2, A3 etc. It should be highlighted that these initiating events are not based on historical data. They result from electrical hazard identification in each area based on the limited information and knowledge about a plant. The data from Synergi were used to identify the eight working areas which are used further for ranking, in regard to Safety & Health for own employees and contractors.

Table 4-3. Assigned ID for identified risks on the eight areas

<i>Initiating events</i>	<i>Assigned ID</i>
Safety switch is not working	A1
Pump/compressor stops working	A2
Failure with remote control	A3
Failure on the insulation	A4
Failure with cooling system	A5
Short circuit	A6
Dust	A7
Deviations i measurement of temperature	A8
Deviations i measurement of flow	A9
Overfilling of an ladle	A10
The emergency stop does not work	A11
Loose wire falls on conveyor belt	A12

Further analysis of these twelve initiating events was performed by using risk matrix as presented in Fig. 4-3. The X-axis shows the expected consequences on Health & Safety for employees if a initiating event from A1 to A12 occurs. The Y-axis expresses the probability that initiating events will occur during the next year. For description of severity of consequences and probabilities 5 categories were used from VL (very low) to VH (very high). Assigning each category was based on the background knowledge. See definitions of consequence categories and probabilities see in chapter 4.1.

Different colors indicate the criticality of the risk for various events. **Red** stands for ‘critical’, **Yellow** stands for ‘significant’ and **Green** means ‘insignificant’. The risk matrix presented below shows the identified risks in the eight predefined working areas.

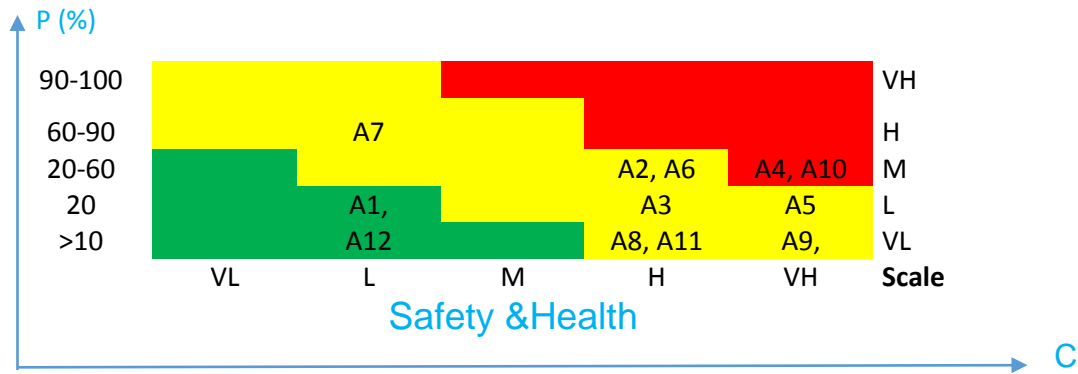


Figure 4-3. Visualizing of risk description for different initiating events

There was a need to make some assumptions for the analysis (see chapter 4.2). The reason is that the different areas have various amount of electrical equipment, number of hours when an operator is located in a special place can be different. The processes that take place in a particular area may have different impact on the implications for health and safety. For example, the tapping area contained a molt metal with temperature above 1000 degrees Celsius is more dangerous for people than packing area with dry and cold powdered metal (Schei et al., 1998). For this reason, it was chosen to use the risk matrix on 12 identified initiating event (see Table 4-3) to visualize a risk impact in different areas later. The ranking of these working areas have been performed in the next subchapter.

Next, in order to classify the areas according to their criticality for personnel it was used as criterion the total effect from all the initiating events related to each area (see Table 4-4). In other words, if the amount of events, which have high risk is the highest, then this area is the most critical for personnel. The results are presented in the table below (Table 4-4).

The delta (Δ) in different colors is used to express what kind risk is related to each specific area. In this case, eight areas were analyzed:

1. Furnacehouse-Furnace 1-Mantel floor.
2. Furnacehouse-Furnace 2 and Furnace 1 Charge floor.
3. Furnacehouse-Furnace 2-Master floor.
4. Furnacehouse-Furnace 2-Tapping hall.
5. Furnacehouse-Furnace 2-Tapping area.
6. After treatment -Cold- CSP.
7. Recovery plant -Boiler house.
8. Row material facility- Transport facility- Storage Silos to Daily silos.

In the Table 4-4 summary of results is presented.

Table 4-4. Identified risks on the plant

Events ID	Identified initiating events	Working areas							
		1	2*	3*	4*	5*	6*	7	8
A1	Safety switch does not working	△	△	△	△	△	△	△	△
A2	Pump/compressor stops working		△	△		△	△	△	△
A3	Failure with remote control		△		△		△		
A4	Failure on the insulation	△	△	△	△		△		
A5	Failure with cooling system							△	
A6	Short circuit		△	△	△	△	△		
A7	Dust		△				△		
A8	Deviations i measurement of temperature					△		△	
A9	Deviations i measurement of flow							△	
A10	Overfilling of an ladle				△	△			
A11	The emergency stop does not work	△	△	△	△	△			△
A12	Wire falls on conveyor belt						△		△
Total	Should this area be further analyzed?	If needed	Yes	Yes	Yes	Yes	Yes	If needed	If needed

*Areas recommended for further analysis that should be more detailed

Identified working areas 2, 3, 4, 5 and 6 will be analyzed further. For simplicity, the areas are expressed by letters instead of numbers.

The areas that were taken for future analysis:

- A. Furnacehouse-Furnace 2 and Furnace 1 Charging floor .
- B. Furnacehouse-Furnace 2-Master floor .
- C. Furnacehouse-Furnace 2-Tapping hall .
- D. Furnacehouse-Furnace 2-Tapping area .
- E. After treatment Cold- CSP .

These areas contain the largest amount of triangles (total amount) and an alternative approach was used to identify the most critical for employees/contractors.

4.3 Ranking of the identified working areas by using an alternative approach

Inspired by Aven (2009) and Abrahamsen (2015) an idea was developed so that one could manage the identified critical areas in relation to their consequences, vulnerabilities and uncertainties. The alternative method consists of six different steps and may be applied in an industrial context.

It should be highlighted that the analysis based on current approach required a high knowledge about the plant and related processes. Assumptions that were used are mentioned in subchapter 4.1. They relate to the amount of equipment and how many people work in each area in an actual plant, etc.

Thus, the approach consists of six steps (Aven, 2009, p. 408):

1. Identify a list of systems (areas) for evaluation.
2. Identify possible initiating events A.
3. Define categories of consequences C (severity classification).
4. Rank the systems according to vulnerability using $E [C | A]$, i.e. the expected consequences given the occurrence of A.
5. Assign probabilities for the events A, calculate the unconditional expected consequences, EC, by $EC = P (A) * E [C | A]$, and rank the systems according to EC.
6. Assess uncertainties in underlying phenomena and processes that could result in surprises relative to EC, and adjust the ranking based on this assessment.

The risk classification/quantification performed by this alternative approach is based on two risk indices. The first one is expressed by two components P (A) and $E[C|A]$. The second one based on expected consequences and uncertainties.

4.3.1 The risk description with components P (A) and $E[C|A]$ or the first risk index

The risk quantification performed using risk index that expresses by expected consequences, EC. The results from this assessment will be taken for future analyses of areas criticality (see the next chapter 4.2.2)

The assessment of working areas starts from step one in the alternative approach. According to scheme:

Firstly, a list of working areas has been identified by using the risk matrix, see Table 4-4.

Secondly, according to this approach possible initiating events (A) were identified. As an example, five possible initiating events that can happen during the next year³ were selected. Results in this case are hypothetical since the presentation of this approach⁴ was the only focus here.

³ Amount of events is a random, since results will be hypothetically.

⁴ For quantifying of results more detailed analysis is required.

Selected initiating events was as followed:

- *Failure with control system.*
- *Power failure.*
- *Operation under deviation (Alarm conditions).*
- *Gathering of dust (Poor cleaning of working areas).*
- *Destroyed insulation of electrical equipment.*

Thirdly, categories of the consequences were defined in the previous chapter 4.1. Since, background knowledge was limited it was difficult to catch the differences between health and safety.

Fourthly, in the step 4, Areas were ranked according to their vulnerability using expected consequences which are given the occurrence of (A) or E [C | A]. The consequence categories range from VL to VH. The results from the assessment are presented in Table 4-5.

Table 4-5. Ranking of areas according to vulnerability (based on limited knowledge about plant)

Initiating events	Working areas				
	A. Charging floor (Furnace 2)	B. Master floor (Furnaces 1,2)	C. Tapping hall (Furnace 2)	D. Tapping area (Furnace 2)	E. After treatment (cold) CSP
1. Failure with control system	H	M	M	VH	VL
2. Power failure	L	VL	VL	M	VL
3. Operation under deviation	VH	VH	L	M	M
4. Poor cleaning of working areas (dust)	L	VL	L	L	M
5. Destroyed insulation	M	M	M	H	M

Fifthly, in step 5, there were probabilities for five initiating events, i.e. the probability that one of these 5 events will happen during the next year in a particular area. Assigned probabilities are shown in Table 4-6.

Table 4-6. Assigning of probabilities (as example)

Events\Probability (%)	Working areas				
	A. Charging floor (Furnace2)	B. Master floor (Furnace 1,2)	C. Tapping hall (Furnace 2)	D. Tapping area (Furnace2)	E. After treatment cold CSP
<i>1.Failure with control system</i>					
	15	10	20	5	30
<i>2.Power failure</i>					
	30	20	10	15	40
<i>3.Operation under deviation</i>					
	15	10	10	25	50
<i>4. Gathering of dust (Poor cleaning of working areas)</i>					
	20	25	45	35	55
<i>5.Destroyed insulation (on electrical equipment)</i>					
	35	20	15	50	45

In future treatment of the results (see step 5) from Table 4-5 and Table 4-6 it is suggested ranking according to expected consequences, EC.

Expected consequence (EC) was found by multiplying probability that event (A) will occur during the next year with an expected consequence given event A ($E [C | A]$), i.e.

$EC = P(A) \times E [C | A]$, i.e. the first risk index.

For risk description in exanimated areas the graphic illustration was used for “Event 1” and “Event 2” (see Table 4-5 for more details). For simplicity⁵, the graphical representation was performed only for these two events.

⁵ Due to presented results are not based on any calculations.

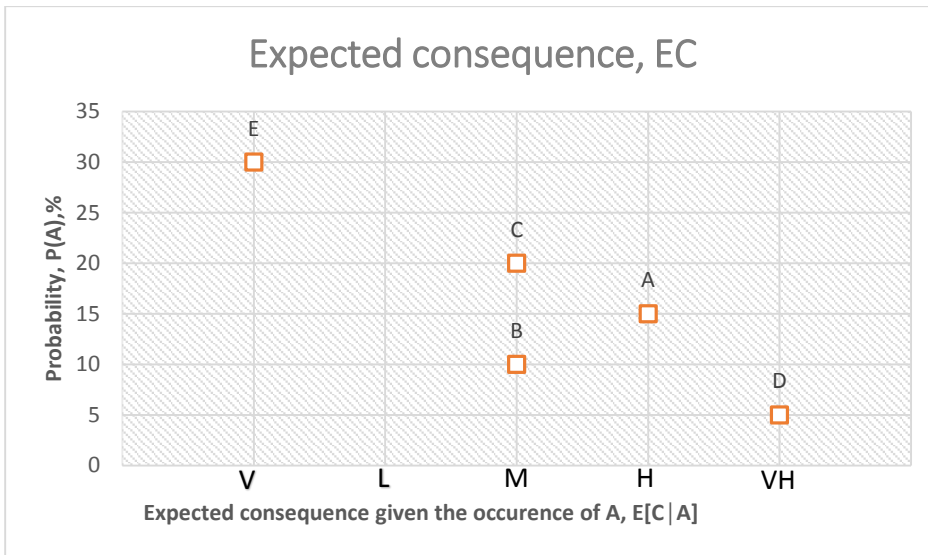


Figure 4-4. Risk description with components $P(A)$ and $E[C|A]$.

The points in Fig. 4-4 represent assessed risk-indices (EC) for five different systems. For the first initiating event according to alternative approach, see Table 4-5.

Since the consequences are expressed by text (not in a numbers), it is not possible to calculate the expected consequences in a form of numbers. Distribution of the expected consequences for initiating event number 2 is presented in the figure below.

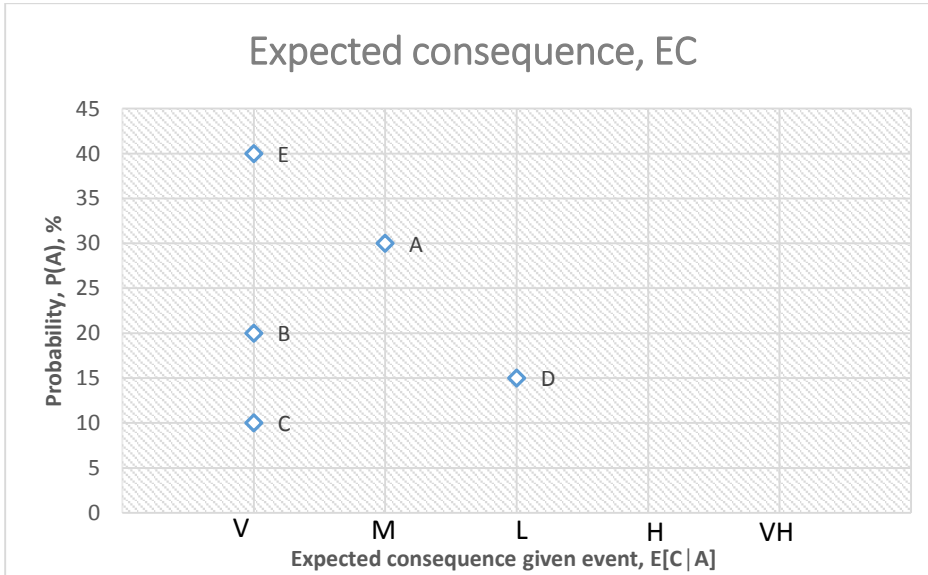


Figure 4-5. Risk description with components $P(A)$ and $E[C|A]$

The points represent assessed risks (EC) according the alternative approach for five different systems for initiating event number 2, see Table 4-5.

Thus, the assessment of most critical areas was performed for eight different areas on the smelting plant. The risk index was used and it is expressed by expected values. There is a standard risk description based on expected consequences which is a product of $E[C | A]$ and probabilities $P(A)$ (Aven, 2009).

Assessment of risk for personnel by using expected consequences:

- High

In case when expected value, EC, has high probability and high expected consequences.

The examination area has high EC or high risk that specified initiating event may occur during the next year. This area is critical.

- Low

Otherwise, the low expected value, EC, shows that the area does not have a high risk for personnel.

Furthermore, the results from the previous step (step No. 5) were used for further assessment of uncertainties. In this case, the risk index is a product of consequences and uncertainties.

4.3.2 Risk description based on EC and uncertainties or the second risk index

This risk index is a result from the last step in this the alternative approach. The step No. 6 involves incorporating the uncertainties which relate to underlying phenomena and process. Assessing uncertainties can help to predict surprises, which are related to EC. It was done by checking conditions as presented in Table 2-1, see chapter 2.1.

There were three categories of uncertainties from L (low) to H (high). An area or an activity has a low uncertainty if *all of these* conditions (present in the Table 4-7) are met, i.e. the answer to following questions was positive (“Yes”) the uncertainty will be low. In the opposite case, the uncertainty should be classified as high. The areas with medium uncertainty are cases between.

Assessment of areas criticality by using identified uncertainties and EC

In case, if working area have a medium risk according to expected value, the category classification should be changed to having a high risk, if the uncertainties in the underlying phenomena and processes are large (Aven, 2009). In other words, by taking into account the uncertainties, the situations can be avoided when large deviations occur between expected values and the actual outcomes.

For each area from A to E (see chapter 4.1.9) the uncertainty was assigned as shown in the last row of the Table 4-7. It was a challenge to assign uncertainty for each initiating event. This was due to limited background knowledge related to the plant. For this reason it was decided to perform an analysis without specifying different initiating events.

The results are presented in Table 4-7.

Table 4-7. Allocation of uncertainty for different areas (without specifying on different initiating events)

Uncertainties (conditions)	Working areas				
	A. Charging floor (Furnace 2)	B. Master floor (Furnace 1,2)	C. Tapping hall (Furnace 2)	D. Tapping area (Furnace 2)	E. After treatment cold CSP
1. How good understood relevant (involved) Phenomena or process?	Not good	Not good	Well	Well	Good
2. How many relevant data is available? Are these data relevant? Irrelevant?	4 events during 5 years. Not so many data	No (1event)	5 events. Not too much, but relevant.	3 events. Not relevant	2 events. Not relevant.
3. Does the models give good predictions?	Some	More or less	Some	Yes	Yes
4. Is there a broad agreement between experts?	No				
5. Are made assumptions seen as very reasonable?	More or less	Yes	Yes	Yes	Yes
Assigned uncertainty	H	H	L	M	M

The main focus (in this chapter) was on the presentation of the suggested alternative method. Therefore, no calculations were performed. Due to this, it was not possible to operate with exactly numbers to express the risk by these two components: Expected consequence and uncertainties in the underlying phenomena and processes. However, assuming that working areas have following values of E[C]: A = 0,1; B = 0,05; C = 0,05; D = 0,02; E = 0,1.

The criticality of working areas by combining the uncertainties and EC is presented in Fig.4-6.

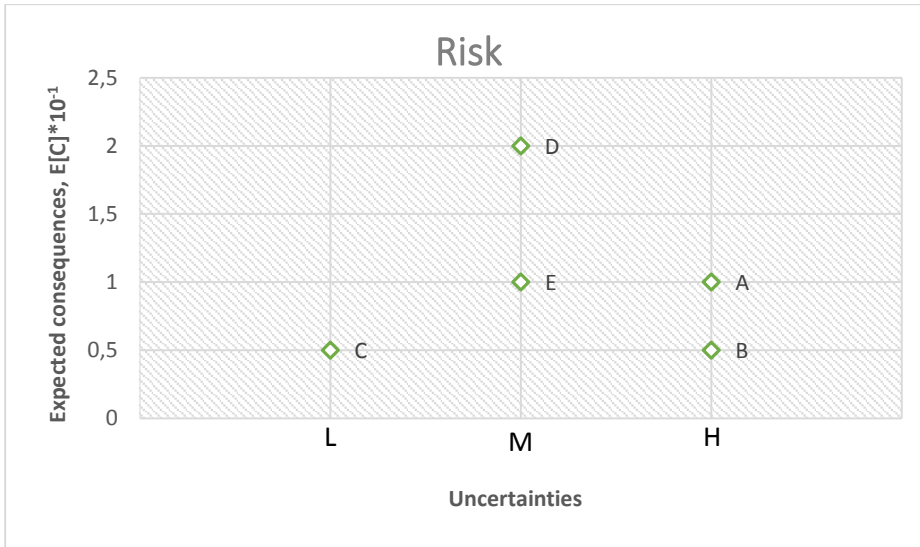


Figure 4-6. A risk description by expected consequence and uncertainties

The green points in Fig. 4-6 represent assessed risk for five different working areas. The most critical area became “A”-area and the last place have the “C”-area.

5. DISCUSSION

It is possible to predict a risk related to electrical hazards when the amount of data is limited. However, in order to have a good basis for the decision maker it is not reasonable to use results from the risk analysis which are based only the expected values and probabilities. Thus, in order to achieve a broad risk picture one should see beyond the expected values. Uncertainties should be taken into account so that the decision maker is given a good support. In this chapter the results from the performed assessment will be presented. In addition, it will be suggest what may be done for future studies.

5.1 Data collection

There are many methods which are available for identification of risk related to personal safety. Some of them use group discussions. Sometimes there is a need for quantitative⁶ or semi-quantitative methods, and in some cases qualitative methods should be used (Abrahamsen et al., 2015).

A broad spectrum of different methods is necessary since each company has different needs, constrains and hazards. The choice of method for identification of critical areas was directly dependent on the amount of data, which would be used for future analysis. There are some other sources that contain information concerning events within low voltage.

5.1.1 Synergi Life

By using the internal database from Elkem, “Synergi Life” it was found the specific information that has been required for the identification of critical areas. It was a challenge to navigate in this database. Moreover, the amount of information was very large. To avoid this problem some constraints for the search were established, among other things, to examine only one plant in Norway, criticality of the areas was evaluated for risks only to own employees and contractors. Despite the fact that a specified information was found which could be adapted to this type of industry, the amount of this data was limited.

During 5 years, it was recovered 143 events related to low voltage. However, more than a half were not relevant for the analysis. There were observations, which should be recorded in the maintenance log instead.

In other words, the selection of the method for the identification of the critical areas was based on the criterion that the amount of relevant data was limited. For that reason it was not possible to use quantitative methods. That is why the idea to use a risk matrix became. Risk matrix can be applied either to the identification of risk level acceptance or to the emphasis which risk should be focused on (Flage & Røed, 2012). Risk matrix is a good implemented tool in this company. For this reason, the use of risk matrix became a base in proposed

⁶ “Quantitative risk analyses is quantified by using probabilities and expected values”.

Semi-quantitative analysis contain information related to inter alia, analysis of failure causes, barrier performance, etc. (Aven, 2008, p. 768).

assessment for identifying of areas for the analysis. These areas were ranked further in the relation to uncertainty.

5.1.2 Other data sources- Accident statistic from DSB

In Norway, it is mandatory to report to DSB accidents related to low voltage. The accident statistics are published in a Safety Journal “Electrical Safety” [Elsikkerhet] which contains a useful set of data collection. The amount of data turned out to be suitable for identification of critical areas (Direktorat for samfunnssikkerhet og beredskap, 2015).

While studying of these data for a while, it was difficult to get an overview of the total risk picture. The presentation of risk level was performed in form of a table that contained many data assigned in groups (see App.A). The graphical presentations of the events which are presented in this safety journal may be recommended to use in future.

Moreover, introduction of some risk value, for example, FAR⁷-value, that could show development of risk related to people concerning low voltage. This value is often related to different categories of activities or personnel. It can be useful for risk description in safety context.(Aven et al., 2010) For this purpose, the reports from International Association of Oil & Gas Producers may be used. These reports consist of many charts and diagrams. For this reason it is easy to interpret the results and see the development in risk level (International Association of Oil & Gas Producers, 2011; Producers, 2014a, 2014c).

5.1.3 Some remarks related to accident statistic from DSB (suggestion for improvement)

In case, if data from DSB were taken for quantitative analysis, the changes in the number of registered events could be presented with the use of trends. They can help to interpret the results from the safety journal.

The presentation of the results is based on the data from safety journal shown on Fig. 5-1. The *X-axis* shows time when the incident was recorded. On *Y-axis* one can see the amount of events with various consequences.

Accidents with fatalities are rare. Therefore, the events due to sickness leave, which relate to different periods, were chosen as the basis for the future work.

⁷ FAR-“ The expected number of fatalities per 100 million exposed hours” (Aven, 2008, p. 768).

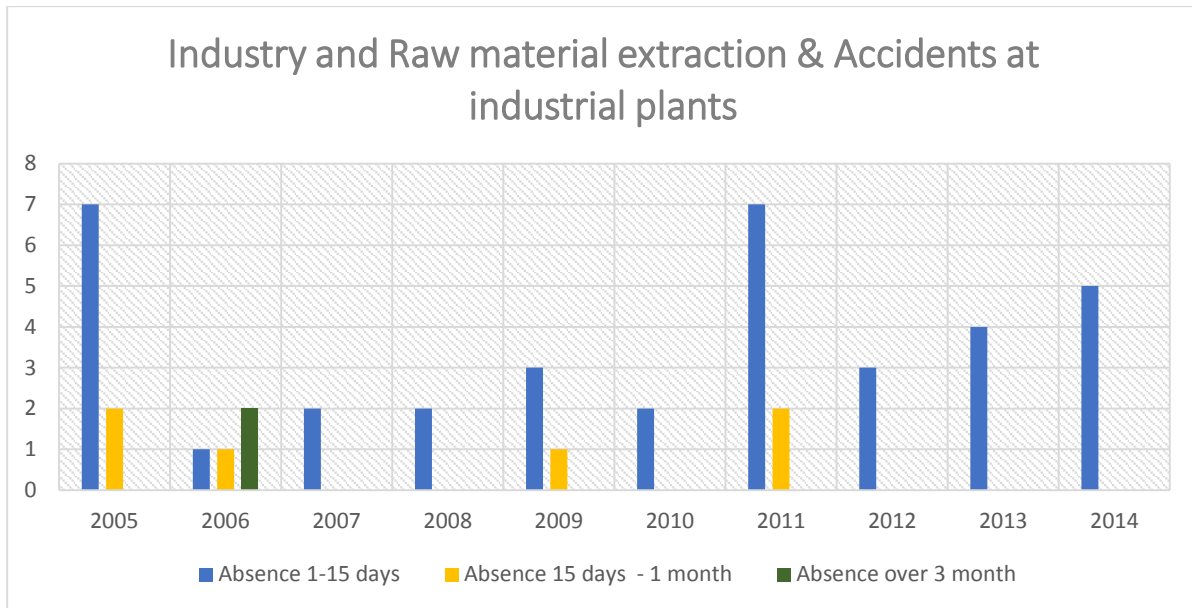


Figure 5-1. The graphical representation of absenteeism related to low voltage during 10 years

It was natural to assign smelting industry to category “Industry and Raw material extraction”.

However, on closer examination it was difficult to distinguish between following groups⁸:

-“Industry and Raw material extraction”.

-“Installation Enterprise (Electro)”.

- “Other Enterprises”.

To clarify the situation, a Chief Engineer (Electrical installations) from DSB Frode Kyllingstad was contacted by email the 2th of February 2016. According to him NACE-codes are used for the industry specification in DSB (Arbeidstilsynet, 2012). This standard is used for coding the industry in business enterprises and companies. The conclusion was the group “Industry and Raw material extraction” covers the smelting industry. Despite the fact that the data was reliable, this category was to grove for identification of critical areas for personnel in a smelting plant. In different circumstances, the data collection from DSB could be used for future analysis.

5.2 Risk matrix

There are some requirements for risk presentation. Vinnem (2014) points out some of the essential requirements (Vinnem, 2014a, p. 639):

- “Balanced and comprehensive presentation of the analysis and results”.
- “Suitable for the ‘target groups’, i.e. stakeholders”.
- “Present results relating to sensitivity and uncertainty”.

⁸ The purpose of checking these groups was to include more data, in case these data should be used for analysis.

Risk matrix as a tool to perform a crude risk analysis fulfills at least two of them. This tool is easy to use and the interpretations of results are not so difficult for all stakeholders. It is questionable that whether a comprehensive risk picture using only risk matrix can be achieved (Cox, 2008; Flage & Røed, 2012).

Various authors have suggested modifications and gave some recommendations how to use the risk matrix. Flage and Røed (2012) refer to Cox (2008) conclude that risk matrix have both positive and negative effects in risk management. Since it is not possible to replace risk matrix in practice it is necessary to know about the challenges and the limitations related to use of risk matrix (Flage & Røed, 2012).

5.2.1 Application of risk matrix

Having used the historical data from database “Synergi Life”, the amount of areas (for testing) was reduced from 17 to 8. Most of the events were related to the maintenance. Obviously, there was some impact from the chosen search criteria “Maintenance Electro”. However, there was a need to have some criteria to sort out the events related to low voltage. The areas that had the events with the highest frequency⁹ did not provide a real picture of hazards for the personnel. The use of frequencies for events screening was not applicable in this case.

Main assumption for performing the analysis in this data is representative for the future, i.e. those eight areas selected with the events which could have the highest potential hazard for personnel in other circumstances. Thanks to the use of risk matrix five critical areas was sorted out. The summary of results is shown in table below¹⁰.

Table 5-1. Distribution of results from risk matrix

Nr.	Name of working area	Amount of risks on one specific area		
		Amount of “Red” risks	Amount of “Yellow” risks	Amount of “Green” risks
2	Furnacehouse-Furnace 2 and Furnace 1 Charging floor	1	5	1
3	Furnacehouse-Furnace 2-Master floor	1	3	1
4	Furnacehouse-Furnace 2-Tapping hall	2	3	1
5	Furnacehouse-Furnace 2-Tapping area	1	4	1
6	After treatment -Cold-CSP	1	4	2

By using the suggested risk matrix it was indicated that “Tapping hall” area (number 4 in Table 5-1) is the most critical since it has two high (red) risks. At the same time, it is not so easy to rank other areas after their criticality for the remaining activities in the table. The

⁹ By frequency means number of times per year.

¹⁰ The results is hypothetical and more detailed analysis is required for practical use.

reason is that there is a limited amount of medium (yellow) risks which varies substantially in different areas according to the results obtained.

What conclusions can one draw from area No 5 “Tapping area” and area No 6 “CSP” based on the results from the risk matrix (see Table 5-1)? These two areas have almost an equal distribution of risks. For that reason, there is no way straight forward to decide which area is the most critical.

On the other hand, will area No 2 “Charging floor” be the best candidate for place number 2 among the five critical ones? It is questionable.

The assessment of these five areas has given results that are not easy to interpret. The possible explanation might be that the identification of hazards in the actual areas was based on the limited knowledge and without taking into the account uncertainties related to processes. In addition, by reading the description of the recorded events (in Synergi Life), it was difficult not to get influenced by it, i.e. one should see beyond the historical data in order to get a complete picture of real electrical hazards. Otherwise, it is highly probable that the view of real hazards will not be correct. For that reason, risk matrix turns out not to be the best tool for this type of assessment or the identification of critical areas in smelting industry. There is a need for more detailed analysis of the identified 5 areas.

5.2.2 Some remarks for future studies or suggestions for improvements

1. Using of risk acceptance criteria

There is always a challenge to perform assessment of “M”-risks, since this type of risk is not acceptable. Risk should be reduced as low as reasonably practicable (ALARP). The risk results may be used in ALARP evaluations (Aven et al., 2010).

Another way to handle “M”-risks is to perform ranking of the identified risks by using an alternative approach, which is based on uncertainty and expected values.

2. Elaboration of risk results using risk matrix

By using of risk matrix some more factors can cause unexpected outcomes. One of them is related to how the risk will be described with risk matrix. The assessment of risks which are related to electrical hazards were based on expected consequence given initiating event, i.e. E [C|A]. For this reason, the conclusion related “to expected consequence given undesired event will be affected of how each expert weights various consequence against each other” (Aven et al., 2010, p. 63). It may cause that some consequences will be ignored and the risk picture will not be complete. To get results that are more trustworthy it may be recommended to build up a risk matrix that is based on consequence categories.

3. Other areas that have potential for improvement

The working areas, which were selected for the analysis can be different when the number of experts involved is higher, i.e. the knowledge level related to systems, activities and processes becomes higher. In addition, in practice it may be recommended for quantifying the risk to use frequencies instead of the evaluation of potential hazards from the description of the

events. Despite the fact that the results from risk matrix are hypothetical, it is a good way to describe the suggested methodology and relevant challenges by using of risk matrix.

Risks that ended up in the middle required special treatment. The recommendation for future studies may be to use the risk matrix carefully and/or it together with other methods in order to achieve a better prediction of results.

5.3 Alternative approach

Probability-based risk definitions are not enough for risk assessment. It is recommended to use uncertainty based risk definitions (Abrahamsen et al., 2015; Aven et al., 2010; Petroleum Safety Authority Norway, 2016; Vinnem, 2014a), etc. It seems reasonable and the writer agrees with these authors. This has had a direct impact on the choice of the method suggested in this thesis.

5.3.1 Application of alternative approach

Five working areas, which were identified by using the suggested risk matrix was the input for this analysis. The results are hypothetical since no calculations were performed. However, the main goal was to suggest an approach that could be used for identification of critical areas in smelting industry. Results based on those assumptions show the issues which related to the use of the alternative approach.

To show the complexity of the approach which was suggested and their results, only the five different initiating events was chosen (amount will vary in real-life situation). The selection was based on the description of the event in “Synergi Life” and the inspection of the plant in Thamshavn. In other words, the events were taken randomly.

The assigning of probabilities was based on the limited knowledge about this plant. It is mentioned before that the output from this approach is 2 risk indices. The first one, EC is a combination of $E [C|A]$ and $P (A)$. The second one, risk is a product of EC and uncertainty. Results based on some assumptions showed issues and challenges related to using of the alternative approach. To clarify the situation a graphical representation of results was used.

The predefined rules to rank the areas were as following:

- EC is high, if expected consequence given initiating event and probability are high, i.e. high criticality.
- Otherwise, the EC is low and applicable working area has low criticality.

The same way for ranking the other areas based on other risk index¹¹ (see step 6, p.29) was used. For simplicity, for graphical presentation were used only 2 out of 5 initiating events, see Table 4-5.

¹¹ Description of this index available at p.33

The distribution of different areas based on EC-index for two initiating events are presented in Fig.4-4 and Fig.4-5. Despite having a predefined set of rules for ranking it is difficult to assign which area is the most critical. The results are presented in Fig.4-4 (relating to the first initiating event) and in case of “Failure with control system”, five concentrated areas occur in the middle.

Does it mean that “E”-area is the most critical? It is under question, since the expected consequences for personnel is VL (very low) for this area.

The distribution of the areas became different by performing the assessment regarding the second initiating event “Power failure”. In this case, the assessment of criticality for areas E, B, C was challenging. Although these areas belong to the same consequence category, the probability was different.

Definitely, according to Fig.4-4 and Fig.4-5, areas that attract attention are “E”-area, “C”-area and “A”-area, since these areas have the highest probability for accidents.

One can assume, that after the assessment of EC-index areas E¹², A, D, B, C became the most critical ones. The following results were found during the assessment of uncertainty:

- High uncertainties: “A”-area, “B”-area.
- Medium uncertainties: “D”-area, “E”-area.
- Low uncertainties: “C”-area.

By taking into account these uncertainties, the criticality of the areas became different. Thus, the most critical area is “A”-area and “C”-area still has the last place.

The assessment of uncertainties is based on the evaluation of various conditions (see Table 2-1, p.9). Some modifications have been made according to the use of these conditions since 2009 (Goerlandt & Reniers, 2016).

5.3.2 Some remarks for future studies or suggestions for improvements

In this chapter it was suggested some modifications in order to improve the alternative approach. There are three potential are areas that may be improved.

1. Allocation of areas by using different colors

The use of different colors for different areas is another suggestion for the assessment of EC-indices. It can be done in the same way as in risk matrix: Red (3)- the most critical area; Green (1) - not critical area and Yellow (2) for cases that are between. The results are demonstrated on Fig.5-3 and Fig.5-4.

¹² The first one is more critical.

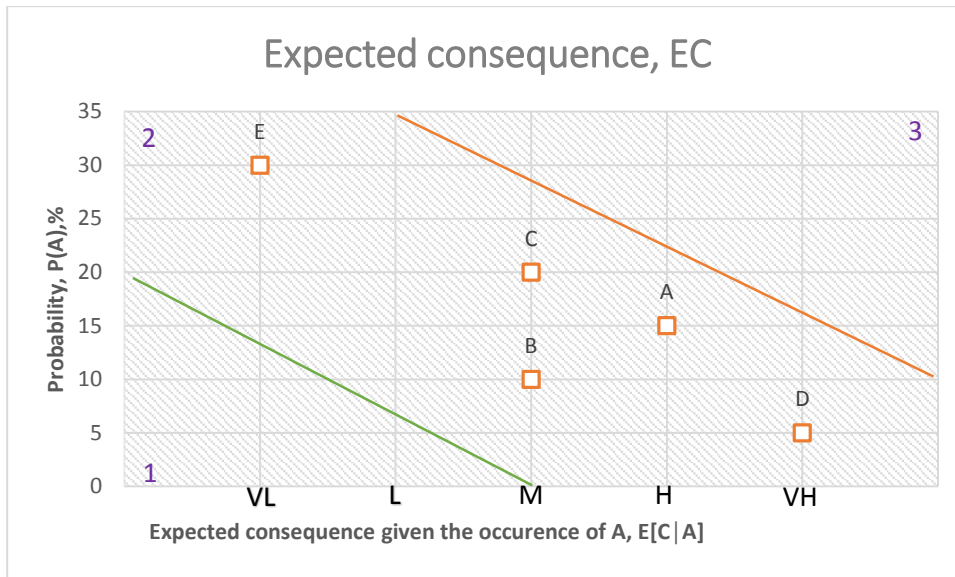


Figure 5-3. Distribution of areas for EC_1 in three different regions

The scaling was not performed in the appropriate way but the researcher tried to present “only” the idea behind that statement. “Coloring should define risks as a monotonously increasing function of consequences and likeliness”(Goerlandt & Reniers, 2016, p. 68).

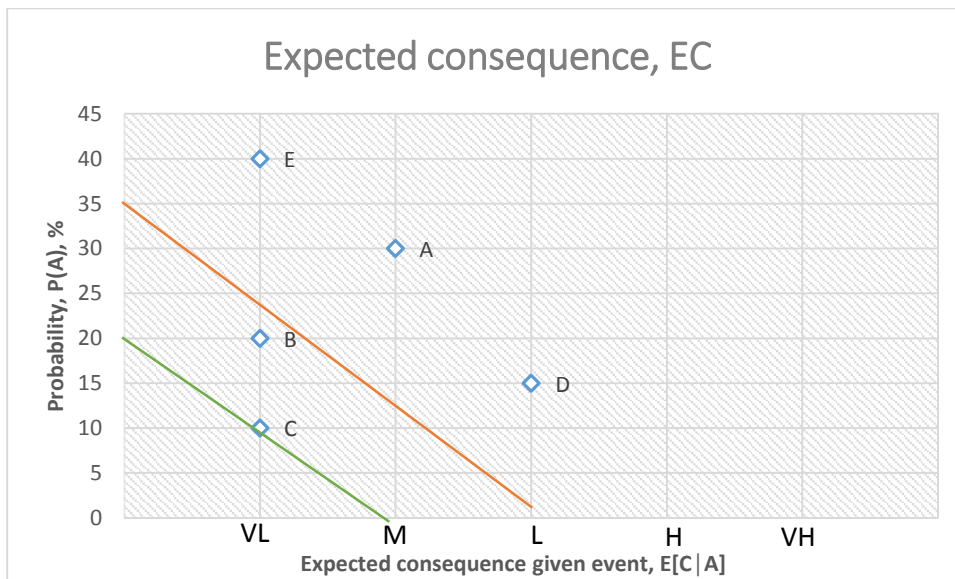


Figure 5-4. Distribution of areas for EC_2 in three different regions

Colorization is not helpful for all cases. For EC_1 it was pointless because all the areas are located in the medium region or all the areas have a medium risk index.

However, for EC_2 both the use of colors and the distribution of the diagram in three different regions was helpful for the assessment of criticality. For instance, the results from Fig. 5-4 may be interpreted that most critical area E, A, D, B and C. However, there is a challenge for areas on Fig. 5-3.

2. *Evaluation of uncertainties*

Modifications from 2012 highlighted the following (Amundrud and Aven (2012) cited by Goerlandt & Reniers, 2016, pp. 66-67):

- Uncertainty is considered high if “one or more conditions are met”.

- Low uncertainty can be assigned when all the conditions are met.

In recent studies, the evaluation of uncertainty for a particular category can be performed by using the same conditions. In this case when "all conditions should be met" regardless whether these conditions are for low or high uncertainty (Goerlandt and Montewka (2015) cited by Goerlandt & Reniers, 2016, pp. 66-67).

The first mentioned modification related to studies from 2012 seems reasonable to use. The main argument for using this modification suggested by Goerlandt and Montewka (2015) is that it can cause some underestimating of the uncertainties. Because of during the assessment of uncertainties the background knowledge/degree of beliefs will vary (in real-life situation). In case, if strength of knowledge is weak (is not adequate), it seems to be easy to assign a medium uncertainty to most areas.

3. *Assessment of the strength of knowledge*

The new risk perspectives have more characterizations and it involves, for instance, strength of knowledge (Aven, 2013). The lack of knowledge may hide some important aspect of uncertainties. Moreover, the description of uncertainty is highly reliant on knowledge and judgments of an assessor (Hafver et al., 2015). For this reason, risk description should contain assessor's knowledge.

During the risk assessment of the working areas, the assigned probability (as a measure of uncertainty/degree of belief) does not reflect the strength of knowledge. In addition, assumptions, which were used for probabilistic analysis, can cause some surprising outcomes. To avoid such situations the proper representing and treatment of knowledge is required (Aven, 2013).

According to Aven (2013) there are several procedures for grading the strength of knowledge. One approach, which is similar to the scoring as suggested by Flage and Aven (2009), will be presented in Table 5-2.

Table 5-2. Strength of knowledge classification scheme (Aven, 2013, p. 138)

Score (knowledge)	Conditions
Weak	<p>“The knowledge is weak if one or more of these conditions are met”</p> <ul style="list-style-type: none"> - The assumptions made represent the strong simplifications. - Data are not available, or are unreliable. - There is a lack of agreement/consensus among experts. - Models are non-existent or known/believed to give poor predictions. The phenomena involved are not well understood.
Strong	<p>“ The knowledge is strong if all of the following conditions are met”</p> <ul style="list-style-type: none"> - The assumptions made are seen as very reasonable. - Much reliable data are available. - There is a broad agreement/consensus among experts. - The phenomena involved are well understood. The models used are known to give predictions with required accuracy.
Medium	Cases in between

It is suggested that the assessment of strength of knowledge should be used as a part of risk description. Despite the fact that this classification is based on a crude direct grading it can help to provide more credible results from the analysis.

6. CONCLUSION

Identification of working areas that were critical for personnel on Elkem smelting plants concerning low voltage was performed in the form of methodology. Qualitative or quantitative methods were the possible alternatives for the selection of methods for the identification. The events that are related to both low voltage and smelting industry was a key information that should make the basis for this thesis. It was a challenge to find the required information. It was due to the fact that either the amount of data was limited (requirements for quantitative methods) or the information found was not related to low voltage and / or the smelting industry. Due to time constraints, it was chosen to focus on the development of a methodology that can be used in an industrial context.

In this chapter the summary of results and recommendations for future studies are presented.

Benefits & Application area:

Investment allocation is a challenging task for many companies. In case when management know the areas where priorities should be done it is easy to decide how resources and activities should be distributed.

Besides many regulations technical risk assessment is also required. Therefore, an alternative way for identification of critical areas was implemented when the large database was absent. This may be a great solution for many companies. In addition, the maintenance crew may use this method as guideline for what may be necessary to focus on, in case when this methodology will be applied on electrical equipment instead of personnel. In other words, when there will be a need to decide what is the most critical components in the system.

Challenges:

Risk will change with time and the consequences defined today may change tomorrow.

Technology development is continuous, i.e. many of the processes have been automated or semi-automated. Technical requirements that were defined for 20-30 years ago have already changed. Many old facilities should be upgraded. Moreover, different plants have different needs.

Databases:

The use of databases for registration of events can be a good support for a risk analyst. Historical data contains important information that can be used for the identification of future risks. Proper treatment of data will provide useful information about the safety level.

There are still some challenges which relate to the recording of events. Many workers who register events perform it an improperly manner. For instance, many of the recorded incidents were not specified in the intern database. That is why treatment of the data related to this group could not provide a useful base for prediction of future risks. In case, when data collection are include in future studies, the following conditions should be met:

- Amount of data is critical in case when there is a need for quantitative assessment.
- Data should be reliable and contain information related to the desired purpose.

There was introduced two options for the identification of critical areas for smelting industry.

Alternative A: Risk matrix

For technological applications RM is an irreplaceable tool. The risk matrix is popular among many companies and is recommended to use with many standards, inter alia, NORSOK (2002), API PR 581 (2008), ISO 31000 (2009). However, risk matrix does not have large theoretical fundament, despite widespread application in practice.

It should be highlighted what role risk matrix could/might play. In this thesis, risk matrix was presented as a qualitative risk analysis method that has coarse risk results as output.

Furthermore, by using the risk matrix one should be deliberately regarding to following aspects:

- There is not a risk analysis method in itself.
- There are different ways to build up a risk matrix.
- Be aware of limitations related to risk matrix.

RM is not the best tool for identification of critical areas related low voltage in smelting industry. This method should be used carefully due to limitation related to the risk matrix.

Alternative B: Alternative approach

Probability-based definitions of risk do not capture all the aspects of risk. There is a need for more comprehensive risk assessments. Other risk perspectives should replace it, inter alia, uncertainty based risk perspectives. This is because the uncertainties can change the type of decision.

The alternative approach can be applied in a few areas. It requires high knowledge about the plant and processes related to smelting. This approach will provide a good risk visualization and the results can be easy to interpret for all the stakeholders.

There was some limitations during the writing, inter alia, time constrains, limited knowledge about the smelting plant and the amount of data, etc.

The main advantage of this method is that it can be used as a ranking tool. The ranking is based on the results from two risk-indices:

- The first one expressing expected values, EC_i , where i-express initiating event. This is a product of $E[C|A]$ (vulnerability) and $P(A)$.
- The second one is based on EC_i and uncertainties.

By including, uncertainties and vulnerabilities (expected consequences given the occurrence of A), the risk will be adequately defined.

However, developments in risk management are continuous. Several new studies have been introduced since this approach was proposed, for instance, issues related to uncertainty assessment, background knowledge etc.

Definitely, use of Alternative B is better options for the purpose in this thesis. Nevertheless, for the practical implementation of this suggestion it needs some adjustments.

Further:

- Assessment of uncertainties should be performed in regard to improved classification scheme.
- Evaluating of strength of knowledge should be included.
- For comparison of various areas related to different risk indices the use of colors may be suggested.
- In the future, work with the ground potential can be mentioned and contact potential between electrodes should have more focus.

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Appendix A - Accident Statistics 2014

Accidents 2014

	In total (related to low voltage)
Categories	26
1. Accidents on electricity plant	20
2. Accidents on industrial plant	160
3. Accidents in installation companies	33
4. Other accidents	239

The numbers of person injuries (Accidents with and without sickness absence)







Time of year	Industry and Raw material extraction	Electro contactors
Dec- Jan-Feb	17	44
Mar - Apr - May	14	26
Jun - Jul - Aug	20	30
Sep - Oct - Nov	12	47
	63	147
Cause		
Breach of technical regulations	4	38
Breach of regulations	4	12
Material failure / Function error	18	17
Negligence/accident	23	60
Ignorance	7	2
Unknown	7	18
	63	147
Activity		
Assembly	9	83
Revision/Measurement/Inspection	8	26
Fuse changing	1	2
Operate	2	2
Other tasks directly on the electrical installation	11	24
Other tasks	32	9
Play/Leisure		1
	63	146

	Industry and Raw material extraction	Electro contactors
Voltage		
DC voltage		
Low voltage under 250 V	38	98
Low voltage 250-480 V	12	41
Low voltage 500-1000 V	1	1
AC voltage unknown	2	1
NA	8	5
	61	146
Voltage system		
IT-system	19	69
TN-system	36	56
TT-system	1	5
Unknown	6	14
NA	1	3
	63	147

Type of damage		
Death		
Sick leave 1 to 14 days	5	24
Sick leave 15 days until 3 months		2
Sick leave over 3 months	11	
Without sick leave		24
	16	50
Damage		
Current through person	12	40
Current through person with consequences		2
Light arch	1	
Light arch with consequences		4
Damage with other causes	3	4

Appendix B - The different ways to interpret the risk with risk matrix

1. Risk matrix based on the expected consequence given event
2. Risk matrix based on the consequence categories

		Consequence				
		NOT extended treatment	Extended treatment	Permanent damage	One death	Several death
Frequency/ likelihood	Prediction more than 10 incidents during one year					
	Prediction 1 to 10 incidents during one year					
	10-50% likelihood for one incident during one year		 			
	1-10% likelihood for one incident during one year					
	< 1% likelihood for one incident during one year					



$E[C|A]$: Expected consequences given an undesired event (1)



$P(C|A)$: Likelihood / frequency for different consequences given an undesired event (2)